Integrated sustainability assessment of BIOLYFE second generation bioethanol

(Deliverable 12.3: Final report)

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Executive summary

Background and objective

The provision of sustainably produced fuels from renewable resources is an important social goal and is also reflected in EU policy. Important objectives include reducing greenhouse gas emissions, reducing the dependency on fossil fuels and generating sources of income in rural areas. However, awareness is increasing that biofuels currently on the market may be accompanied by some considerable drawbacks, because of competition with foodstuffs, substantial remaining greenhouse gas emissions and negative impacts on other environmental factors such as eutrophication and acidification.

Alternative biogenic fuels are therefore currently being developed to increase benefits and reduce drawbacks. A very promising option here is the conversion of lignocellulosic (woody and fibrous) biomass to bioethanol. A consortium formed for this purpose worked in a common project named BIOLYFE ("Second generation bioethanol process: demonstration scale for the step of lignocellulosic hydrolysis and fermentation"). The project developed technologies allowing an increased and economically viable utilisation of the lignocellulosic feedstock for the production of 2nd generation bioethanol. In order to achieve this objective, the BIOLYFE project focuses on hydrolysis and fermentation steps. BIOLYFE started in January 2010 and lasted for 4 years. The project is co-funded by the European Commission in the 7th Framework Programme (Project No. FP7-239204). In the BIOLYFE framework was launched what is currently the world's largest lignocellulose-bioethanol facility in Crescentino, Italy.

An integrated sustainability assessment of the realisation of 2nd generation ethanol biorefineries in Europe in the period 2014-2020 is also performed as part of this project. It analyses whether a future, large-scale dissemination of the BIOLYFE 2nd generation ethanol process using mature technology provides benefits from environmental, economic and social perspectives compared to the use of existing biofuels or fossil fuels. This comprehensive analysis investigates scenarios[1], which model various possible future implementations of this technology and its whole life cycle integration, from the provision of raw materials to the energy utilisation of the bioethanol, and a variety of optimisation options.

This study successfully demonstrates how established assessment methodologies such as environmental life cycle assessment (LCA) and cost-benefit analysis from a business perspective can be supplemented by innovative approaches to cover and integrate all sustainability-related aspects of future BIOLYFE biorefineries. In respect to the environment, LCA methodology primarily covers global and regional impacts but is still under development regarding local and site-specific impacts. To still provide reliable decision support, it is extended by a new qualitative, life cycle based assessment of local aspects termed life cycle

[1] This study does not make prognoses or predictions on the technological development but examines the effects of plausible developments depicted in scenarios supplemented by sensitivity analyses where critical variability exists.

environmental impact assessment (LC-EIA), which uses methods originating from environmental impact assessment (EIA). Furthermore, a SWOT analysis (strengths, weaknesses, opportunities, threats) qualitatively examines all sustainability aspects not covered by environmental and economic assessment. Besides several particular aspects, the SWOT analysis focusses in this study on social impacts and competition about biomass. The used innovative approach for an integrated sustainability assessment includes harmonisation of settings for all individual assessments beforehand and a later joint evaluation of results using multi-dimensional comparison metrics and a structured transparent discussion. This way, the integrated sustainability assessments helps decision makers to manage complexity instead of hiding it.

BIOLYFE bioethanol general impacts

In general terms, the pattern of benefits and drawbacks of BIOLYFE bioethanol follows that known of established biofuels. BIOLYFE bioethanol can contribute to environmental benefits in terms of climate change, saving non-renewable energy resources and photochemical ozone formation (summer smog). However, other negative environmental impacts such as acidification or nutrient input into ecosystems must be taken into account – like for first generation biofuels, too. Unlike European first generation biofuels, BIOLYFE bioethanol can be produced from perennial crops, which can be cultivated with relatively low local environmental impacts especially on soil and fauna. Land use competition may occur, in particular if cultivated biomass such as Arundo or other energy crops are used as a feedstock. In contrast to first generation biofuels, this risk can and should be minimised within the BIOLYFE supply chain by exploitation of agricultural residues (e.g. wheat straw) where feasible and combination of their use with possible dedicated crop cultivation – preferentially on idle (abandoned) land.

According to Biochemtex calculations, from a market prospective, BIOLYFE bioethanol production costs are more competitive than first generation biofuels, and depending on oil price, they can even aim at competing with conventional fossil fuels. Thus, BIOLYFE bioethanol can also contribute to farmers' income and generate permanent jobs in both industry and agriculture.

BIOLYFE bioethanol presents an option for helping to achieve the sustainability goals of climate protection, energy security and promoting rural development. Advantages in these aspects can be seen in comparison to fossil fuels and under certain conditions also compared to other biofuels.

Great efforts were done to explain each step of this study. Before general conclusions should be taken, a careful comprehension of the work is advised. Please note that quantitative results shown in this study are greatly influenced by the agreed methods used, boundary conditions and technology development depicted in the scenarios. Thus, comparisons are only valid within the same framework of setting, which are uniformly applied to all scenarios within this study. The very point of strength of this study is its innovative approach.

Advantages for BIOLYFE bioethanol can result from specific impacts

In its specific impacts, there are important differences between BIOLYFE bioethanol and competing biofuels. From an overall environmental perspective, the provision and utilisation of BIOLYFE bioethanol produced from wheat straw and, subordinately, from the dedicated crop Arundo donax, in particular from idle (abandoned) land, provides more benefits compared to the majority of established biofuels (e.g. 1st generation biofuels) in some aspects such as climate change and competition about land. In other aspects, it is comparable or associated with only minor drawbacks if local conditions such as water availability and humus content of the soil are taken into account. The integrated assessment shows that fibre sorghum presents limited benefits as a feedstock for ethanol production compared to other kinds of biomass, e.g. potentially regarding water use, and drawbacks in other aspects. Under less favourable conditions, bioethanol from fibre sorghum can even lead to higher greenhouse gas emissions than gasoline.

The economic analysis by Biochemtex reveals that BIOLYFE bioethanol produced from wheat straw and Arundo can also be less expensive in the future than bioethanol produced from fibre sorghum or than most established biofuels of today. Nevertheless, lignocellulosic ethanol, similarly to other advanced biofuels, will depend on suitable framework policies steering instruments such as directives for a certain transition period.

Compared to the production of alternative innovative biofuels such as certain types of BTL (biomass-to-liquid, via the Fischer-Tropsch process) from the same biomass, the BIOLYFE bioethanol process displays cost benefits. Depending on the BTL production process and its way of implementation, BIOLYFE bioethanol produced from Arundo and wheat straw can lead to substantially higher or substantially lower quantitative environmental impacts compared to estimation for the BTL route. It must be taken into account that today no BTL process from renewables has been developed at industrial demo scale like in the case of BIOLYFE. Thus, while lignocellulosic ethanol is assessed at industrial scale, all BTL routes are estimations and expectations, still to be confirmed at production scale similar to the Crescentino plant. Since the situation additionally varies from case to case, a conclusive evaluation on the environmental performance of BIOLYFE bioethanol relative to BTL cannot be made.

In technological terms, further optimisation is still possible and necessary as the Crescentino plant is an industrial demonstration unit. This bioethanol facility, which uses the innovative PROESA® technology, represents a very important step in this direction. Its successful operation will open up opportunities for additional facility construction projects and logistics concepts and can induce positive societal effects in terms of innovations. To increase benefits and reduce drawbacks for future BIOLYFE bioethanol plants, several optimisation options for environmental and economic performance are identified and described in this report. Among the most promising aims are further reductions of enzyme consumption and an increase of energy efficiency to not only produce all required process energy from by-products but also surplus electricity or, alternatively, to export the fraction of lignin rich stream that is not used for energy purposes as co-product. Further specific optimisation options and recommendations are detailed in the report.

A promising element for a bio-based economy if land use competition is managed

Regardless of advantages and further optimisation options, any future biofuel strategy must be integrated in a higher-level biomass and land use strategy. This is because biomass and land demand will probably also increase in the fields of bio-based materials, biogenic chemicals and bioenergy, which also aim at sustainability goals like environmental and employment benefits as well as energy independence. Considerably lower demand is neither envisaged with regard to the production of food and fodder.

If biofuels can be produced from by-products such as straw or from energy crops on idle (abandoned) land, they basically do not compete with foodstuffs or fodder. Whenever dedicated crops from currently managed land are considered, it is advisable to extend this study with additional land use studies specific for the respective geographical situation. Politically, it is required to establish a higher-level biomass and land use strategy to manage competition and local planning based on it in order to take the site-specific benefits and drawbacks of various energy crops into consideration.

BIOLYFE bioethanol has the potential to become an important element in a future bio-based economy, which could be sustainably implemented with the aid of European biomass and land use plans, for example.

1 Introduction, goal and scope

Ethanol production is dictated by the need to find alternatives to fossil-based fuels. The 1997 Kyoto Protocol /UN 1998/ and the EC directive 2003/35/EC /EP & CEU 2003/ impose in fact the use of 5.75 % biofuels by 2010 and of 10 % by 2020. Given the difficulties in producing energy for transportation through alternative technologies like fuel cells, the only option available today is represented by biofuels. The need to reach the target of 10 % of biofuels by 2020 means that the EU is forced to produce nearly 16 million t / a of bioethanol and 26 million t / a of biodiesel. Almost all current production of bioethanol is carried out with 1st generation technology. The achievement of the goals set by the EU in this area using 1st generation biofuels seems very unlikely (almost impossible) due to lack of feedstocks, need for large imports (1st generation), supply costs, other uses of biomass and land, regulation, and sustainability issues.

On the other end, the calculated benefits of fuel ethanol production from lignocellulosic materials are substantial. 2nd generation biofuels that are based on various agricultural lignocellulosic residues, such as corn stover, wheat and barley straw or sugar cane bagasse, dedicated energy crops, as well as residues from forest and paper industry or municipal streams, are claimed to be much more energy efficient and contribute significantly more to reduce CO_2 emission.

The European Commission funded project "Second generation bioethanol process: demonstration scale for the step of lignocellulosic hydrolysis and fermentation (BIOLYFE)" develops, builds and evaluates an industrial demonstration unit for second generation bioethanol. The overall goal of the project is to develop and promote techniques for a sustainable and economic production of bioethanol from lignocellulosic raw materials at industrial scale, in particular an enhancement of the enzymatic hydrolysis and fermentation steps. The industrial demonstration unit built within this FP7 project shall produce 40,000 t of ethanol per year by processing about 160,000 - 180,000 t of dry biomass per year.

As part of the project, the sustainability of the BIOLYFE system is evaluated by a multi-criteria integrated sustainability assessment taking into account the results from the environmental, economic and SWOT (strengths, weaknesses, opportunities, threats) analyses in order to identify and depict the most sustainable pathways among the different BIOLYFE life cycles investigated and the most promising optimisation potentials. This report presents the results of the integrated sustainability assessment.

The main goal of this assessment is the integrated evaluation of the sustainability of BIOLYFE bioethanol from a techno-economical, environmental and social point of view. The integrated assessment considers the entire supply chain (life cycle) from biomass production through ethanol processing, distribution and usage (i.e. well-to-wheel / cradle-to-grave). This study assesses future options of implementing biorefineries on large industrial scale using the technology of the industrial demonstration unit based on scenarios for 2020. The core questions for this sustainability assessment are listed below. They have been selected by all project partners.

- From a sustainability point of view, what are the advantages and disadvantages of 2nd generation ethanol produced via the BIOLYFE system compared to fossil gasoline?
  - Which parameters or life cycle stages make the largest contribution to the overall results and can opportunities to improve the sustainability performance of the BIOLYFE system be deduced from this?
  - Do the results of the assessment change if BIOLYFE bioethanol is not used as fuel but converted further into bio-based ethylene to be used in the chemical industry instead of fossil-based ethylene?
  - How does the BIOLYFE system perform if different feedstocks are used?
- From a sustainability point of view, how does the BIOLYFE system perform compared to
  - alternative systems and / or technologies being commercially available to produce bioethanol?
  - alternative uses of the same area to produce commercially available biofuels for transportation?
  - alternative uses of the same biomass for commercially available other biofuels for transportation?

This report contains all methodologies used as well as some definitions and settings (chapter 2.1) and the description of the assessed system and its reference systems (chapter 3) as well as the results of the environmental assessment (chapters 4.1 and 4.2), the economic assessment (chapter 4.3), and the SWOT analysis (chapter 4.4). All these individual sustainability aspects are joined in a multi-criteria integrated assessment (chapter 4.5).

2 Methodology, definitions and settings

General definitions and settings can be found in chapter 2.1. Specific definitions and settings for the environmental assessment, economic assessment, SWOT analysis, and integrated assessment are described and explained in chapters 2.1.6 - 2.5 together with the specific methods used in these analyses.

2.1 General definitions and settings

The general definitions and settings guarantee a consistent assessment of the environmental and economic implications of the BIOLYFE system as well as further issues addressed in the SWOT analysis. The general definitions and settings are described and explained in this chapter.

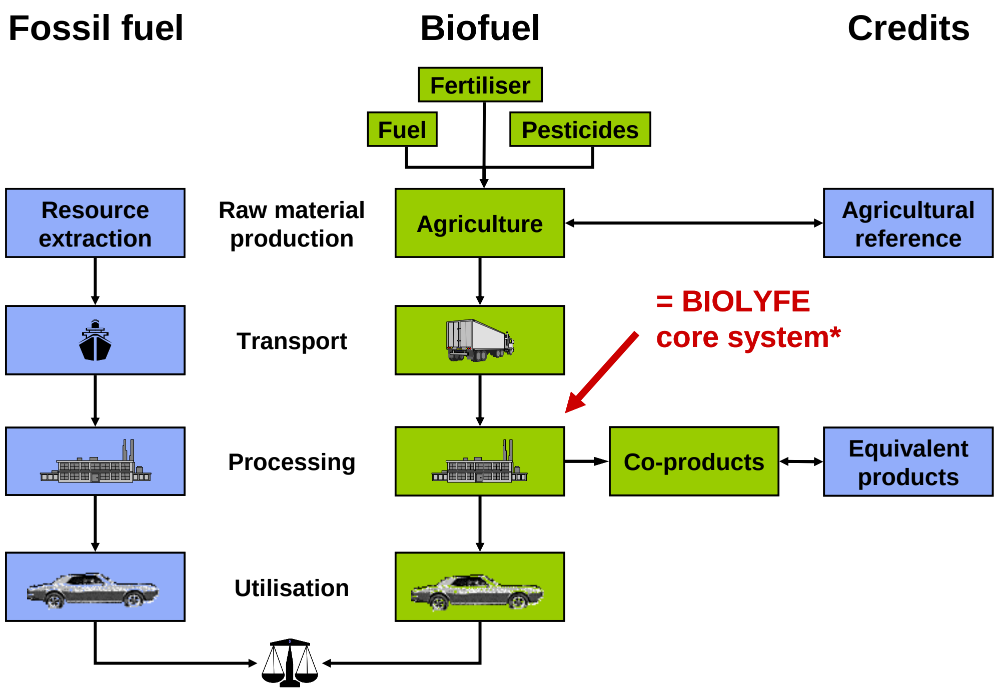


Fig. 2-1 System boundaries applied in the case of BIOLYFE
*: details in chapter 3.2

2.1.1 System boundaries

System boundaries determine which processes are included into the assessment and which not, e.g. if the whole life cycle is analysed or only a part of it.

The integrated assessment of the BIOLYFE system takes the entire supply chain (life cycle) into account from the feedstock production to the distribution and use of ethanol, including the provision of all required material and energy inputs as well as an agricultural reference system (Fig. 2-1).

2.1.2 Technical reference

The technical reference describes the state of technology that is assessed (e.g. laboratory scale, demonstration or mature technology). For the BIOLYFE project, the technical reference is an industrial scale, mature technology plant with an annual output of 100,000 t of ethanol. It was decided to evaluate this scale and level of maturity of a plant instead of the demonstration plant, which was inaugurated recently in Crescentino (about 40,000 t of ethanol per year). Otherwise, biases would arise when comparing the BIOLYFE system to other bioethanol producing systems if those are described on a mature technology scale. Details about the system are described in chapter 3.

2.1.3 Timeframe

The BIOLYFE system must be described not only in space but also in time. The timeframe of the assessment determines for example the marginal fuel mix that is replaced by bioethanol fuel from the BIOLYFE plant. 2020 is the timeframe for the main scenario (mature technology, industrial scale plant).

2.1.4 Geographical coverage

Geography plays a crucial role in many sustainability assessments, determining e.g. agricultural productivity, waste management systems, transport systems and electricity production. Moreover, ecosystems' sensitivity to environmental impacts differs regionally.

As one of the objectives of the study is to deliver information for further development, transferability and promotion of 2nd generation bioethanol, the BIOLYFE scenarios are examined with the whole EU as geographical background. Sensitivity analyses are applied to consider regional variability.

2.1.5 Functional unit

The functional unit is a reference to which the environmental and economic effects of the studied system are related. It typically is a measure for the function of the studied system, i.e. the produced good or service. The functional unit is the basis for the comparison of different systems.

Usage basis: 1 t of ethanol

Besides the functional unit, various other reference units may be relevant to answer specific questions. For example, if availability of agricultural land is the limiting factor for bioethanol production, the environmental and economic effects per area can be a more relevant indicator for decision support than per amount of product. According to the goal and scope questions raised in chapter 1, following additional reference units are used depending on the question to be answered:

- Area basis: 1 hectare and year of land use
- Raw material basis: 1 t of biomass (dry matter)

2.1.6 Origin of data

Biomass production data was supplied by Agriconsulting /Agriconsulting 2010/ and supplemented by data from IFEU. The PROESA® process was modelled by Biochemtex according to own proprietary data and experience under various conditions. Scenarios were defined based on the modelling results. An overview of the data can be found in annex chapter 8.1. Secondary data sources on inputs and outputs (e.g. acquired natural gas) are specific for each part of the assessment.

2.2 Methodology of the environmental assessment

The environmental assessment analyses all environmental implications associated with the BIOLYFE systems and infers their environmental optimisation potentials. It consists of two parts: a screening life cycle assessment (LCA) and a life cycle environmental impact assessment (LC-EIA).

LCA is a standardised methodology addressing primarily global or regional environmental impacts related to a specific product or process. A summary of the life cycle assessment methodology applied in the BIOLYFE project is provided in chapter 2.2.1.

However, the assessment of several important environmental aspects, especially those regarding local and site-specific impacts, is still under methodological development in LCA. Currently, balanced quantitative results regarding these aspects, which are certain enough for decision support, cannot be provided. The screening LCA is therefore supplemented by a qualitative assessment of local and site-specific impacts using methods originating from environmental impact assessment (EIA). The LC-EIA uses elements of EIA methodology with a focus on local, site-specific environmental impacts but applies them to the whole life cycles of the assessed scenarios instead of on a specific site. Details about the environmental impact assessment methodology are given in chapter 2.2.2 of this report.

Further details of all assessment methods can be found in deliverable 12.2 /Kretschmer et al. 2012/.

2.2.1 Life cycle assessment (LCA)

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 (biofuels) or farm-to-fork (food). The objective of carrying out an LCA in BIOLYFE is to identify the most promising BIOLYFE pathways, to identify optimisation potentials and to compare the BIOLYFE concept to conventional production chains (for details on goal and scope see chapter 1).

The BIOLYFE life cycle assessment is based on the international ISO norms 14040 & 14044 on life cycle assessments and is conducted as a screening life cycle assessment. It largely follows the ISO standards except for the level of detail of documentation, the quantity of sensitivity analyses and the mandatory critical review. Nevertheless, the results of these screening LCAs are reliable due to the close conformity with the ISO standards.

2.2.1.1 Settings for Life Cycle Impact Assessment (LCIA)

Within the BIOLYFE project, the impacts are assessed at midpoint level. The assessed midpoint indicators are listed in Tab. 2-1. The life cycle inventory (LCI) parameters and the respective characterisation factors are shown in Tab. 8-2 in the annex. All impact categories are standard categories in life cycle assessments /Wolf et al. 2012/.

Some impact categories (not listed in Tab. 2-1) are excluded because they are i) irrelevant for the BIOLYFE systems (e.g. ionising radiation) or ii) still under methodological development and classified worse than level II (recommended, but in need of some improvement) in the ILCD Handbook such as human- and ecotoxicity, water depletion and land use /Wolf et al. 2012/.

Normalisation

Normalisation helps to better understand the relative magnitude of the results for the different environmental impact categories. It transforms a category indicator result by dividing it by a selected reference value, e.g. a certain emission caused by the system is divided by this emission per capita in a selected area.

Where normalisation is applied in the BIOLYFE LCA study, the environmental advantages and disadvantages for the European scenarios are related to the environmental situation in the EU27. The reference information is the yearly average energy demand and the average emissions of various substances per inhabitant in Europe, the so-called inhabitant equivalent (IE). The reference values are listed in Tab. 8-3 in the annex.

Due to the uncertainty related to future emissions of various substances, the inhabitant equivalents are calculated based on 2010 emissions. These values are subsequently used to normalise data, which is calculated for 2020 (timeframe for BIOLYFE systems).

Tab. 2-1 Environmental impact categories and their description

Impact category	Description
Depletion of non-renewable energy resources	Depletion of non-renewable energy resources, i.e. fossil fuels such as mineral oil, natural gas and different types of coal as well as uranium ore. The procedures and general data for the calculation are documented in detail in /Borken et al. 1999/.
Climate change	Global warming as a consequence of the anthropogenic release of greenhouse gases. Besides carbon dioxide (CO_2) from combustion of fossil energy carriers, a number of other trace gases – among them methane (CH_4) and nitrous oxide (N_2O) – are included. The latter two are converted into carbon dioxide equivalents (CO_2 equiv.) using GWP100 factors /IPCC 2007/. Further details: /Borken et al. 1999/.
Acidification	Shift of the acid / base equilibrium in soils and water bodies by acidifying gases (keyword ‘acid rain’). Emissions of sulphur dioxide, nitrogen oxides, ammonia, and hydrogen chloride are playing a major role.
Terrestrial eutrophication	Input of nutrients into soils and by gaseous emissions. Excessive nutrient intake into ecosystems harms endangered and rare species as well as fragile ecosystems like forests or calcareous grasslands. Among others, nitrogen oxides and ammonia are responsible for this.
Aquatic eutrophication	Input of nutrients into surface water (marine and freshwater) directly or via input into soils and gaseous emissions. Excessive nutrient intake into water bodies harms endangered species and can lead to excessive growth of algae. Among others, nitrogen and phosphorous species as well as organic matter contribute to this (keyword ‘algal bloom’).
Photochemical ozone formation	Formation of specific reactive substances, e.g. ozone, in presence of nitrogen oxides, volatile hydrocarbons and solar radiation in the lower atmosphere (keyword ‘ozone alert’ or ‘summer smog’).
(Stratospheric) Ozone depletion	Loss of the protective ozone layer in the stratosphere by certain gases such as CFCs or nitrous oxide (keyword ‘ozone hole’). All ozone depleting gases are converted into CFC-11 equivalents. For N_2O, Ravishankara’s value /Ravishankara et al. 2009/ is used.
Respiratory inorganics (particulate matter emissions)	Damage to human beings due to air pollutants such as fine, primary particles and secondary particles (mainly from NO_X, NH_3 and SO_2). Heavy industries, electricity and heat production from liquid and solid fuels, as well as road traffic and agriculture are important sources of these pollutants (keyword ‘winter smog’ or ‘London smog’).

Weighting

Weighting is not applied. Weighting uses numerical factors based on value-choices to compare and sometimes also aggregate indicator results, which are not comparable on a physical basis.

2.2.1.2 Further methodological issues

Consequential vs. attributive 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 /Wolf et al. 2012/. Since “meso / macro-level decision support” applies to BIOLYFE, consequential modelling is used.

Solving multifunctionality

The goal of this LCA is to assess the environmental implications of the whole life cycle of a complete biorefinery. If by-products are produced, system expansion is applied. This approach is most suitable to answer the questions raised in chapter 1.

Systematic exclusion of activity types

Infrastructure is excluded from the system. This applies to production and processing equipment, vehicles such as tractors, buildings and streets connected with the crops’ production and use. 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/). However, this only applies to the environmental impacts considered in LCA. In contrast, investment and capital costs for process equipment or buildings are an important part of the economic assessment.

Biogenic carbon

There are two possible sources for carbon dioxide (CO_2) emissions: (recent) biogenic or fossil carbon stocks. For biofuels, the amount of CO_2 released into the atmosphere from direct biofuel combustion equals the amount of CO_2 that has been taken up by the plants recently (short carbon cycle). This release of biogenic CO_2 is considered carbon neutral, i.e. it does not promote climate change. Therefore, only fossil carbon is taken into account for calculating greenhouse gas balances in BIOLYFE, which is the standard approach among LCA practitioners.

Direct land use change and changes in organic carbon stocks

Changes in direct land use and related changes in organic carbon stocks of above- and below-ground biomass, soil organic carbon, litter and dead wood are in principle covered by the environmental assessment. In the scenarios assessed in the LCA, a significant decrease in organic carbon stocks can occur if idle (abandoned) land or non-rotational fallow land, which is idle for a sufficiently long time, is cultivated again. The use of these kinds of land only occurs in scenarios on cultivation of perennial crops. Thus, the decrease of original carbon stocks is partially or fully compensated by the build-up of new carbon stocks e.g. in rhizomes. As there is not enough data available, under which boundary conditions this leads to a net decrease of organic carbon stocks, this effect cannot be quantified.

Carbon sequestration in agricultural soils by annual cultures, which could also result from a land use change, 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, it is impossible to assure that the carbon is sequestered permanently. As there is no scientific consensus about this issue, carbon sequestration in agricultural soils is not accounted for.

The possible effect of releasing CO_2 from organic carbon stocks is by far not the only consequence of land use changes. Regarding quantitative indicators in LCA, even less data is available on e.g. release of nitrogen or phosphorous through land use changes so that these effects cannot be quantified in this assessment. Nevertheless, many qualitative effects e.g. on fauna, flora or biodiversity can be determined. They are assessed in the LC-EIA part of the environmental assessment and have a significant influence on the results.

Indirect effects

New systems using biomass can indirectly affect environmental indicators by withdrawing resources from other (former) uses. One of the most common indirect effects is indirect land use change: Biomass formerly used for other purposes (e.g. as food or feed) has to be produced elsewhere if it is now used for biorefineries. This can cause a clearing of (semi-)natural ecosystems (= indirect land use change) and hence changes in organic carbon stocks and damages to biodiversity. There is an ongoing international debate about these effects mainly focussing on organic carbon stocks. As the estimates on so-called iLUC factors regarding carbon stocks are deviating massively between studies and less is known about the influence of iLUC on other environmental impact categories, iLUC is not assessed quantitatively in this report but discussed qualitatively. Any short excursus regarding iLUC quantification would fall short of appropriately assessing it and it is not a main aim of this study to do so.

Withdrawing biomass from other uses may affect not only land use patterns but also other goods and services. Therefore, the BIOLYFE system is not only compared to one agricultural reference system but also to alternative ways of using the same biomass.

Origin of data

The origin of primary data on agricultural processes and the biorefinery plant is described in chapter 2.1.6. Data on background processes (provision of non-biomass material inputs and conventional reference products) was deduced by IFEU (/IFEU 2013/, /Ecoinvent 2010/).

Generally, all inputs into and outputs from the assessed system, for which no production data specific to the assessed system is available, are assessed according to average production data for the region of reference, in this case the EU. For additionally produced renewable energy, in this case power, a different approach is followed because of consequences that arise from the reactions of the utility providers to the rising supply of renewable energy. Additional power supply of new plants such as biorefineries to the grid gradually causes that old conventional power plants are shut down or new conventional power plants are not built. Because of political boundary conditions, additional renewable energy does not replace existing renewable energy. Thus, the replaced marginal energy mixes are different from average mixes. This was simulated in detail for Germany /Fraunhofer ISI 2009/, /UBA 2013/ and simulation results are continuously updated. As there are no simulations for whole Europe, a simplified mixture of 50 % power from natural gas and 50 % power from hard coal is used in this study where applicable.

2.2.2 Life cycle environmental impact assessment (LC-EIA)

In task 12.2 of the BIOLYFE-project, local environmental impacts are assessed. There are a number of environmental management tools, which differ both in terms of subject of study (product, production site or project) and in their ability to address environmental impacts occurring at different spatial levels. Environmental life cycle assessment (eLCA), for example, addresses potential environmental impacts of a product system (see chapter 2.2.1). However, for a comprehensive picture of its environmental impacts, also site-specific impacts on environmental factors have to be considered. Local or site-specific impacts are for example the loss of natural habitats and the disturbance of ecosystems or human settlements, e.g. by noise or light emissions. Although methodological developments are under way, these site-specific impacts are not yet covered in standard eLCA studies. Thus, for the time being, eLCA has to be supplemented by elements borrowed from other tools.

The methodology developed and applied in BIOLYFE borrows elements from environmental impact assessment (EIA, see chapter 2.2.2.1) and was termed life cycle environmental impact assessment (LC-EIA, see chapter 2.2.2.2).

2.2.2.1 The methodological basis: Environmental impact assessment (EIA)

Environmental impact assessment (EIA) is a standardised procedure for evaluating proposed projects concerning their potential to affect the environment. It is based on the identification, description and, if possible, quantification 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. The EIA process concentrates different sustainability goals on the related legal bases, e.g. soil conservation, nature conservation and conservation of water bodies.

By doing this, it helps decision makers to identify more environmentally friendly alternatives as well as mitigation and compensation measures.

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

Regulatory frameworks related to EIA

As the BIOLYFE project covers several regions in Europe, ideally all regions should be considered.

Within the European Union, it is mandatory to carry out an environmental impact 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 supplemented three times:

- 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/

Basically, an EIA covers direct and indirect effects of a project on the following environmental factors /CEC 1985/:

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

Steps of an EIA

An EIA generally includes the following steps:

- 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

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.

Impacts are related to the

- Construction / installation of the project; temporary impacts expected, e.g. by noise from construction sites.

- Project related: buildings, infrastructure and installations; durable impacts expected e.g. by sealing of soil on the plant site.
- Operation phase of the project; durable impacts expected, e.g. by emission of gases.

2.2.2.2 The LC-EIA approach in BIOLYFE

Objectives and approach

Within the BIOLYFE project, several life cycle scenarios are analysed. Each scenario is defined by its inputs, the conversion, the downstream processes and the final products. This is also reflected in the objectives of the sustainability assessment in WP 12: the aim is to qualitatively assess the impacts associated with each of the (hypothetical) BIOLYFE concepts (in the sense of technological concepts) at a generic level. The assessment is not meant to be performed for a specific BIOLYFE 2G bioethanol plant at a certain geographic location.

Environmental impact assessment (EIA), however, is usually conducted at a site-specific / local level (see chapter 2.2.2.1) for a planned (actual) project. Concerning the actual BIOLYFE 2G bioethanol plant in Italy, there is no need to repeat the work to assess a proper EIA as this was already done before starting the construction of the plant.

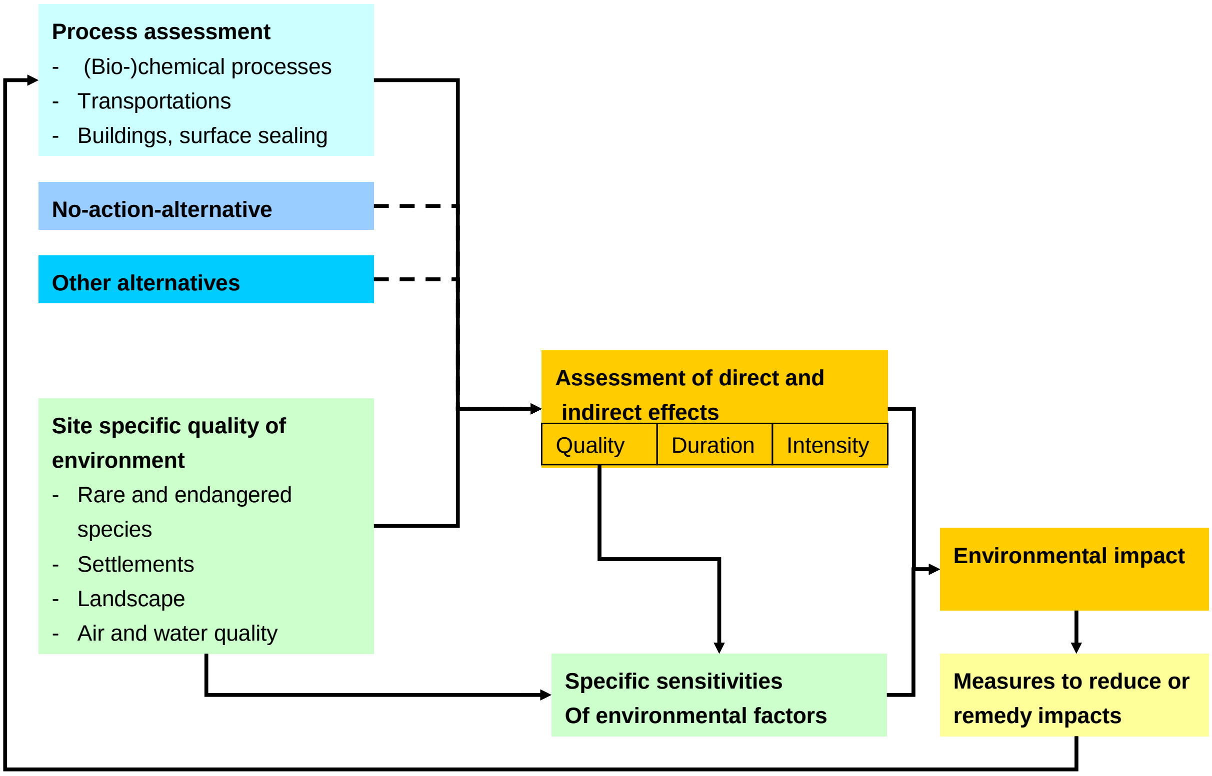


Fig. 2-2 Structure of the LC-EIA in the BIOLYFE project

For the purpose of the BIOLYFE scenarios, which encompass neither the actual site of biomass (investigated at generic level) nor the plant's actual location, it is therefore not appropriate to perform a full-scale EIA according to the regulatory frameworks mentioned in chapter 2.2.2.1. 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 were omitted within BIOLYFE. Nevertheless, elements of environmental impact assessment (EIA) are used to characterise the environmental impacts associated with the BIOLYFE scenarios at a generic level.

The elements of EIA used in BIOLYFE are shown in Fig. 2-2.

Reference systems

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. 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.

For BIOLYFE, the scope, and therefore also the reference system, 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 corresponds 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. They are described in chapter 3.4.

Impact assessment

The assessment of environmental impacts of biomass production, conversion and use is carried out as a benefit and risk assessment. This is useful if no certainty exists regarding the possible future location of fields for 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 of biomass production (see also Fig. 2-3).

- 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.

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

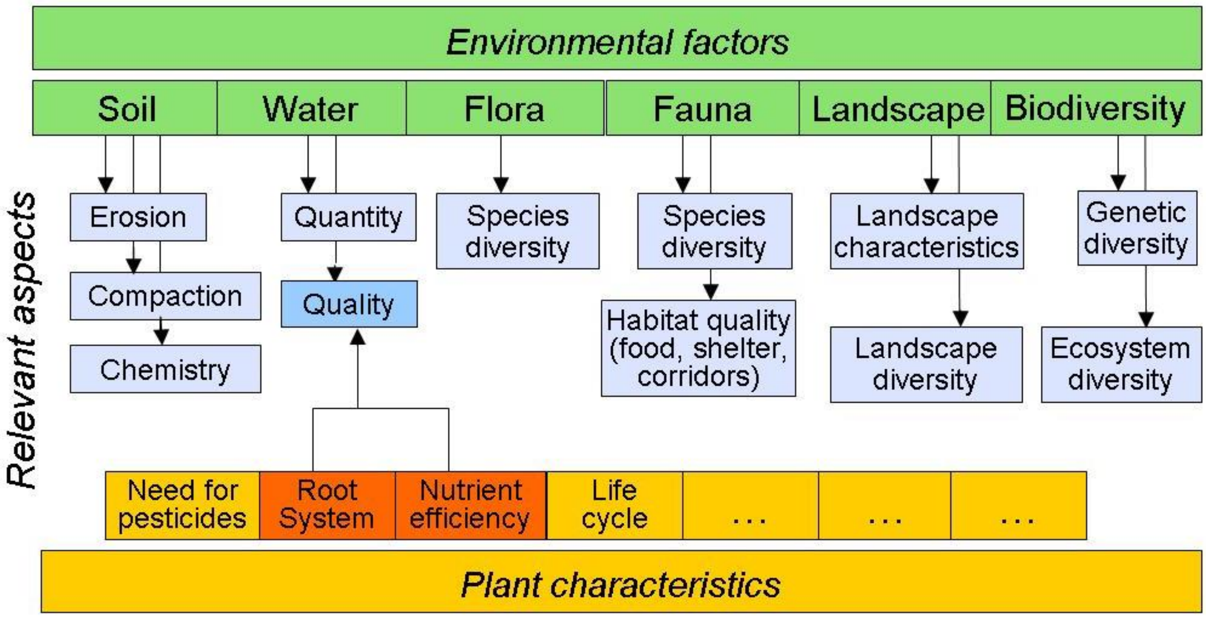


Fig. 2-3 Identification of factors for the EIA of biomass production

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 a conversion plant, including the use of bio-based energy carriers and materials as well as by transportation of biomass feedstock and intermediates. The benefits and risks assessment for biomass conversion, use and transportation investigates potential effects of conversion and use units on the local environment. The aspects human health, soil, flora, fauna and landscape are studied. Effects beyond the local environment (e.g. climate change) are in fact covered by the LCA but partly mentioned here, too.

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 Tab. 2-2.

Tab. 2-2 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	Annoyance by an increase of environmental noise or gaseous emissions
Waste water and waste water treatment	Water	Depletion of water resources Nutrient input into water bodies causing eutrophication
Amount of traffic (noise and gaseous emissions)	Human health	Annoyance by an increase of environmental noise or gaseous emissions
Size and height of conversion plants	Soil Flora Fauna Landscape	Soil compaction or soil sealing Loss of vegetation Loss of habitat Landscape disturbance

Development of conflict matrices

Aggregated conflict matrices are created based on the biomass-specific benefits and risks, which summarise the impacts of biomass production, conversion and use on the selected environmental factors.

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

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

2.3 Methodology of the economic assessment

This task aims to provide a feasibility analysis based on process calculation and economical evaluation of the different process options developed for both hydrolysis and fermentation steps. The economical evaluation takes into account not only these two units but also their impact onto the entire industrial demo plant; a sensitivity analysis useful for future 2nd generation business plans has also been performed.

In order to carry out these activities it has been necessary to develop a model that proves as a simple and flexible tool for a preliminary estimation of:

- simplified mass and energy balances for the hydrolysis and fermentation steps on the basis of pilot plant data with, when possible, integration based on the Demo.
- key factors involved in the integration activity and a rough estimation of their effects on the process cost (sensitivity analysis).

In order to preserve the simplicity of the tool, it was decided to follow a descriptive approach with the aim to foresee the behaviour of the system. In other terms, experimental data are fundamental to calculate the parameters (such as conversion or yield) of every step because not all the input variables are related to the operative conditions. This is also the best choice in order to perform a sensitivity analysis, because all the main input can be easily varied.

Further methodological details extending this chapter can be found in the annex, chapter 8.6.

Economics evaluation:

The economic evaluation of second generation bioethanol production takes into account many factors that can affect production costs, such as variable costs (OPEX) and fixed costs (CAPEX).

OPEX (OPerating or OPerational EXpenditure) is the cost required to manage a product, a business and has been calculated by an accountant from raw materials, utilities and labour demands. CAPEX (CAPital EXpenditure) is the fixed capital investment that a company pay if the processing plant has been bought. The estimation of equipment cost sizing has been conducted with the help of an economic modelling tool included in a process simulation software on the basis of equipment cost data from existing plants. The analysis does not deep to an equipment list detail level but considers available capital investment cost data divided by section, which is then converted to the selected plant size through power law.

Battery limits:

The battery limits considered for the economic evaluation of ethanol production include raw material handling, the hydrolysis and fermentation sections and ethanol purification. The battery limits do not consider any costs related to the auxiliary equipments (e.g. cogeneration packages and cooling towers) and the disposal of waste products outgoing the auxiliary sections of the plant (e.g. ash from burner).

Both operative costs (e.g. raw material, utilities, …) and capital investment have been estimated for the sections included in the battery limits (see Fig. 2-4).

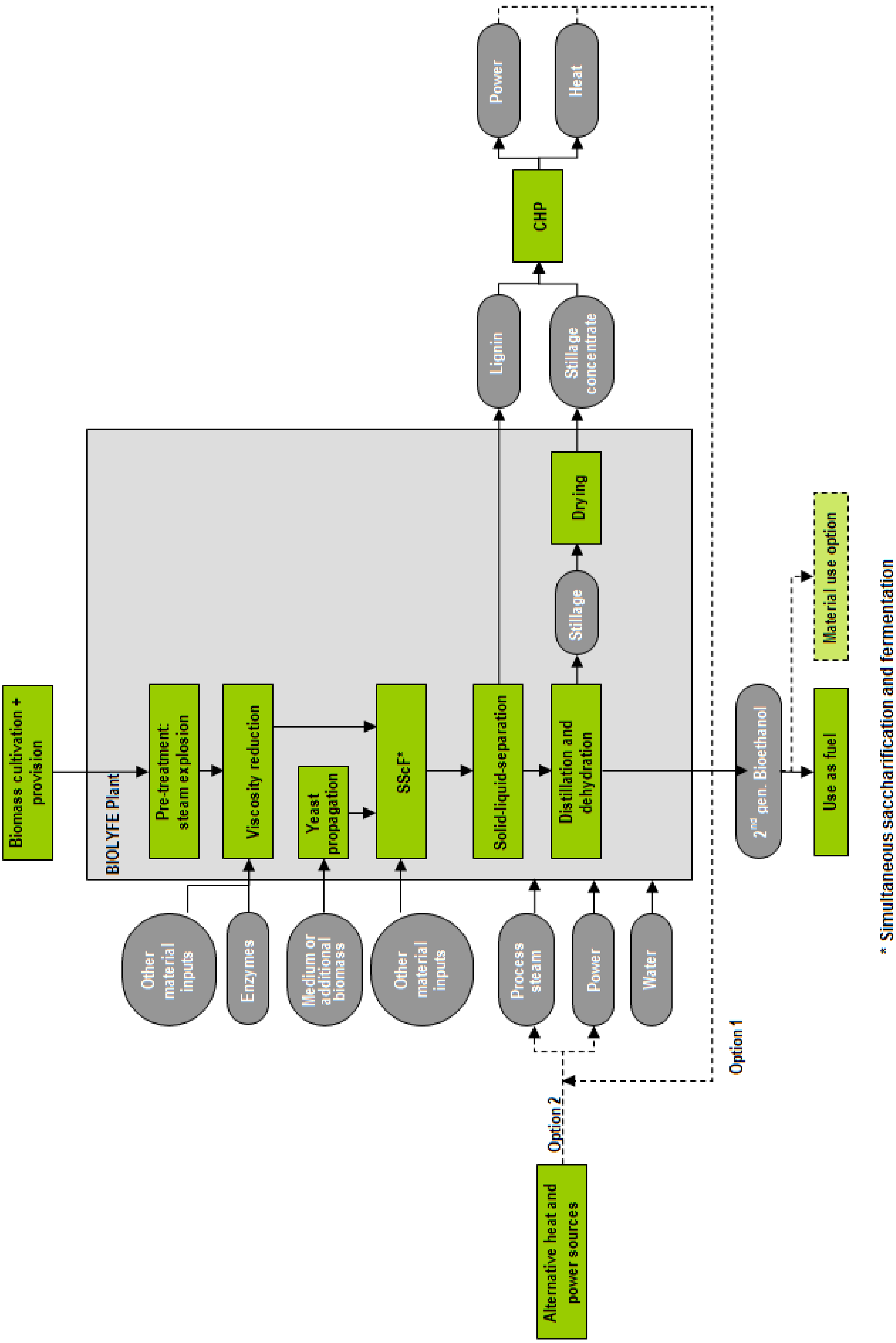


Fig. 2-4 Schematic overview of the BIOLYFE bioethanol plant. Here, system boundaries (battery limits) of the plant relevant for the economic assessment are displayed.

2.3.1 Input of the assessment

A number of assumptions have been adopted to carry out the economic study of the process. In the following, these assumptions are described for the main scenario selected to develop the model.

The study of the project is based on a plant that foresees all the elements required for the implementation of a complete 100,000 t / a second generation bio ethanol production facility. The plant is a continuous operation system.

The following work has been focused on the sensitivity analysis of the following parameters:

- feedstock;
- enzyme dosage.

The sizing of the different sections of the plant depends on two main parameters:

- ethanol yield (that impacts on the quantity of feedstock entering the plant);
- dry content in viscosity reduction and downstream operation.

Plant has been designed to guarantee flexible operation with different feedstock and to maximise ethanol yield.

By a process point of view, the intermediate yields and utilities consumptions have been assumed as entries data. Each parameter is set to the optimal value in accord with current Biochemtex knowledge. It is possible to vary the default values in order to meet the process requirements and improvements. The entries are divided into two main sections: “Process Input” and “Economics Input”. Each entry is described below.

Process input:

- Feedstock type: the model considers different types of feedstock and users can set these parameters through a dedicated drop-down menu. Up to now data are set for Arundo donax, wheat straw and fibre sorghum. The composition utilised in tool is referred to standard feedstock type in agreement with Biochemtex’s analytical results. Biochemtex has the possibility of updating the feedstock database with new types of raw materials or specific compositions when it is needed. The feedstock behaviour in the process (consequence of the biomass structure and recalcitrance to pre-treatment) is included in the model according to Biochemtex experience.
- Production capacity: the user can set the production throughput in terms of tonnes per year. In this case the production capacity of the plant is fixed at 100,000 t / a. The frontend requirement for the feedstock is calculated on the basis of specified production needs.
- Sugars conversions and selectivity of sugar reaction: these parameters are always the same for all types of biomass as the sensitivity analysis is made only on the initial composition of feedstock.

  Enzyme dosage: during enzymatic hydrolysis step, the model considers different enzyme input in order to meet the process requirements. Data are set according to Biochemtex’s experiences with the commercial enzyme supplier. The enzyme input parameters are normalised based on a standard value (set as consequence of Biochemtex experience) which is expressed as “1X”. The other ones are calculated on the basis of predictions about enzyme formulation performances and improvements. Indeed, several enzymes suppliers foresee the development of new generation cocktails with very specific side activities and able to reduce dosages and cost and to improve performances.

- Fermentation yields: for this section, the main entries are split for two different classes, C5 and C6 sugars. The main data entries of the stage are :
  - sugar conversion (fraction of monomers reacting during the process)
  - selectivity (reacting sugars can be converted to ethanol or dedicated to yeast growth and maintenance)

Economics input:

The model allows setting the economic inputs that are divided into variable, fixed costs and capital investment.

The variable production costs are classified in three main areas:

- Raw material: the economic impact of the biomass is related to biomass type and to plant location. Price can be adjusted in agreement with the considered scenario.
- Consumables: this area includes chemicals, yeast and enzyme costs. The enzyme cost is set according to the information provided by the supplier, while the chemicals cost depend on dosage and on the yield of the process.
- Utilities: total equivalent energy consumption is compared to the overall energy production coming from the lignin and the concentrated stillage resulting from the process. If an energy import is necessary, an external load of electricity and natural gas is foreseen. The impact of the utilities cost is estimated for an energetic scenario in which an OSBL CHP plant produces the steam and the electricity necessary for the 2nd generation bioethanol plant. Only the lignin surplus amount coming from lignin and stillage in excess for the energy requirement of the plant is sold.

The fixed production costs considered by the assessment is related to labour and maintenance costs of the plant. The estimation requires the setting of specific parameters for the calculation of these items:

- Labour: the economic impact of the section is strictly related to plant type and location. The user can adjust the different voices in agreement with his needs.
- Maintenance: the maintenance and repair cost is estimated as a percentage of the capital investment.

Regarding the capital investments costs, they have been considered as divided by plant section; the cost of each section has been adjusted to the selected plant size through power law, with the proper exponent set according to the section type. Key equipment costs have been evaluated based on existing offers, Biochemtex worldwide experience and finally validated through process simulation software and available databases.

Capital investment have been estimated only for the sections included in the battery limits that include raw material handling, the hydrolysis and fermentation sections and ethanol purification. They do not consider any costs related to the auxiliary equipments and the disposal of waste products outgoing the auxiliary sections of the plant.

2.3.2 Output of the assessment

The output of the assessment is divided in process and economics data.

Process output:

- Ethanol yield: expressed as the amount of dry biomass needed to produce 1 ton of bioethanol
- Biomass consumption
- Consumables consumption

  Lignin total production: lignin cake is separated from sugars during the saccharification process and it represents a relevant energy source for the overall process. The total amount could be affected by biomass type and process parameters.
- Concentrated stillage production
- Overall plant duty: the output, expressed as energy unit per year, represent the net plant duty as difference between energy plant requirements and energy content recovered from the available lignin and stillage.

Economics output:

- Second generation ethanol operating costs: the cash cost of 2G-ethanol is the sum of variable and fixed production costs.
- Plant capital investment

2.4 Methodology for SWOT analysis, social impact assessment and biomass competition analysis

A SWOT analysis is a tool to assess the performance of a project, a product or a company. It originates from business management and it is a strategic planning tool to identify and assess the Strengths, Weaknesses, Opportunities and Threats of the surveyed object. Thereby strengths and weaknesses are defined as internal characteristics of the assessed system, while opportunities and threats are external factors determining the success or failure. The results of a SWOT analysis are generally summarised in a SWOT matrix. The general structure of a SWOT matrix is shown in Fig. 2-5.

In the BIOLYFE project, SWOT analysis is used to describe the strengths, weaknesses, opportunities and threats of the BIOLYFE biorefining concept.

The objective of the SWOT analysis is to supplement the results of the technological, environmental and economic assessment task 12.1 – 12.3 by catching up success and failure factors not covered in the other tasks and thereby to broaden the basis for the integrated assessment of sustainability in task 12.5. Therefore, the objective of SWOT analysis is NOT to give a full summary of all success and failure factors identified in task 12.1 – 12.3. This is done in task 12.5.

A main focus of the SWOT analysis is on social aspects. Social sustainability is one of the three pillars of sustainability, beside economic and environmental impacts. The results of the SWOT analysis and additional information from project reports and literature were used for a short screening analysis of social hot spots in BIOLYFE value chains (chapter 2.4.2). The screening analysis was carried as qualitative analysis and highlights areas of concern that have to be analysed in detail in specific projects and further research. As biomass availability is a crucial issue for the success and failure of biomass based value chains, the results from SWOT and social hot spot analysis are complemented by a short summary on biomass availability.

	Success factors	**Failure factors**
Internal	**Strengths**	**Weaknesses**
External	**Opportunities**	**Threats**

Fig. 2-5 Structure of a SWOT matrix

2.4.1 SWOT methodology in BIOLYFE

2.4.1.1 Goal and scope of SWOT analysis in BIOLYFE

The SWOT analysis in BIOLYFE relates to the main BIOLYFE pathway as described in Deliverable D12.1 /Weibel et al. 2011/.

The SWOT statements address a large variety of sustainability aspects, in particular the following:

- Social aspects
  - Income and employment opportunities, benefits for smallholders
  - Working conditions
  - Gender aspects
  - Health aspects
  - Food security: Competition for food production, food and feed prices
  - Public perception and acceptance (for different groups, in particular farmers, residents, users of final product)

- Technical aspects
  - Feasibility of feedstock production: Agricultural / technical success and failure factors
  - Feasibility of feedstock harvest, storage and transport: Technical success and failure factors
  - Maturity of technology and knowledge gaps
  - Difficulties to achieve quality requirements
  - Risks (e.g. risk of explosion, toxicity etc.)
  - Differences of final product compared to reference product with regard to functionality
- Legal and political aspects
  - Subsidies and other political support
  - Legal restrictions
  - Norms and standards to be considered
  - Intellectual property issues
- Environmental aspects not covered in LCA and LC-EIA (task 12.2)
- Economic aspects not covered in economic assessment (task 12.3)

2.4.1.2 System boundaries: Distinguishing internal and external factors

A SWOT analysis covers internal and external success and failure factors. This requires a clear definition of what is internal and what is external to the assessed system.

In BIOLYFE SWOT analysis, internal and external factors are distinguished as follows:

- **Internal:** All aspects that relate to intrinsic and demonstrated properties of the main BIOLYFE pathway are defined as internal: E.g. general properties of the feedstock, the processing chain and the final product related to the standard production and processing technologies and use.
- **External:** All aspects that relate to
  - expected but not yet demonstrated technological achievements (e.g. breeding success, increased fermentation yields etc.)
  - future developments in economy, society, technology etc. (e.g. of prices, demand, feedstock availability, acceptance, subsidies, laws etc.)
  - characteristics of sensitivity pathways as far as they represent optimisation potentials (opportunities) or risks (threats) for the performance of a BIOLYFE biorefinery.

2.4.1.3 Structure of SWOT analysis in BIOLYFE

The SWOT analysis is separated into two parts: “Feedstock production and provision” and “feedstock conversion and use”. In the following the methodology used for these two parts of the SWOT analysis are described in detail.

SWOT analysis on feedstock production and provision

Within the BIOLYFE project, different feedstocks and cultivation systems are analysed. The SWOT analysis covers the most important options as identified in previous BIOLYFE reports (in particular deliverable D 1.1). Tab. 2-3 gives an overview on the SWOT analysis carried out for feedstock provision. The respective SWOT tables are given in chapter 4.4.1.

The analysis covers the cultivation, harvest, storage and transport to the processing plant (Fig. 2-6). By carrying out the SWOT analysis, the authors bore in mind the agricultural reference systems and reference products as used for task 12.2 (environmental sustainability assessment). These are: rapeseed for biodiesel production, maize for biomethane production, sugar beet for 1st generation ethanol and idle land (combined with fossil fuel use). The results of SWOT analysis are presented in chapter 4.4.1.

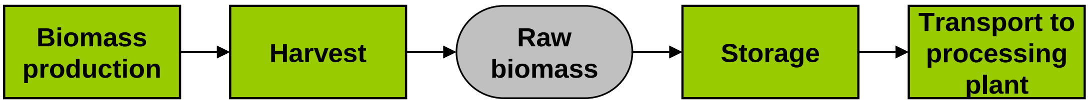


Fig. 2-6 Scope of SWOT analysis on biomass production and provision

Tab. 2-3 Overview on SWOT matrices for biomass provision

Chapter	Content	Table
3.1	Lignocellulose crops	
3.1.1	General aspects	Tab. 4-16
3.1.2	Specific crops	
3.1.2.1	Giant reed (Arundo donax)	Tab. 4-17
3.1.2.2	Fibre sorghum (Sorghum bicolor)	Tab. 8-23
3.1.3	Cultivation systems	
3.1.3.1	Traditional cultivated land, high input	Tab. 8-24
3.1.3.2	Traditional cultivated land, low input	Tab. 8-25
3.1.3.3	Marginal (idle / abandoned) land: low input	Tab. 8-26
3.2	Agricultural residues: straw	Tab. 8-27
3.3	Use of feedstock mixes	Tab. 8-28

SWOT analysis on feedstock conversion and use

Biomass conversion in the context of the BIOLYFE scenarios is divided into several single processes such as biomass pre-treatment, hydrolysis, separation, distillation etc. But all these processes form one single pathway. Therefore, only one SWOT analysis for the biomass processing is carried out. Possible strengths and weaknesses of a mature plant are classified as “opportunities” and “threats”. By carrying out the SWOT analysis, the authors bear in mind (supported) the reference products as used for environmental sustainability assessment in task 12.2:

- Biogasification & Fischer-Tropsch synthesis (production of diesel)
- Fermentation (production of 1st generation bioethanol)
- Anaerobic digestion (production of methane)
- Transesterification from seed oils (production of fatty acid methyl ester, biodiesel)
- Crude oil refinery (production of fuels).

I.e., the SWOT analysis describes strengths, weaknesses, opportunities and threats of a BIOLFYE 2nd generation ethanol plant in comparison to the mentioned alternatives for fuel provision. The SWOT matrix for the BIOLYFE biomass conversion and use is presented in chapter 4.4.2.

2.4.2 Hot spot analysis of social impacts

2.4.2.1 Introduction to social sustainability

Social aspects are one of the three pillars of sustainability, together with environmental and economic aspects. The BIOLYFE project did not include a separate task for social sustainability assessment as it is for environmental and economic sustainability. Instead, social aspects are assessed in a short screening analysis based on SWOT analysis outcomes and literature.

The concept of social sustainability covers various aspects. Most prominent is the fulfilment of basic needs on a local and global scale /UN 1987/. This includes explicitly justice for all groups of society, in particular woman, ethnic minorities, indigenous groups, etc. Basic needs include first and foremost the human rights as defined in the *Universal declaration on human rights* /UN 1948/, the *International Covenant on Civil and Political Rights* /UN 1966a/ and – last but not least - the *International Covenant on Economic, Social and Cultural Rights* /UN 1966b/. Closely related to the concept of “basic needs” is the concept of “human wellbeing”. “Human wellbeing” is a multidimensional concept including a broad range of aspects including bodily integrity, health, economic security, freedom, self-expression, knowledge or friendship /Alkire 2002/. To measure or to describe human development or “human wellbeing”, the capability approach developed by Amartya Sen /Sen 1993/ is nowadays the most common approach. This concept delivers the basis for the Human development Index, which is reported regularly at UN level science 1990. The main question of the “capability approach” is what is needed for a “good human life”. Material goods and income are only a mean to achieve the goal “good life”. The concept rather points out that a human being needs certain capabilities to shape their lives, including e.g. access to education, social security, control over ones environment and affiliations /Nussbaum 2000/.

The sustainability concept in general combines intra-generational and inter-generational aspects, i.e. basic needs have to be fulfilled not only for the present but also for future generations.

To sum up, social sustainability includes (1) securing human existence, (2) sustaining the productivity of the society, (3) sustaining options for development and action and (4) sustaining and achieving a high quality of life for all people /Bleicher & Groß 2010/.

Social impacts are very complex and difficult to assess, because they are a function of many influencing factors like politics, economy, ethics, psychology, legal framework, culture etc.. Human beings and societies are reactive, and so social impacts feed back to the production system and change other social and environmental impacts. Therefore, a final definition of social impacts needs active involvement of stakeholders to catch up with personal and subjective preferences of the involved persons.

2.4.2.2 Social sustainability indicator sets

Because of the dependence of social sustainability on institutions like legal framework and political system as well as on culture issues, sustainability is mostly assessed on a society level. Therefore, it is difficult to assess the impact of a single company or business model on social sustainability. Normally, differences in social sustainability vary a lot between regions and less between companies within the same regions. Nevertheless, some indicator sets and methodological approaches for assessing social impacts of companies or business cases have been developed. There is also an ongoing and intense discussion on social sustainability indicators for bioenergy.

The global reporting initiative (GRI) for corporate sustainability reports includes social sustainability assessment and addresses all types of companies. The Global Bioenergy Partnership (GBEP) provides indicators for the assessment of bioenergy policies and programs. An ISO norm 13065 “sustainability criteria for bioenergy” is currently under development.

Another approach for social sustainability assessment is the SETAC approach for “social life cycle assessment” (sLCA) which aims to assess social impacts of products along the entire life cycle. For BIOLYFE, the sLCA indicator set is considered most suitable because it addresses specific production chains and is in line with the eLCA approach carried out for environmental sustainability assessment.

The S-LCA approach is in line with the ISO 14040 and 14044 standards for Life Cycle Assessment. It classifies social impacts first by stakeholder categories, distinguishing the stakeholder groups “workers”, “local community”, “society”, “consumers” and “value chain actors”. Social impacts for each stakeholder category are grouped by subcategories, which are social and socio-economic issues of concerns (Tab. 2-4).

Tab. 2-4 Overview on sLCA-subcategories for the different stakeholder categories
Source: /UNEP 2009/, p. 48

Stakeholder category	Sub categories
Worker	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities / Discrimination Health and Safety Social Benefits / Social security
Consumer	Health and safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Local Community	Access to material resources Access to immaterial resources Delocalisation and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Society	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

The sLCA methodology is still under development and rarely applied. Methodologies for the assessment in different impact categories are far less developed compared to environmental LCA. Nevertheless, it is a suitable tool to highlight areas of concern ("hot spot analysis") and helps to identify topics where further research or particular caution is needed.

To identify the most relevant indicators, the complete list of sLCA indicators was first assessed against the legal framework in EU 27 (=geographical frame for BIOLYFE sustainability assessment). In a second step, indicators specifically influenced by BIOLYFE value chains were identified. Finally, for the indicators relevant for EU 27 and specifically influenced by BIOLYFE, the type of impact was specified (Fig. 2-7).

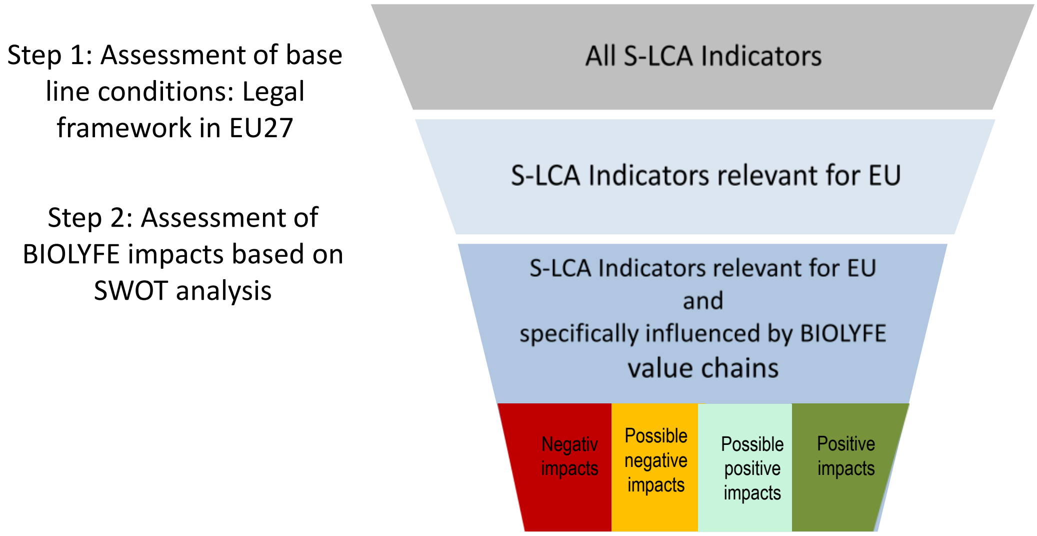


Fig. 2-7 Hot-spot analysis of social impacts based on sLCA indicators

2.4.3 Biomass competition analysis

Success and failure of biomass-based industries strongly depend on the availability of sustainable biomass supply. Therefore, a short separate investigation on biomass potentials was carried out. The analysis consists of two parts: A screening of biomass availability in Crescentino region (case study assessment) and a literature review on biomass potentials in Europe.

2.5 Methodology of the integrated assessment

There are several options of how to implement BIOLYFE bioethanol plants or adopting alternatives to this technology. These are represented in this assessment in the form of scenarios. On each scenario, various indicators from economic assessment, environmental assessment via LCA and LC-EIA and from the assessment of other sustainability aspects via SWOT analysis such as social impacts are made available in this study. All these aspects have to be integrated into an overall picture to facilitate decisions between the options.

There are two general options of integrating this information:

Weighting and mathematical integration

All indicators could be mathematically combined into one score using weighting factors. This approach cannot be entirely based on scientific facts but depends on personal value based choices. Furthermore, conflict situations do not become apparent and decisions regarding these conflicts depend on weighting factors, which are hard to understand for decision makers not involved in the study. Therefore, this approach is not applied.

Structured discussion

All pros cons and conflicts of the options can be discussed verbally argumentatively. This can make conflicts transparent and enable their active management. Considering the amount of options and indicators, this requires a structured approach. This approach is followed in this study. This section describes the methodology used for the structured comparison and presentation of decision options based on a multi criteria analysis.

2.5.1 Collection of indicators and results

Indicators and results for all scenarios are provided by the individual assessments (see chapters 4.1 to 4.4). They are collected in overview tables. In some cases, indicators are selected or aggregated to focus on the most relevant aspects for decision support. In this study, this mainly applies to LC-EIA and SWOT indicators.

2.5.2 Additional indicators

Climate protection under the condition of limited financial resources has to use the available financial resources as efficiently as possible. Efficiency means here to achieve the highest possible greenhouse gas (GHG) emission savings with the lowest monetary expenditures necessary for that. CO_2 avoidance costs are frequently used as indicator for this purpose. CO_2 avoidance costs are defined as quotient of the differential costs for a CO_2 reduction measure and the avoided CO_2 emissions by this measure.

In analogy to $CO_{2,}$ avoidance costs, similar indicators can be defined for other environmental impact categories like for example acidification as SO_2 avoidance costs or Resource depletion as non-renewable energy savings costs. The same methods apply for those indicators as discussed in the following for the example of CO_2 avoidance costs.

CO_2 avoidance costs are used for microeconomic decisions as well as for the decisions in energy policy. Microeconomic decisions are always based on business analyses. If political decisions like the implementation of support programmes are concerned, the valuation is often more difficult, as the macroeconomic dimension, possible external effects as well as second- and third-round effects have to be considered. For the determination of CO_2 avoidance costs, different methodological characteristics have to be considered concerning:

- the determination of a baseline, which is in this case use of fossil fuels, particularly gasoline.
- the inclusion of different cost items (e.g. full costs vs. additional costs)
- the inclusion of temporal dynamics of systems under consideration (e.g. developments of investment costs of systems, of prices for energy carriers, etc.)
- the different perspectives – especially microeconomic and macroeconomic approaches

However, the sole consideration of CO_2 avoidance costs is often not sufficient to come to sustainable decisions. On the one hand, they do not contain any information about the amount of emissions that can be avoided and on the other hand, they do not take other environmental impacts into account. Therefore, CO_2 avoidance costs do not represent a single combined indicator resulting from the sustainability assessment but only one additional criterion.

CO_2 avoidance costs from a microeconomic perspective are calculated as follows:

$$\mathbf{CO_2\ avoidance\ costs} = \frac{\mathbf{costs - costs\ (benchmark)}}{\mathbf{GHG\ emissions - GHG\ emissions\ (benchmark)}}$$

CO_2 avoidance costs are expressed in Euro per tonne of CO_2 equivalents. Costs refer to the fuel costs consisting of variable and fixed costs including discounted investments as defined in chapter 2.3 and greenhouse gas emissions (GHG emissions) expressed in CO_2 equivalents as defined in chapter 2.2.1.1.

One methodological option is to discount the avoided greenhouse gas emissions (GHG em) for the calculation of the avoidance costs as well, in order to create a preference for temporally preceding measures (with a discount rate *i*, which should reflect this preference).

$$GHG\ em - GHG\ em(benchmark) = \sum_{t=0}^{n} \frac{\Delta GHG\ em(t)}{(1+i)^t}$$

Otherwise, a later realisation of the measure could be reasonable for decision makers. Moreover, a discounting reflects an assumed uncertainty about the degree and the time point of the environmental impact. Generally, a discounting of the environmental costs results in higher CO_2 avoidance costs as without discounting. However, for further calculations in this study it is assumed that the discounting is neutralised by the fact that the environmental impact increases parallel to the so-called social preference rate. The social preference rate consists of the time discounting and the growth accounting /Nordhaus 1994/, /IPCC 1996/, /Fankhauser 1995/. Therefore, the method without discounting is used.

As CO_2 avoidance costs represent an efficiency indicator, they are only defined in the case that the primary goal is met, this is, that there are greenhouse gas emission savings by the process under investigation compared to the benchmark. If the goal is not met, one obviously cannot define an indicator on how efficiently the goal is reached. This means, the CO_2 avoidance costs can be interpreted or not depending on the results of the numerator and the denominator.

Fig. 2-8 shows that out of nine possible result options only two allow an interpretation of the avoidance costs. If negative avoidance costs occur it has to be reconsidered if this results from the lower total costs or from the possibly higher emissions. Differences approaching zero make a calculation of avoidance costs impossible. If two differences are compared to each other, it can lead to overproportional influences of uncertainties. This is especially the case if either the emissions or the costs of the compared pathways are very similar. If for example the CO_2 emissions of the two pathways differ by 10 % then a 5 % error of estimating these emissions can lead to a deviation in CO_2 avoidance costs of 100 %. Furthermore, small emission savings mathematically lead to very high and at the same time very uncertain avoidance costs. Therefore, avoidance costs are only then a reliable indicator if the uncertainties of emissions and the costs are small compared to the respective differences between the pathways.

Δ profit / Δ emissions	> 0	≈ 0	< 0
< 0	calculation possible (less costs than for reference)	no calculation possible	calculation possible
≈ 0	no calculation possible	no calculation possible (similar systems)	no calculation possible
> 0	no CO_2 avoidance (not defined)	no CO_2 avoidance (not defined)	no CO_2 avoidance (not defined)

Fig. 2-8 Different result options for the calculation of CO_2 avoidance costs (modified from /Pehnt et al. 2010/)

The second limitation is that avoidance costs are very prone to changes in the course of time because they can generally be very sensitive to changes as discussed above and they depend on the technological developments as well as market changes for two different systems. Therefore, it is especially important only to compare avoidance costs if they are determined for the same timeframe and under the same conditions. This makes it difficult to find comparable avoidance costs outside of this study although there is plenty of data on avoidance costs in literature.

Taken together, avoidance costs for environmental burdens such as greenhouse gas emissions can help to decide how mitigations of environmental burdens can be reached for the lowest price or even with profits. A possible outcome of the decision process could also be that none of the environmentally beneficial options under investigation is realised because they cause high costs per tonne of emission savings compared to emission reductions elsewhere outside of the scope of this study. Therefore, it has to be assured that the avoidance costs have a sufficient certainty and are not misleading in comparison to avoidance costs published elsewhere.

For further details and a critical review of the method see /Pehnt et al. 2010/.

2.5.3 Benchmarking

For the comparison of many different processes, a common benchmark has to be defined. This benchmark has to be chosen according to the questions to be answered and the respective perspectives of various stakeholders. In this case, the benchmark could for example be the economically or environmentally most favourable pathway, or the currently most used option.

For all quantitative indicators, the benchmarking process involves calculating the differences between the respective scenario and the benchmark. These comparisons should serve as a decision support to answer the question whether a scenario performs better than the benchmark regarding a certain indicator. Therefore, these quantitative differences are categorised into very advantageous (++), advantageous (+), neutral (0), disadvantageous (-), or very disadvantageous (--). A certain minimum difference was chosen as a cut off value for the category neutral. According to the purpose, this threshold is set as a percentage of the bandwidth from the best results to the worst result among all scenarios regarding a specific indicator. The certainty of this rating is evaluated by additionally taking the bandwidth of the data into account. If the scenario under consideration achieves better results under less favourable conditions than the benchmark does under standard conditions, it is rated very advantageous (++). If not, but all direct comparisons under identical conditions show e.g. 10% better results than the benchmark, it is rated advantageous (+). If there is no bandwidth available for the scenario under consideration, it is rated very advantageous (++) if it is e.g. 10% better than the benchmark under favourable conditions. For all qualitative indicators, rating of differences is done analogously but without applying minimum differences.

2.5.4 Overall comparison

For an overall comparison, structured overview tables containing the integrated assessment results support a verbal argumentative discussion of decision options.

The integrated sustainability assessment of this project is based on five qualitative technological indicators originating from the SWOT analysis, nine quantitative and five qualitative environmental indicators, two quantitative economic indicators supplemented by two additional quantitative efficiency indicators, and five qualitative social indicators resulting from the SWOT analysis (see chapter 4.5.1 for an overview). These are a subset of all possible indicators, which were assessed and found to be relevant for decisions in the previous steps of the sustainability assessment. From all assessed scenarios, the 14 most relevant were selected to be displayed in overview tables. Depending on the question to be answered, overview tables may contain all or a part of these selected indicators and scenarios. Furthermore, the unit of reference is chosen according to the question.

3 System and scenario descriptions

Within this chapter, the properties of the whole BIOLYFE system from feedstock provision to final product use (Fig. 3-1) are described in detail. Scenarios are possible modes of operation of the system under various internal and external conditions, which do not need to reflect the current reality. They are consistent amongst themselves and serve the purpose of assessing the impact of choices and external influences.

The main goal of this sustainability assessment is the evaluation of a potential industrial scale, mature technology BIOLYFE plant in the year 2020 to ensure comparability to other bioethanol producing systems. Therefore, the main scenario is based on the technical, temporal and geographical settings as described in chapters 2.1.2 to 2.1.4. Several other scenarios are studied as additional scenarios and sensitivity analyses.

The evaluation of additional scenarios and sensitivity analyses allows to:

- evaluate the effects of main parameters on process performances (e.g. feedstock type and composition, enzyme dosage and activity)
- evaluate the effects of bioethanol utilisation and compare it with a traditional process for the polymers production process
- compare different locations and study the most promising possibilities for the process positioning
- make process optimisation based on obtained results and study the most promising possibilities for process configuration

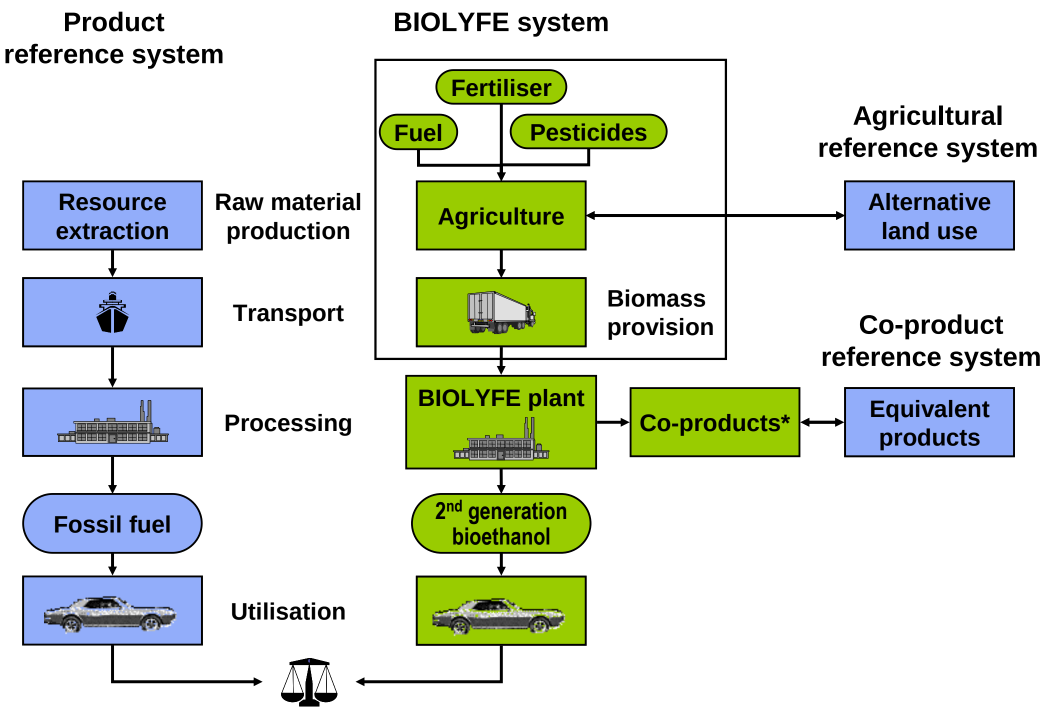


Fig. 3-1 Relevant systems for the BIOLYFE life cycle assessment
*: if applicable (depending on scenario)

3.1 Biomass provision

The biomass provision is the main limiting factor for a large-scale production of bioethanol. Therefore, it is important to achieve high biomass yields per area while using as little resources such as fertiliser and water as possible. For the BIOLYFE system, several feedstocks, cultivation methods, harvesting methods, and logistic systems for just in time delivery are investigated (Fig. 3-2).

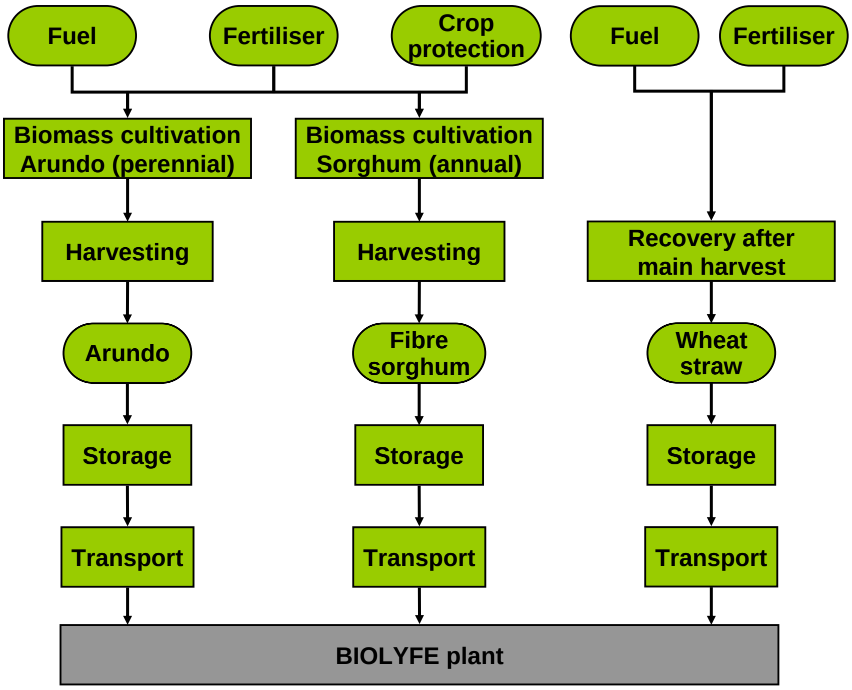


Fig. 3-2 Schematic overview of the BIOLYFE biomass provision

3.1.1 Feedstocks

The BIOLYFE plant is able to process a variety of lignocellulosic feedstocks. The plant will be run in campaign mode switching from one feedstock to another when necessary. In a multi-stage decision process, the following feedstocks were identified as the most promising ones for the BIOLYFE plant /Agriconsulting 2010/, /Kretschmer et al. 2012/:

- Giant reed (Arundo donax) as main scenario.
- Alternative scenarios:
  - Fibre sorghum
  - Wheat straw

3.1.2 Biomass cultivation

The expenditures and economic and environmental implications of biomass production depend on the feedstock, the regional conditions, e.g. type of soil and climate, as well as on agricultural management, such as fertiliser application. The scenarios for biomass cultivation aim to depict average practice in 2020. They include improvements compared to today's practice but do not reach the same performance that could be shown in highly optimised field trials.

Additional scenarios:

For fibre sorghum and Arundo donax, different yields coming along with different fertilisation intensities (high / low) are examined. Additionally, cultivation on low fertility soil is assessed, as this is the reason for a part of available idle land to be currently abandoned. They are combined with soil quality. The following scenarios are assessed:

- Fibre sorghum:
  - Traditional cultivated land: a) high yield and fertilisation; b) low yield and fertilisation;
  - Low fertility soil: low yield and fertilisation.
- Arundo:
  - Traditional cultivated land: a) high yield and fertilisation; b) low yield and fertilisation;
  - Low fertility soil: low yield and fertilisation.

For the agricultural residue wheat straw, only the extraction of the residue including compensatory fertilisation is accounted for but not the cultivation of the wheat itself because it is planted and used for other purposes.

Sensitivity analyses:

One sensitivity analysis examines an agricultural practice optimised for low nutrient contents in the harvested Arundo biomass. This helps to reduce fertiliser inputs. As the cultivation of perennial energy crops is no standard practice yet and some field trials are very promising in this regard, substantial optimisation seems possible.

Another sensitivity analysis investigates a "business as usual" cultivation of annual crops (fibre sorghum and wheat) without progress compared to today's average over-fertilisation rates.

3.1.3 Harvesting and storage

Harvesting: Harvesting is modelled according to the most suitable harvesting technologies identified within WP 1.

Storage: Feedstocks need to be stored before being used for bioethanol production, in particular if they can be harvested only once a year like fibre sorghum. The plant has a storage facility for 6-10 days. Feedstocks that can be harvested all year (Arundo) are harvested just in time. Crops with one harvesting period per year (fibre sorghum, straw) are stored at the farms and delivered to the plant at need.

Harvesting and storage are modelled for each biomass source via a simplified biomass logistics model.

3.1.4 Transport distance

The average transport distance from the farm to the bioethanol plant is based on the project regions radius of 70 km around the demonstration plant. As the industrial scale plant has about the fourfold capacity, it will acquire biomass from a region with double the radius. The average transport distance is approximately 2 / 3 of the radius. To account for non-linear routes, an average distance of 100 km is set for the main scenario.

Sensitivity analyses:

As sensitivity analyses, average transport distances of 50 and 200 km are analysed additionally.

3.2 Bioethanol plant

The bioethanol plant uses a continuous process developed by Biochemtex, which is termed PRO.E.SA^{TM} (*Produzione di bioetanolo da biomassa lignocellulosica*). It is currently being implemented in a demonstration plant in Crescentino, Italy. Based on this technology, a scenario for a mature technology, industrial scale plant is defined. It is set to be in operation for 8000 hours per year and 333 working days per year. The capacity is 100,000 t of ethanol per year. The scenario depicts a generic European background and is thus independent of the specific location. The process can be divided into the sections biomass pre-treatment, viscosity reduction, simultaneous saccharification and co-fermentation (SScF), lignin separation, and ethanol recovery and purification (Fig. 3-3). Besides this main process, the bioethanol plant or an external provider of utilities nearby operate a combustion unit, which converts the co-products lignin and stillage concentrate into power and heat for the main process. An important external unit, the enzyme production, is analysed within this assessment, too. It can have an important impact on the economic and environmental performance of the whole process. Therefore, generic data on enzyme production, which usually has a very wide bandwidth, is not suitable for modelling the whole BIOLYFE life cycle.

Sensitivity analyses:

In sensitivity analyses, the location is specified to be in Northern, Eastern, or Central Europe.

3.2.1 Biomass pre-treatment

After handling and cleaning, the biomass is pre-treated by an advanced steam explosion technology.

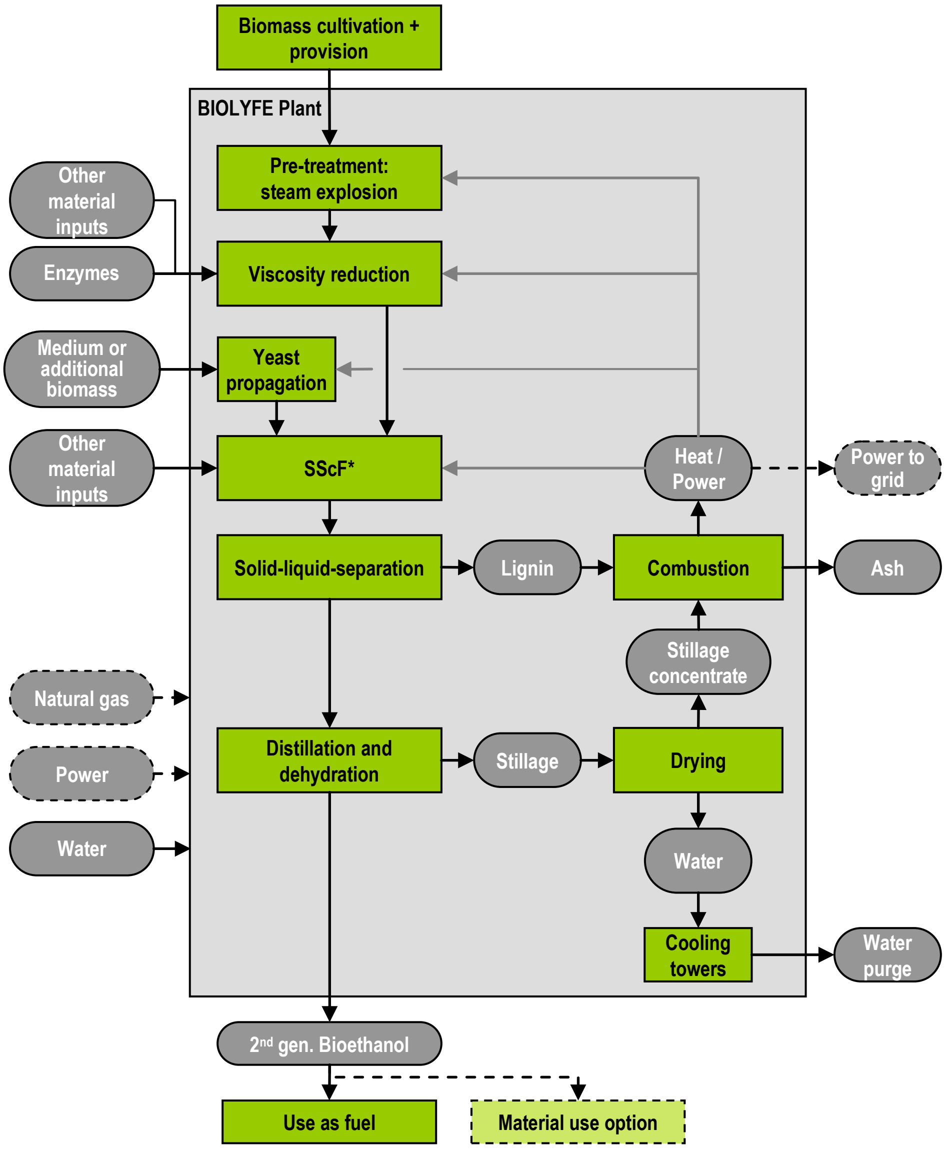


Fig. 3-3 Schematic overview of the BIOLYFE bioethanol plant. Here, system boundaries of the plant relevant for the environmental assessment (as one part of the assessed whole life cycle) are exemplarily displayed. Deviating boundaries apply in the economic assessment. Please refer to the methods sections for details (chapter 2.3.1). *: Simultaneous saccharification and co-fermentation

3.2.2 Viscosity reduction

During the viscosity reduction process, part of cellulose and hemicellulose is converted to lower carbohydrates and this way the pre-treated biomass is liquefied within few hours. The conversion is catalysed by an enzyme cocktail. The viscosity reduction step is performed in a first reactor until a pumpable material is obtained; afterwards, the material is sent to a second reactor where a simultaneous saccharification and co-fermentation (SScF) step is carried out.

Sensitivity analysis:

Enzymes are among the most costly inputs of the BIOLYFE process. Different enzyme cocktails and costs are analysed in sensitivity analyses in the economic assessment.

3.2.3 Simultaneous saccharification and co-fermentation (SScF)

In the BIOLYFE process, the hydrolysis of cellulose and hemicellulose continues simultaneously to the fermentation process. The co-fermentation stands for simultaneous fermentation of C5 and C6 sugars by a yeast strain. The yeast is pre-cultivated in small fermenters on site before it is added to the main reactor. The reactor is optimised for high conversion rates, short retention time, low energy consumption and low enzyme consumption, and can run with high dry matter content for high ethanol yields. The enzymes and the yeast strain used for saccharification and fermentation, respectively, are optimised towards an efficient co-fermentation of hexoses and pentoses.

3.2.4 Production of enzyme cocktails

Enzyme cocktails for the liquefaction of lignocellulosic biomass are innovative products and represent a central element in any conversion process of this feedstock. Although their production takes place in plants of suppliers, the efficiency of the production and the enzyme cocktail properties are of high relevance for the economic and environmental performance of the BIOLYFE system.

Sensitivity analysis:

Different production and price scenarios are considered in the economic and environmental assessment.

3.2.5 Solid-liquid separation

After fermentation and saccharification, the solid and liquid phases of the biomass are separated. The solid phase mostly consists of lignin. Further treatment of the lignin phase is described in chapter 3.2.7 (co-product handling). The liquid phase consists of water, ethanol and other organic and inorganic compounds. The further treatment of the liquid fraction is described in chapter 3.2.6 (distillation).

3.2.6 Distillation and dehydration

The liquid phase is distilled for ethanol separation. The resulting ethanol is dehydrated by means of adsorption to molecular sieves to yield 99.8 % ethanol, which is suitable for the use as transportation fuel.

3.2.7 Co-product handling

The main co-products of the BIOLYFE process are the solid hydrolysis residues, mainly consisting of lignin and unconverted cellulose and hemicellulose fibres. Furthermore, considerable amounts of liquid residues containing different organic and inorganic compounds are produced. The major part of the liquid residues is formed by the remains of the distillation process (stillage). Its composition depends on the type of feedstock.

3.2.7.1 Lignin handling

For the main scenario, lignin is burned for heat and power generation. The energy is used within BIOLYFE process. If excess lignin is available, it is burned for power generation, which is then fed into the national grid.

3.2.7.2 Liquid residue handling

Liquid residues are obtained mainly in the distillation process. For the main scenario, the following process chain is assessed:

Liquid residues are dried to yield stillage concentrate. Stillage concentrate is burned in a combined heat and power plant for internal energy generation. Ash is landfilled.

Sensitivity analysis:

A target scenario depicting the N_2O emission reduction potential in biomass combustion processes is assessed.

3.2.8 Energy provision

The main scenario is based on the setting that the biorefinery can supply all required steam and power by combustion of process residues in a combined heat and power (CHP) plant. In those scenarios, in which additional power or, in few cases, steam is needed, power is imported from the grid and natural gas is burned additionally, respectively. If there are surplus process residues (lignin-rich fraction), which are not needed for process energy provision, they are burned for power generation to be fed into the grid.

Sensitivity analyses:

- Different production and price scenarios for power are considered in the economic and environmental assessment.

- Energy efficiency: The main biorefinery processes require 10 % more or less energy. The steam demand is preferentially covered by the CHP plant and residual power demand or excess power generation result in power import from or export to the grid, respectively.

3.3 Distribution and usage

As main option, bioethanol is used as a transportation fuel. It is used in fuel blends with gasoline. Therefore, the same logistics are used as for gasoline.

Additional scenario:

A material use of the bioethanol within the chemical industry as a precursor for polyethylene production is assessed. Here, the same logistics are used as for conventional polyethylene.

3.4 Reference systems

The basis of life cycle comparisons is that the utility of the compared systems is identical. This means that for example those amounts of biofuel and conventional fuel are compared, which are needed to drive the same distance.

3.4.1 Product reference system

Bioethanol, which is used as transportation fuel, replaces conventional gasoline from fossil resources (Fig. 3-4). The comparison is based on the energy content of the fuel, which implies the same combustion efficiency of gasoline and ethanol-gasoline blends. Therefore, average European conventional gasoline provision from well to wheel is assessed as a reference system.

Additional scenario:

Bioethanol is used within the chemical industry as a precursor for polyethylene production (PE). In this scenario, conventional fossil resource based PE is used as a reference system and conversion of bioethanol via bio-based ethylene to bio-based PE is assessed additionally.

3.4.2 Co-product reference system

In the main scenario, no co-products leave the system but only ash and water. In some scenarios or sensitivity analyses, excess power is fed into the grid. In the main scenario, a European marginal power mix is replaced. This means that power from those power plants is replaced, which are most likely shut down first or not built additionally if the power demand in the EU is lower due to additional sources of power such as biorefineries.

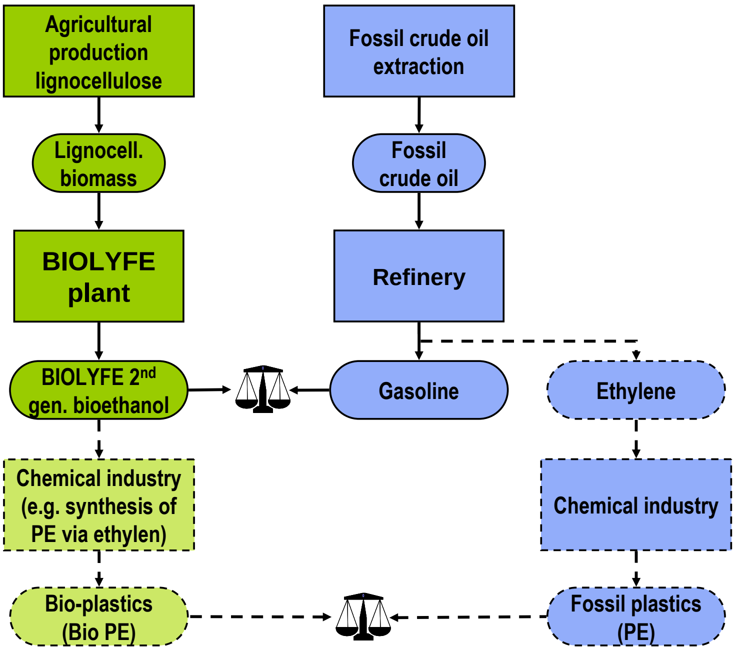


Fig. 3-4 Reference systems to the BIOLYFE system for the main biofuel scenario and the alternative material use scenario (dashed)

3.4.3 Agricultural reference system

If the BIOLYFE system is established, it needs biomass or land to produce the biomass. Either these resources are underutilised before or they are withdrawn from other uses.

In a first step, the BIOLYFE life cycle is compared to not using the agricultural land that would be needed to produce the biomass (idle land) or to leaving the agricultural residues on the field, respectively. Nevertheless, there are impacts of the reference system, too. For example, straw serves as fertiliser if it is left on the field and ploughed in. These impacts of the reference system are ascribed to the BIOLYFE biorefinery, which leads to the reduction of its environmental impacts (if burdens are avoided) or to additional impacts (if benefits are prevented). In the case of extracting wheat straw, additional fertiliser has to be applied to the field to compensate for the extracted nutrients.

Furthermore, there are several kinds of idle land that could be used for biomass production. As energy crops are mostly cultivated on arable land, the reference system for the assessment of the annual crops (e.g. fibre sorghum) is rotational set-aside land. For perennial crops like Arundo, non-rotational set-aside land is chosen as reference system.

As both underutilised agricultural residues and idle land are only available to a certain degree or even not at all depending on many boundary conditions, the BIOLYFE system is compared in a second step to other ways of using the same agricultural land or biomass. This is subject of chapter 3.4.4.

3.4.4 Alternatives to BIOLYFE

One of the main objectives of the integrated assessment of sustainability is to evaluate the performance of the BIOLYFE system in comparison to alternative ways of producing bioethanol and to alternative uses of the same area or the same biomass for producing transportation fuels (see core questions, chapter 1). For each class of alternatives, common crops and conversion processes are investigated as listed in Tab. 3-1. According to goal and scope, biomass production is only assessed for Europe and thus alternative land use options are assessed for the same region (see chapter 1). These alternative scenarios are presented graphically in Fig. 3-5. A comparison to fossil fuels is included in each of these alternative scenarios. A graphical overview over further alternative scenarios on alternative biomass use and alternative bioethanol production is given in Fig. 3-6 and Fig. 3-7, respectively. The production of heat and power from biomass e.g. by combustion in a combined heat and power plant (CHP) is not considered as a competing alternative because a core idea behind BIOLYFE is that biogenic transportation fuels will be needed besides biogenic heat and power production. Furthermore, the BIOLYFE system is not compared to other commercially available 2nd generation bioethanol systems such as from Inbicon / DONG Energy or Abengoa because there is not enough data publicly available for a scientifically sound comparison.

Tab. 3-1 Assessed alternative scenarios to the BIOLYFE system

Type	Technology	Feedstock	Name
Alternative biomass use			
(compared per t dry biomass)	BTL*	Same as for BIOLYFE	Arundo BTL Sorghum BTL Straw BTL
Alternative land use			
(compared per ha and year)	1st generation bioethanol	Wheat Sugar beet	Wheat ethanol Beet ethanol
	Biodiesel	Rapeseed	Rapeseed biodiesel
	Biomethane	Maize, whole plant	Maize biomethane
Alternative bioethanol production			
(compared per t of ethanol)	1st generation bioethanol	Wheat Sugar beet Maize, grains (US) Sugar cane (Brazil)	Wheat ethanol Beet ethanol Corn ethanol Cane ethanol

* BTL: biomass to liquid

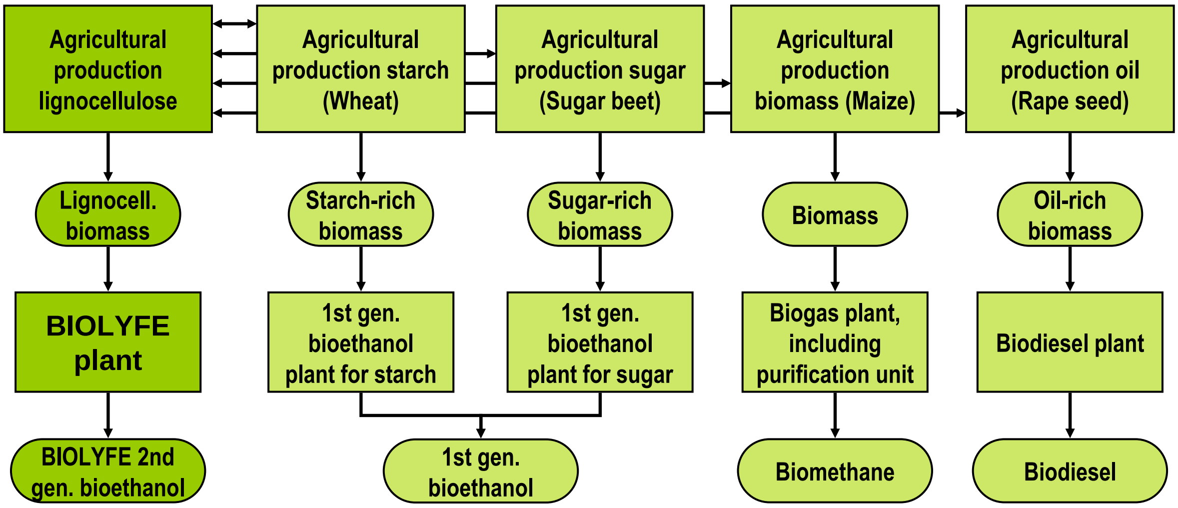


Fig. 3-5 Alternatives to BIOLYFE: use of the same agricultural land for biofuel production

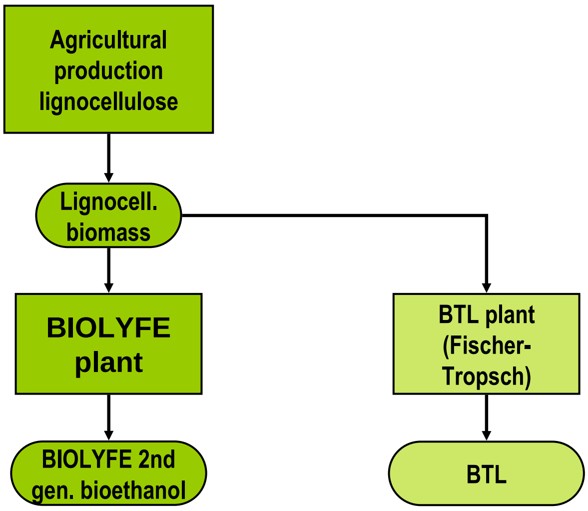


Fig. 3-6 Alternatives to BIOLYFE: use of the same biomass for biofuel production

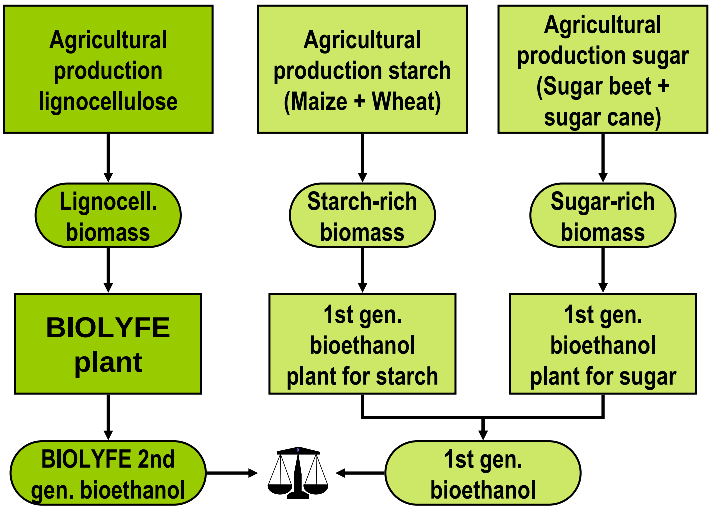


Fig. 3-7 Alternatives to BIOLYFE: other kinds of bioethanol

3.5 Summary: scenario overview

Summarising chapters 3.1 to 3.4, the main scenario, additional scenarios and sensitivity analyses, which are assessed in the BIOLYFE sustainability assessment, are listed in Tab. 3-2. For details on the scenarios, please refer to those chapters. Schematic overviews of the main scenario and the additional scenarios on feedstocks are given in Fig. 3-8 to Fig. 3-9.

Tab. 3-2 Assessed BIOLYFE scenarios

Scenario	Description
Main scenario	
Arundo	Bioethanol from Arundo donax in a mature technology, industrial scale plant in 2020, use as transportation fuel
Additional scenarios: feedstock	
Fibre sorghum	Bioethanol from fibre sorghum instead of Arundo donax
Straw	Bioethanol from wheat straw instead of Arundo donax
Additional scenario: product use options	
Biopolymers	Use of Arundo ethanol for polyethylene production instead of use as fuel
Sensitivity analyses*	
Energy efficiency	The main biorefinery processes require 10 % more or less energy
Energy provision	Varied options of energy provision and thus different prices and emissions associated with power
Cultivation intensity	Varied yields and fertiliser input
Low fertility soil	Cultivation of feedstock on idle land with low fertility soil
Agricultural practice	Improvements beyond or below those postulated in main scenario
Transport distance	Varied transport distance for feedstock
Enzymes	Varied enzyme production and use efficiency
Low N_2O emissions	Target scenario for N_2O emission reduction potential in biomass combustion processes
Regional variability	Influences of the plant location (specific for Northern, Eastern, and Central Europe)

*: Sensitivity analyses vary between individual parts of the sustainability assessment because of the different relevance for the respective analysis.

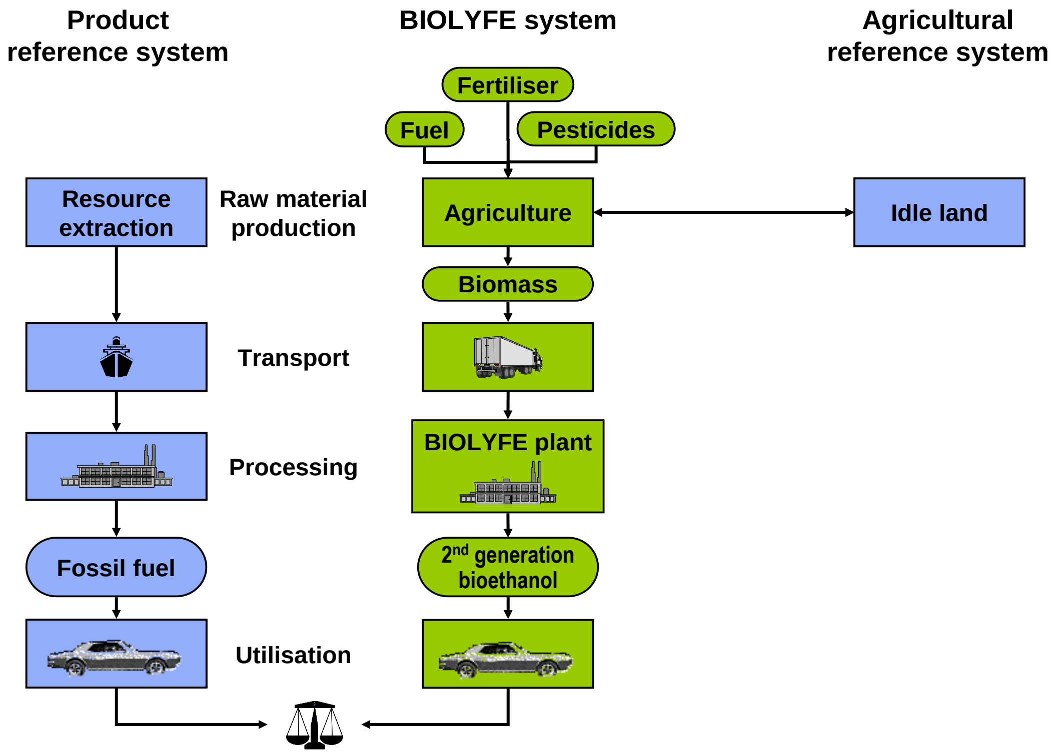


Fig. 3-8 Scheme of the life cycle comparison in the main scenario (Arundo) and in the additional scenario on fibre sorghum

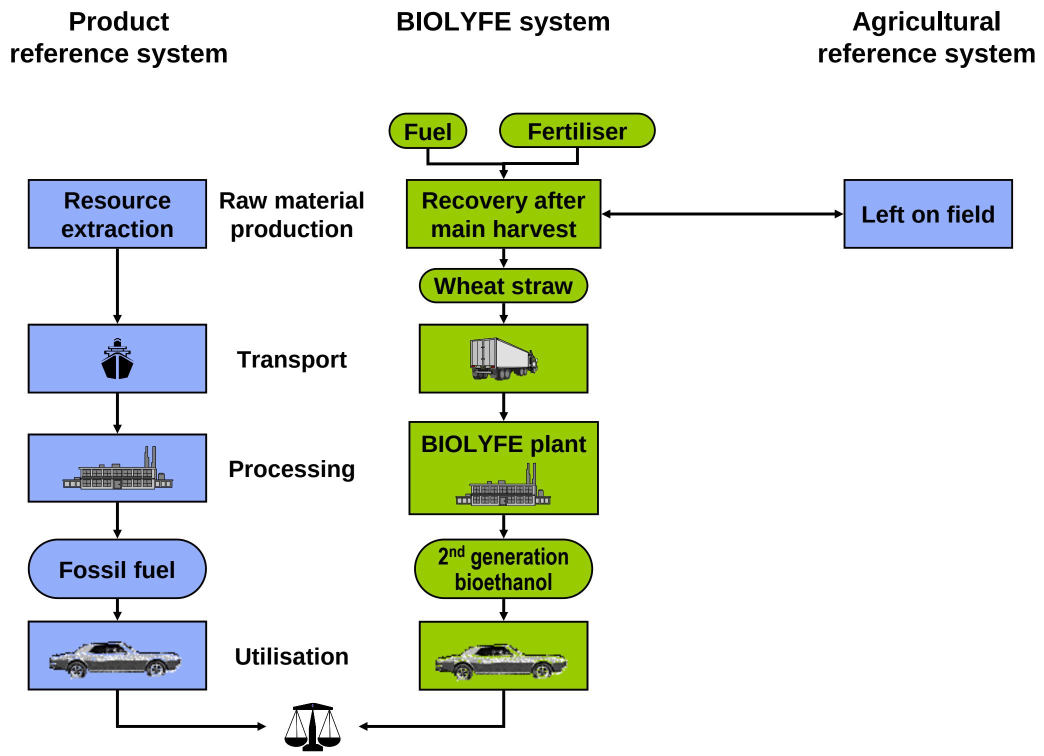


Fig. 3-9 Scheme of the life cycle comparison in the additional scenario on the feedstock wheat straw

4 Results

This chapter contains all results of the BIOLYFE integrated sustainability assessment contributed by several partners. First, the individual impacts of the BIOLYFE system on the environment on a global and supra-regional scale (chapter 4.1, contributed by IFEU), on the local environment (chapter 4.2, contributed by IUS), on involved businesses (chapter 4.3, contributed by Biochemtex), and on other fields (chapter 4.4, contributed by IFEU) are presented. This is followed by an integration of those aspects into a general picture (chapter 4.5).

4.1 Environmental assessment: global / regional impacts

Environmental impacts on a global and regional scale are assessed by a screening life cycle assessment based on international standards for life cycle assessments (for methodology see chapter 2.2.1).

4.1.1 Main scenario

Fig. 3-8 depicts the entire life cycle of the main BIOLYFE scenario on bioethanol production and use with Arundo donax (giant reed) as feedstock. All green processes are established if this biorefinery scenario is implemented and then replace all blue conventional processes. In this scenario, the biorefinery only produces ethanol as a usable product. It replaces equivalent amounts of gasoline.

The environmental impacts from this scenario are exemplarily shown for the impact category climate change in Fig. 4-1. Depicted are the impacts of individual life cycle stages (coloured sections of upper bars) and how they contribute to the overall results (brown bars). There are expenditures associated with each biorefinery life cycle, which are depicted as positive (additional) emissions in Fig. 4-1. They arise from the green processes in Fig. 3-8, which are established if the biorefinery is implemented. The avoided emissions from the replaced processes (blue in Fig. 3-8) are credited to the biorefinery and are thus depicted as negative emissions in Fig. 4-1.

Although the scenario is the same, the results vary considerably depending on the conditions under which the biorefinery is implemented and operating. The variations between these subscenarios mainly concern agricultural yields, transport distances, conversion efficiencies in the biorefinery and amounts of material inputs besides biomass. Most of these variations reflect possible technological developments until 2020. The bandwidth of net results shows that there is not one result for a future BIOLYFE biorefinery according to this scenario but several possible ones. Nevertheless, the possible results are robust concerning the point that there are greenhouse gas emission savings compared to using gasoline.

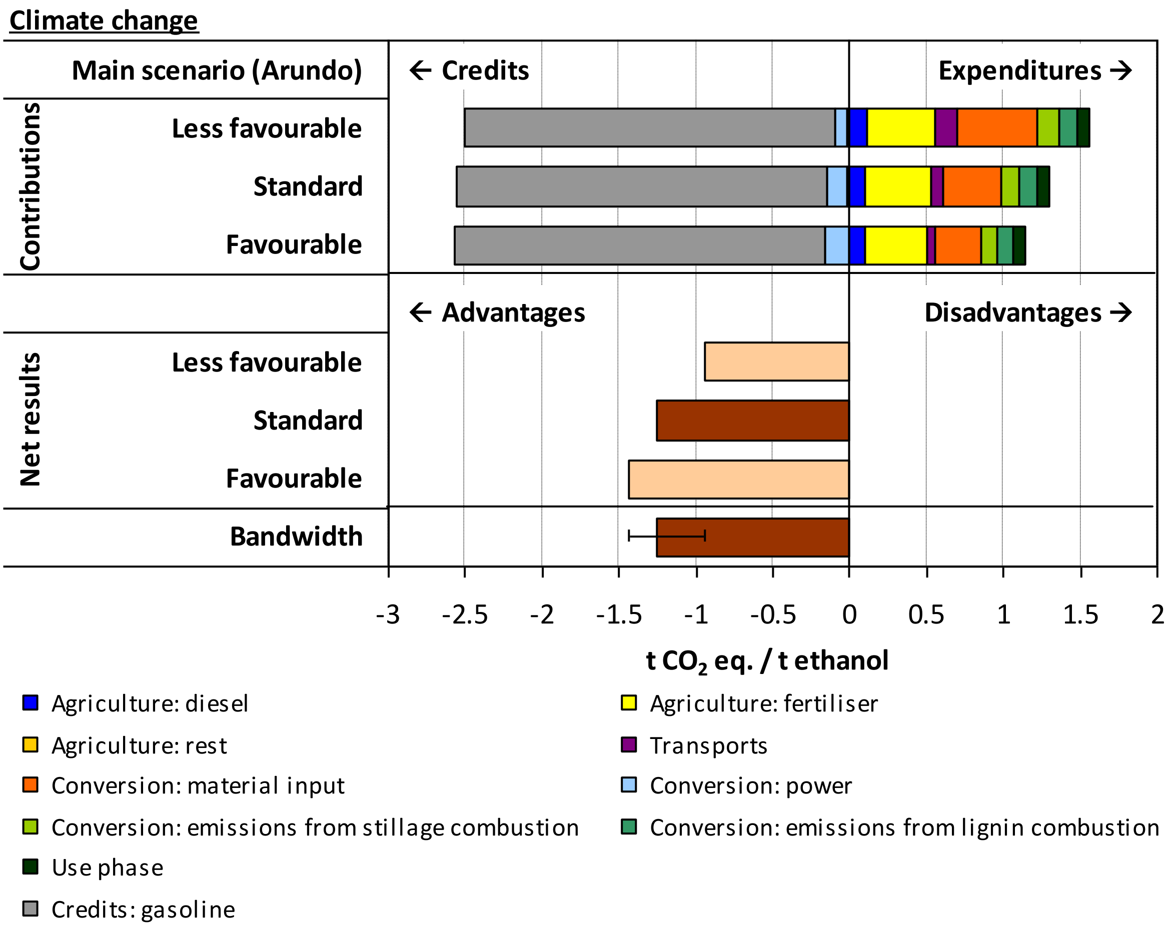


Fig. 4-1 Contribution of life cycle steps to the net results of the main scenario (Arundo) in the environmental impact category climate change. The scenario is evaluated for favourable, standard and less favourable conditions resulting in a bandwidth of net results. Material input: chemicals, enzymes etc.

How to read the first bar in Fig. 4-1 (contributions under less favourable conditions):

The production and use of 1 tonne of ethanol from Arundo causes the emission of about 1.5 t of greenhouse gases (expenditures, expressed in CO_2 equivalents). The biggest contribution is caused by the provision of material inputs like chemicals and enzymes into the conversion process (about 0.5 t CO_2 eq., orange bar). On the other hand, about 2.5 t of greenhouse gases are saved (credits), mostly by replacing gasoline (2.4 t CO_2 eq. / t ethanol, grey bar).

This kind of certainty of results compared to the fossil resource based equivalents can be observed for most scenarios and environmental impact categories in this study. However, the impact of BIOLYFE bioethanol on the environment is not always positive. Fig. 4-2 shows that BIOLYFE bioethanol causes additional acidification. Likewise, additional environmental burdens are caused in the environmental impact categories terrestrial and aquatic eutrophication, respiratory inorganics (particulate matter) and ozone depletion (see annex, chapter 8.3.1, for detailed results). Besides climate change, mitigation of environmental burdens is achieved regarding the depletion of non-renewable energy resources and photochemical ozone formation (summer smog). Thus, BIOLYFE bioethanol is not per se environmentally friendly but causes both advantages and disadvantages for the environment and optimisation is necessary to reduce disadvantages and increase advantages.

The following chapters detail environmental impacts of several variations of the main scenario regarding feedstock (chapter 4.1.2), product use options (chapter 4.1.3), power provision (chapter 4.1.4), agricultural practice (chapter 4.1.5), use of enzymes (chapter 4.1.6), and other aspects (chapter 4.1.7). Finally, the possible implementations of the BIOLYFE biorefinery are compared to competing options of using limited biomass and land or producing bioethanol (chapter 4.1.8).

4.1.2 Additional scenarios: feedstock

Besides Arundo, fibre sorghum and wheat straw were investigated as feedstocks for the BIOLYFE bioethanol plant. Fig. 4-2 and additional results in the annex (chapter 8.3.1) show that the patterns of environmental advantages and disadvantages found for Arundo (see also chapter 4.1.1) are similar for wheat straw. However, there are major differences in the extent of these effects. BIOLYFE bioethanol from fibre sorghum consistently shows worse results than bioethanol from Arundo mainly because the conversion is less efficient and additional power is required for conversion, whereas the Arundo scenario is self-sufficient in terms of energy. The quantitative difference between the results of Arundo and fibre sorghum bioethanol in some cases even lead to a qualitative difference compared to gasoline: In the impact category climate change, for example, there even can be disadvantages for fibre sorghum bioethanol compared to gasoline under less favourable conditions.

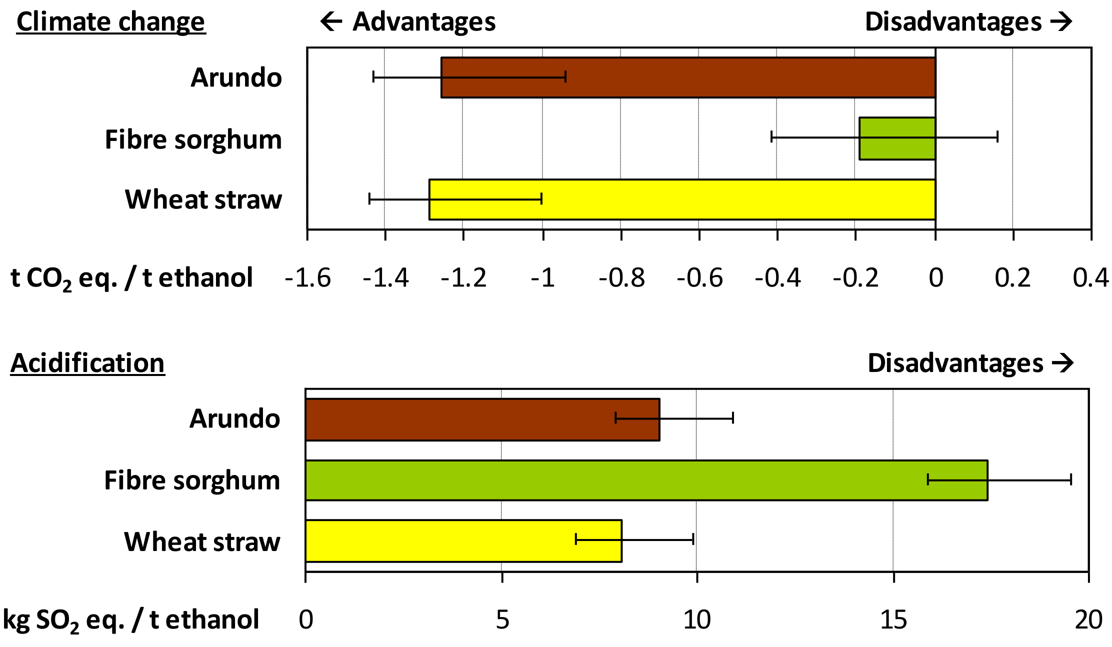


Fig. 4-2 Comparison of the main scenario (Arundo) to additional scenarios with different feedstocks on a product basis. Bandwidths of net results are displayed per t of ethanol for the environmental impact categories climate change and acidification. For further categories see annex, chapter 8.3.1.

In contrast, bioethanol from wheat straw mostly achieves similar results per tonne of bioethanol compared to bioethanol from Arundo. However, the comparison on a product basis gives no indication for e.g. the maximally achievable mitigation of climate change due to BIOLYFE bioethanol because the amount of produced ethanol is not a limiting factor. Instead, there is most likely not enough agricultural land and biomass available in the EU to substitute the complete demand of gasoline by bioethanol. Therefore, a comparison based on these limiting factors is more relevant to answer the questions raised in chapter 1.

Compared on an area basis, bioethanol from Arundo achieves the highest greenhouse gas emission savings (Fig. 4-3). The use of wheat straw results in lower but robust savings. For fibre sorghum, small savings or under certain conditions even additional emissions are caused. However, the cultivation of Arundo and fibre sorghum requires additional agricultural land, whereas wheat straw is harvested from already cultivated land with the main purpose of wheat production. Thus, the production of bioethanol from wheat straw is most efficient in terms of the requirements for limited *available* agricultural land. If the potential of wheat straw from land already under cultivation is used, Arundo represents the next best of the assessed alternatives for the production of BIOLYFE bioethanol. Fibre sorghum is not an option from an environmental standpoint because it shows substantially worst results in most environmental impact categories (see also annex, chapter 8.3.1, for detailed results).

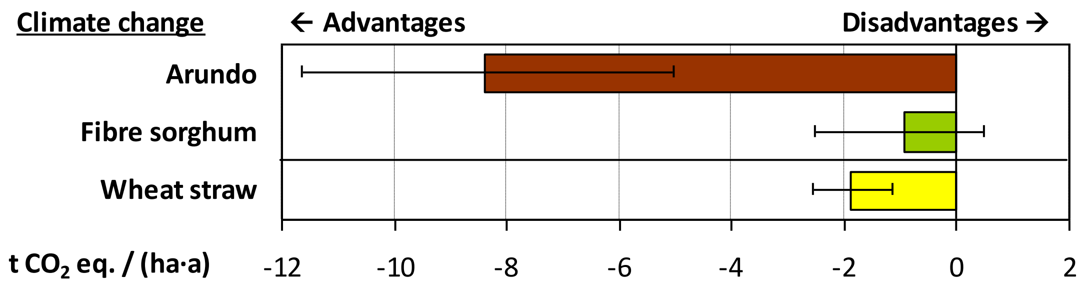


Fig. 4-3 Comparison of the main scenario (Arundo) to additional scenarios with different feedstocks on an area basis. Bandwidths of net results are displayed per hectare and year for the environmental impact category climate change. Arundo and fibre sorghum require additional agricultural land, whereas wheat straw is harvested from already cultivated land. For further categories, see annex, chapter 8.3.1.

Excursus: Inhabitant equivalents

Especially if there are conflicts between advantageous results of a scenario in one environmental impact category and disadvantageous results in another category, the question comes up how to compare these figures. As specified in the methodology section (chapter 2.2.1.1), a decision to accept certain disadvantages in favour of other advantages requires weighting on the basis of value choices beyond scientific arguments, which is not done in this study. Nevertheless, a comparison of the magnitude, not the severity, of different impacts on a scientific basis can be done based on inhabitant equivalents. In this case, the impacts caused by a certain process e.g. per tonne of ethanol are compared (normalised) to the average annual impact that is caused by an inhabitant of the reference region. For normalisation factors please see the annex, chapter 8.1.

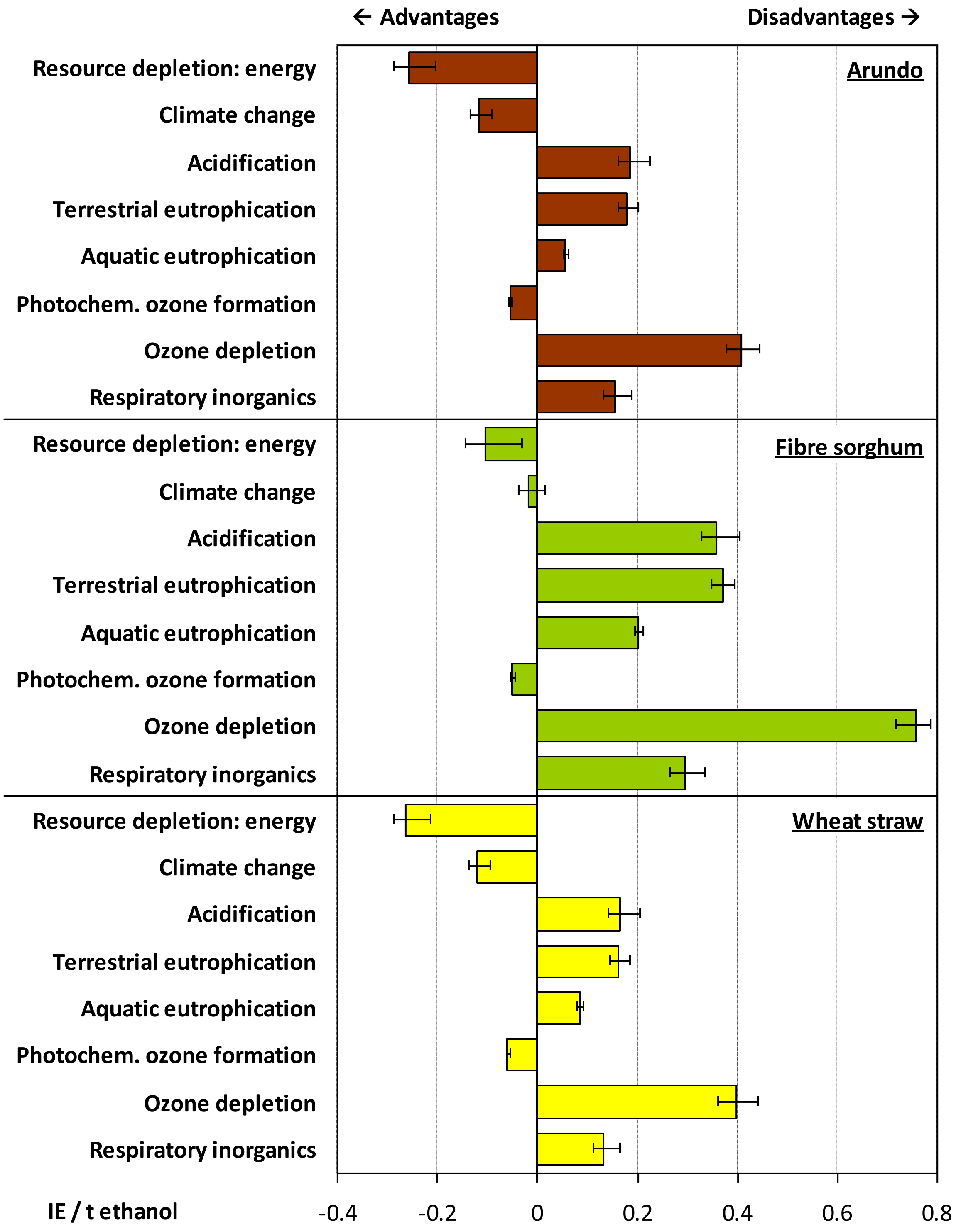


Fig. 4-4 Overview of net results for the main scenario (Arundo) and additional scenarios on feedstocks per tonne of ethanol normalised to inhabitant equivalents (IE).

How to read the first bar in Fig. 4-4:

The production and use of 1 tonne of bioethanol from Arundo instead of gasoline saves as much of non-renewable energy resources as about 0.2 to 0.3 European inhabitants consume each year.

As Fig. 4-4 shows, BIOLYFE biorefinery scenarios have e.g. a comparatively big impact on the categories depletion of non-renewable energy resources and ozone depletion but a rather small impact on photochemical ozone formation relative to the average emissions per European inhabitant. This figure emphasises that BIOLYFE biorefineries do not only have important impacts on climate change and energy resources but also on other environmental aspects, which have to be taken into account in the same way.

4.1.3 Additional scenario: product use options

Bioethanol can not only be used as a transportation fuel but also as a feedstock for the production of biopolymers. In that case, bioethanol is catalytically dehydrated to ethylene in a process that consumes some natural gas as energy source. This ethylene can be used instead of ethylene from fossil resources for the production of e.g. bio-based polyethylene.

Fig. 4-5 exemplarily shows for bioethanol from Arundo how this alternative product use option affects the environmental impacts. If bioethanol is used for the production of bio-based polymers, it replaces a product that is more energy intensive and causes higher greenhouse gas emissions (compare grey bars in Fig. 4-5). Therefore, the scenario on biopolymers receives higher product credits for the same amount of ethanol. The additional expenditures through natural gas consumption in the conversion process are smaller than the increase in credits. This leads to a substantial advantage of the scenario biopolymers over the main scenario regarding savings of non-renewable energy resources and a smaller advantage regarding mitigation of climate change. In this comparison, overlapping bandwidths do not indicate uncertainty whether one scenario is better than the other because the factors leading to this bandwidth are identical for both scenarios (e.g. amounts of consumed enzymes). Regarding all other environmental impact categories, there are no big differences between the scenarios (see annex, chapter 8.3.2). Thus, the use of bioethanol for the production of biopolymers represents an advantageous further use option of BIOLYFE bioethanol. However, it does not contribute to the provision of sustainable transportation fuels, which is the main aim of the BIOLYFE project.

4.1.4 Sensitivity analysis: energy provision

The conversion of lignocellulosic biomass to ethanol consumes power and heat. This heat and power is at least partially provided by combustion of lignin fraction and dried stillage concentrate in a combined heat and power (CHP) plant. If Arundo or wheat straw is used as feedstock, the internally produced energy more or less meets the energy demands of the process. Under standard conditions, some surplus processing residues are available for power generation to be fed into the grid. In case of fibre sorghum, additional power from the grid has to be acquired.

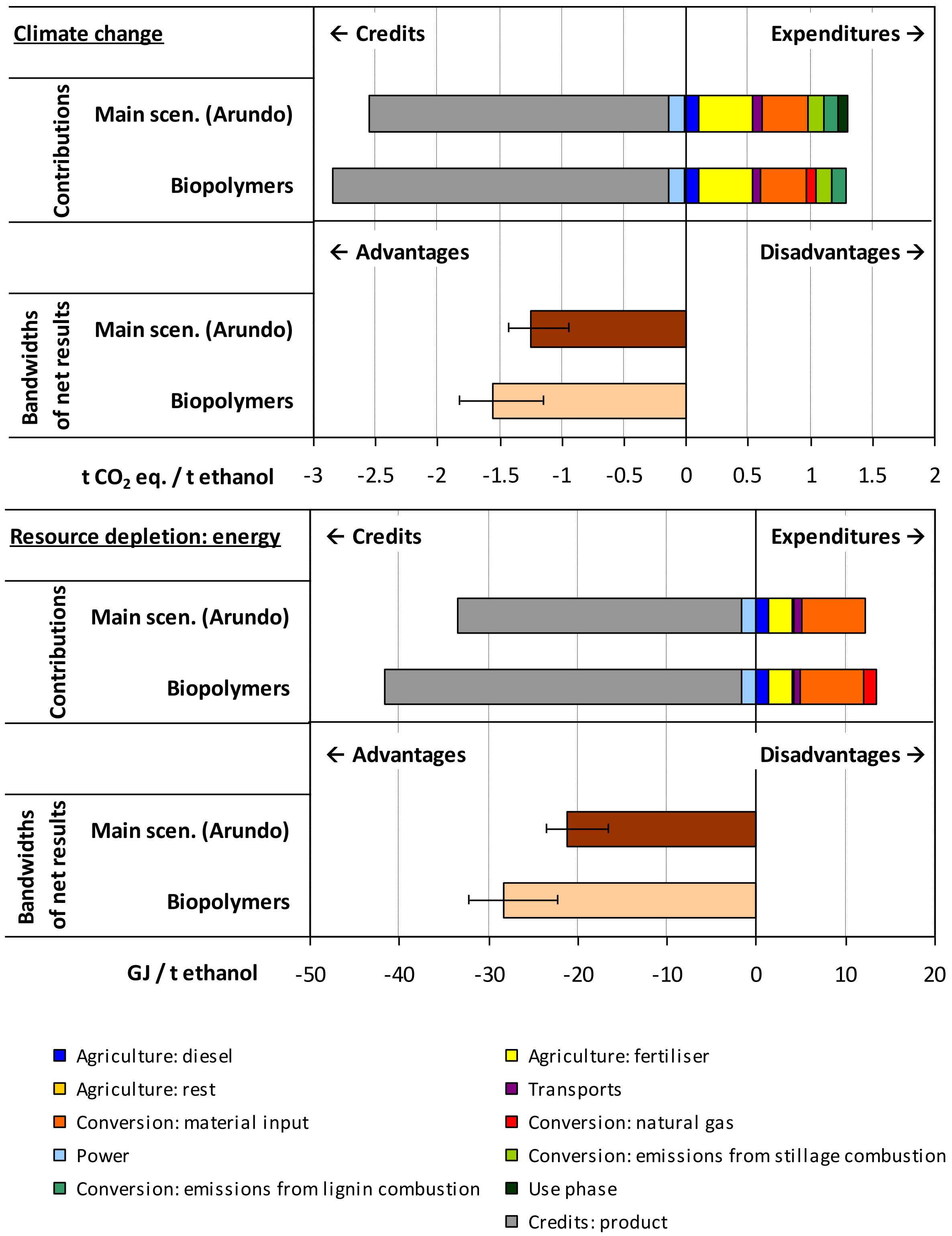


Fig. 4-5 Comparison of the main scenario (Arundo) to the additional scenarios on biopolymers. Bandwidths of net results are displayed per t of ethanol for the environmental impact categories climate change and non-renewable energy resource depletion. For further categories, see annex, chapter 8.3.2.

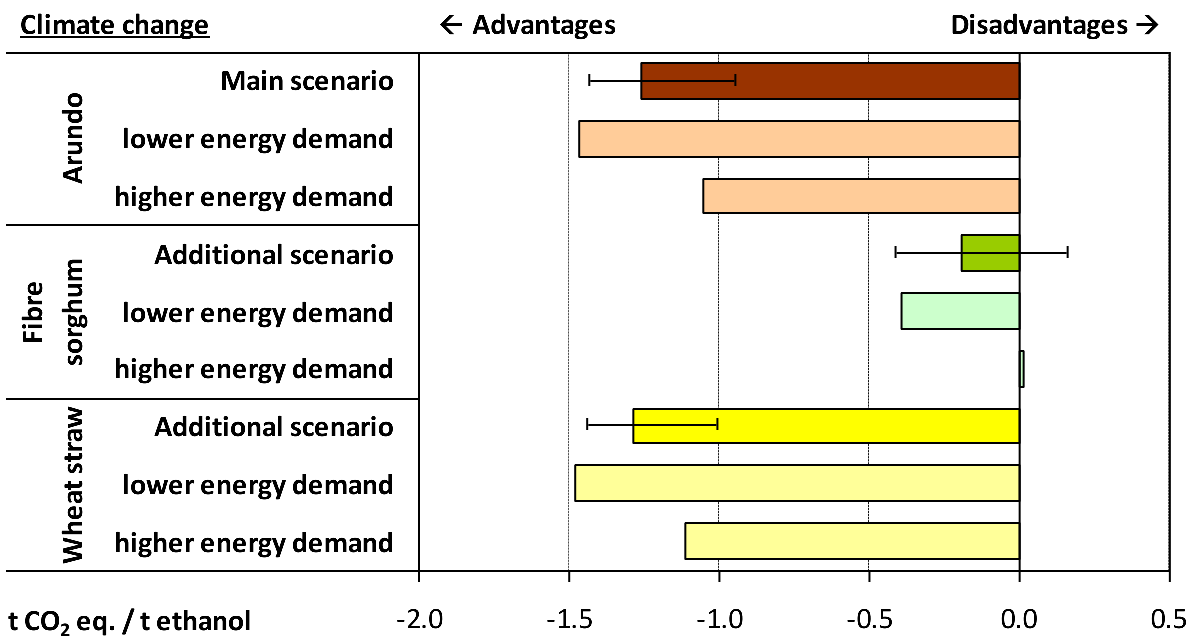


Fig. 4-6 Results of sensitivity analyses on process energy demand compared to the respective main or additional scenarios. Net results are presented per t of ethanol for the category climate change.

The sensitivity analyses presented in Fig. 4-6 show the effect of deviations in process energy demand of 10 %. In all cases, the demand for steam can be met by combustion of processing residues, but the power output of the CHP is varying substantially, leading to increased or reduced power imports or exports depending on the scenario. In both cases and for all feedstocks, the ranges of results of the sensitivity analyses are similar to the bandwidth resulting from varying other parameters such as conversion efficiency and enzyme demand. This underlines the extraordinary importance of an energy-efficient process. Optimisation measures should not only aim for energy self-sufficiency but for surplus energy production.

The environmental impacts of power provision, however, are strongly dependent on the source of power. As a default, all scenarios are based on power provision from an average mixture of European power plants. In a sensitivity analysis, alternative sources of power are assessed (Fig. 4-7). The bandwidth of environmental impacts ranges from power provision dominated by hard coal (worst case estimate: 100 % hard coal) to a “greened” power sector due to new policies (IEA scenario “new policy” for 2020 /IEA 2010/). The results of this sensitivity analysis show that the source of electricity has a considerable impact on greenhouse gas emissions in the fibre sorghum scenario. However, this can only be affected by the operator of the biorefinery if he opts for installing additional power generation capacity on site. The scenarios with Arundo and wheat straw as feedstocks are not affected because there is no demand for external power provision.

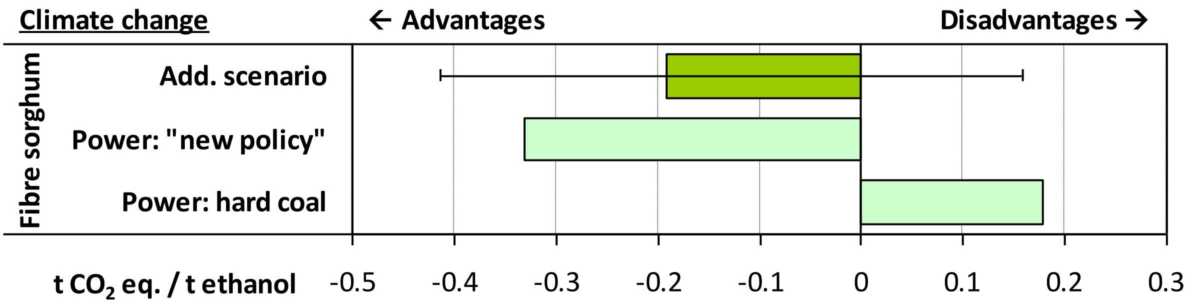


Fig. 4-7 Results of the sensitivity analysis on power provision compared to the additional scenario on fibre sorghum. Net results are presented per t of ethanol for the category climate change.

4.1.5 Sensitivity analyses: agriculture

There are various options of how to improve agriculture including breeding, which lead to a bandwidth of agricultural yields and expenditures. In one sensitivity analysis, only the cultivation intensity (agricultural yields and fertiliser input) is varied and the rest of the parameters are left constant. This results in considerable changes of environmental impacts e.g. on climate change when compared on an area basis (Fig. 4-8, agricultural yields). These variations are responsible for a big part of the overall bandwidth of results of the main scenario, which is due to a variation of parameters in all life cycle stages.

Furthermore, it might be possible to use idle (abandoned) land for the cultivation of energy crops such as Arundo. If idle land should be characterised by less fertile soil, as postulated in the respective scenario, the agricultural yields are rather low and lead e.g. to less greenhouse gas emission savings per hectare and year. Even then, this option is still preferable over the use of conventional agricultural land because first, the impacts per tonne of product do not differ very much and second, possible detrimental indirect effects due to competition about agricultural land are excluded. These possible indirect effects include the reduction of other environmentally beneficial uses of biomass e.g. for energy generation and the increased import or decreased export of food. The latter is known for the danger of causing clearing of natural ecosystems such as rainforests for food production elsewhere (indirect land use change, iLUC). Estimates about the extent of this effect vary widely and thus iLUC is not quantified in this study (see also methods section, chapter 2.2.1.2). Nevertheless, qualitative effects have to be taken into account, which leads to a preference of using idle (abandoned) land instead of currently cultivated agricultural land if possible.

In another sensitivity analysis it was examined how a low nutrient content of the harvested perennial biomass and thus a lower fertiliser demand affects the environmental impacts. Fig. 4-8 (see “low nutrient”) exemplarily shows the effect on climate change as other categories are affected similarly. These low nutrient contents (- 50 % nitrogen and potassium, - 25 % phosphorous) could be reached by a highly optimised agricultural practice (e.g. harvesting times) in some field trials. If this can be achieved in the whole Arundo supply chain for the biorefinery, too, the environmental effects improve notably. Finally, average fertiliser demand in 2020 for annual cultures as postulated in the standard scenarios (Fig. 4-8, additional scenarios on fibre sorghum, wheat straw) was compared to a higher fertiliser demand due to over-fertilisation as it is today's average practice (Fig. 4-8, fertilisation BAU, "business as usual"). This has a more pronounced effect for fibre sorghum due to its generally higher fertiliser demand.

Taken together, agricultural practice shows an important optimisation potential especially regarding energy crops that are not traditionally cultivated in Europe.

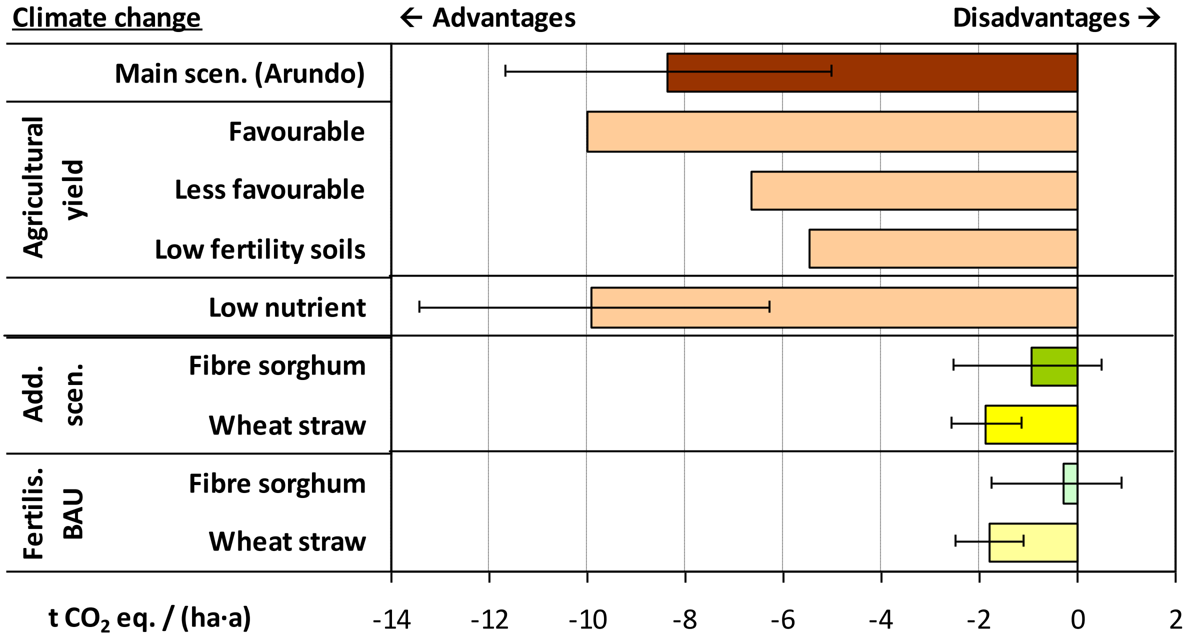


Fig. 4-8 Results of the sensitivity analyses on agricultural practice compared to the main or additional scenarios, respectively. Net results are shown per hectare and year for the category climate change. Add. scen.: additional scenarios, fertilis. BAU: fertilisation business as usual. Please note that for wheat straw only additional impacts due to its extraction from already cultivated land (wheat) are given.

4.1.6 Sensitivity analysis: enzymes

The provision of enzymes (mainly cellulases) causes a significant part of the expenditures in the production of BIOLYFE bioethanol. At the same time, the industrial enzymatic hydrolysis of cellulose is a rather new technology, for which substantial improvements are expected in the coming years. For definition of the 2020 scenarios, past developments in enzyme production and enzyme efficiency were conservatively extrapolated to the future. Both effects together make up a bandwidth of environmental impacts, which are part of the overall bandwidth (Fig. 4-9, top bars). When varying only the parameters on enzyme production and efficiency, it can be observed that these make up a considerable part of the bandwidth in most impact categories including climate change and terrestrial eutrophication (Fig. 4-9). Thus, enzyme production and performance are critical optimisation parameters from an environmental viewpoint.

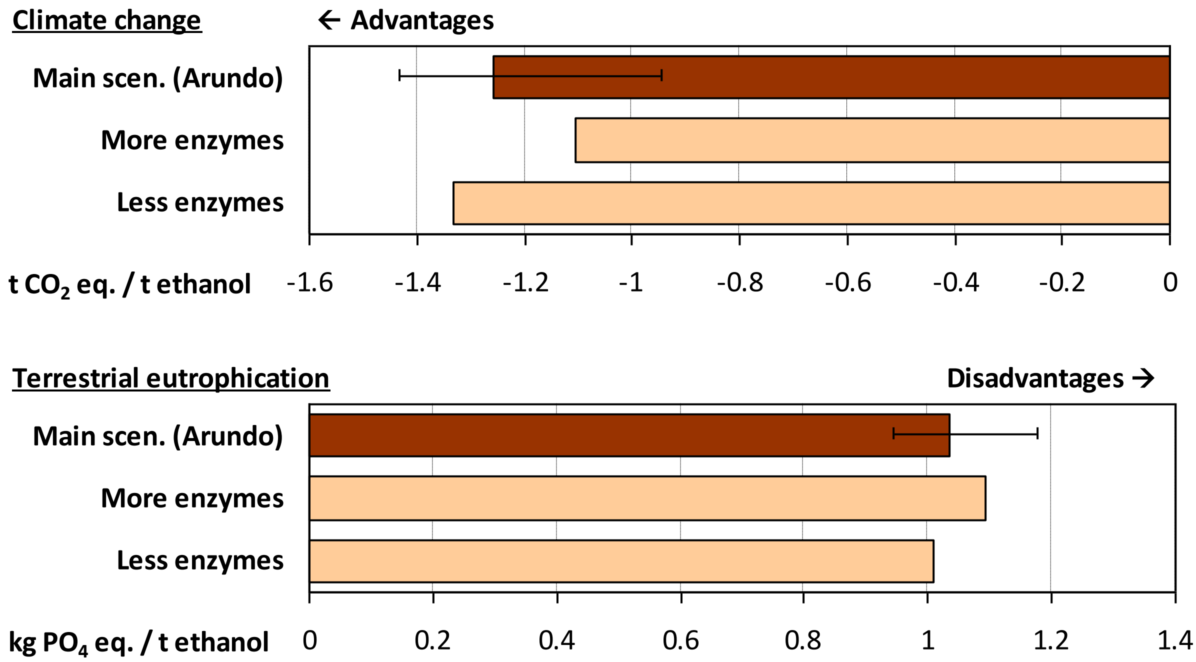


Fig. 4-9 Results of the sensitivity analysis on enzyme consumption compared to the main scenario. Net results are shown per t of ethanol for the category climate change.

4.1.7 Other sensitivity analyses

Several other sensitivity analyses with less relevance for the overall results were conducted additionally to the ones shown above. One of these is the variation of transport distances. Fig. 4-10 exemplarily shows the effect of setting twice or half the average transport distance compared to 100 km set for the main scenario under standard conditions on the impact category climate change. Distance changes by a factor of two do not affect the overall results very much. Similar effects are observed for the other impact categories.

Furthermore, we analysed potential region-specific effects of building the biorefinery in Northern, Southern, Eastern or Western Europe. The location of the biorefinery does not affect environmental impacts of the biorefinery itself because the technology can be established anywhere in Europe. Furthermore, it does not affect impacts of inputs or outputs, which are traded on the European or world market. Region-dependent are provision of external power (if applicable for the respective scenario) and biomass. The sensitivity of the results towards variations of these parameters were already generally analysed in chapters 4.1.4 and 4.1.5. Power provision is much more dependent on each national policy than on the region within Europe and would have to be analysed for each country separately. The bandwidth of possible effects is shown in chapter 4.1.4. For many crops, agricultural yields tend to be higher in North-Western Europe and decline towards the very north, very south and east /FAOSTAT 2013/. However, there is no data on the crops under investigation, *Arundo donax* and fibre sorghum. Therefore, this effect cannot be quantified. In total, regional variations of the overall environmental impacts should be within the given bandwidths with possible local exceptions due to especially high or low agricultural yields.

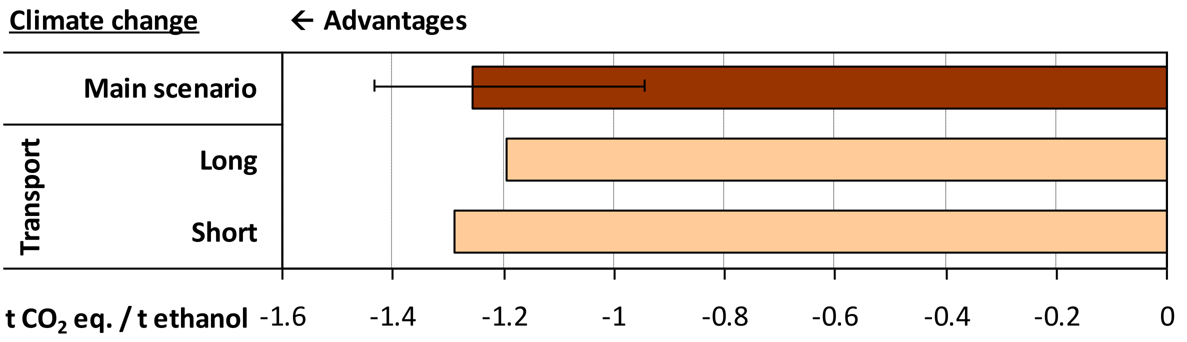


Fig. 4-10 Results of the sensitivity analysis on transport distances compared to the main scenario. Net results are shown per t of ethanol for the category climate change.

4.1.8 Alternatives to BIOLYFE

Biomass and agricultural land for the production of biofuels are limited. Therefore, each biofuel production process has to be compared to alternative biofuel production processes to see which of these uses those limited resources most efficiently.

If lignocellulosic biomass is available, it could be used for the production of alternative second generation biofuels. One of them is BTL (biomass to liquid), a synthetic biodiesel, which is produced via the Fischer Tropsch process. Fig. 4-11 exemplarily compares the performance of BIOLYFE bioethanol and BTL production and use from one tonne of each kind of biomass, which is assessed in this report, regarding the impact on climate change and respiratory inorganics. With the exception of the feedstock fibre sorghum, BIOLYFE bioethanol is clearly better than BTL in mitigating climate change. This is due to a more efficient conversion of biomass into fuel. However, data on BTL production from other feedstocks had to be extrapolated to the conversion of fibre sorghum. It cannot be excluded that certain components of fibre sorghum, which decrease the yields of BIOLYFE bioethanol, may also inhibit BTL production. In the category respiratory inorganics, BTL shows lower disadvantages. Similar trends are observed for further environmental impact categories (see annex, chapter 8.3.3, for further results). Thus, BIOLYFE bioethanol production shows the same pattern of environmental advantages and disadvantages as BTL production. Yet, the magnitudes of impacts differ substantially. BIOLYFE bioethanol achieves bigger environmental advantages but also causes higher additional burdens than BTL. As the relation of additional burdens to advantages is very similar, BIOLYFE ethanol is the preferable option because of its efficiency – if one chooses to accept the environmental disadvantages common to all biofuels (see also Fig. 4-12).

Unfortunately, there is not enough data publicly available for a robust and balanced comparison of BIOLYFE bioethanol to other second generation bioethanol processes.

Instead of using the same kind of biomass for biofuel production, other kinds of biomass could be cultivated for biofuel production on a certain area of agricultural land instead of Arundo or fibre sorghum. As wheat straw provision does not occupy additional agricultural land, this competition is not relevant for this feedstock. On European agricultural land, biofuels are mainly produced from wheat and sugar beet (bioethanol) as well as rapeseed (biodiesel). Biomethane from maize can be used as transportation fuel, too, although it is of lower importance in the transportation sector.

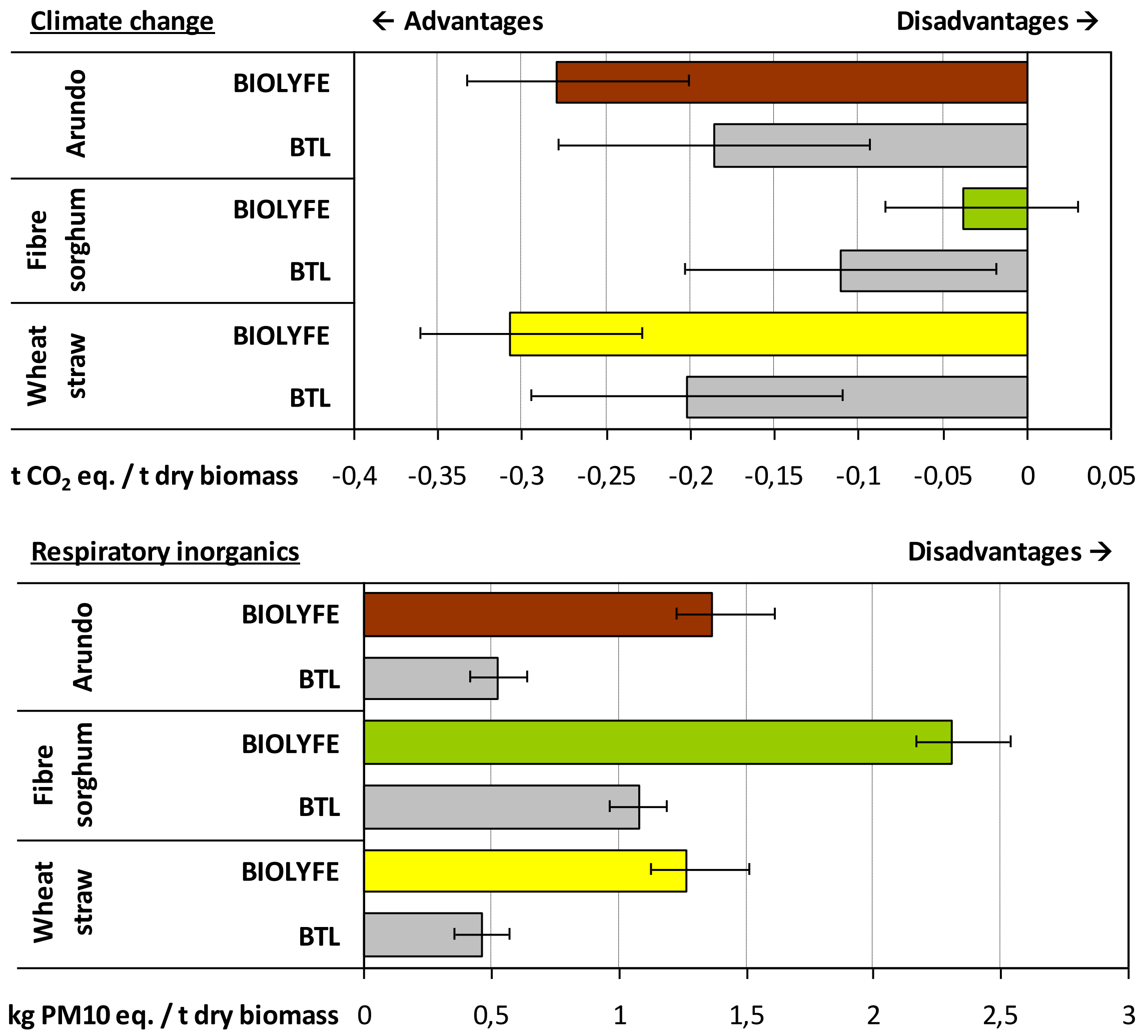


Fig. 4-11 Comparison of BIOLYFE bioethanol to producing BTL biodiesel (biomass to liquid) from the same biomass.

Compared to 1st generation biofuels that could be produced using the same agricultural land, BIOLYFE bioethanol shows the same general pattern of environmental advantages and disadvantages (Fig. 4-12). Some biofuels partially deviate from this pattern as their provision and use cause about as much of greenhouse gas emissions as those of fossil fuels (BIOLYFE bioethanol from fibre sorghum and maize biomethane as a transportation fuel) or that no additional acidification is caused (sugar beet ethanol). Overall, the global and regional environmental impacts of BIOLYFE bioethanol per hectare and year are within the range of 1st generation biofuels with Arundo partially exceeding the best 1st generation biofuels (regarding savings of non-renewable energy and mitigation of climate change under favourable conditions). However, BIOLYFE bioethanol also shows negative impacts close to or partially exceeding the worse end of the bandwidth given by 1st generation biofuels.

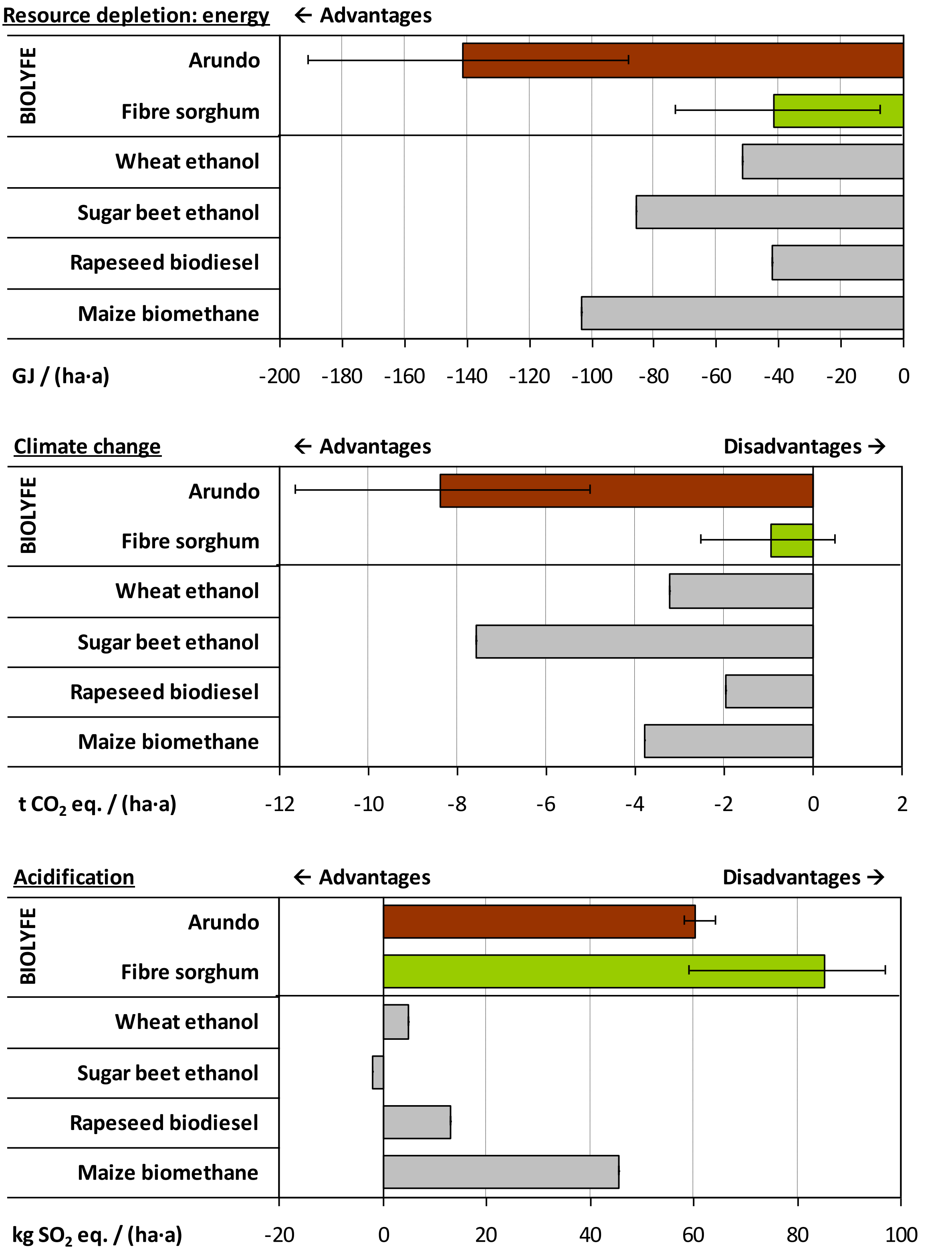


Fig. 4-12 Comparison of BIOLYFE bioethanol to producing other biofuels from crops cultivated on the same land

Furthermore, BIOLYFE bioethanol is compared to other kinds of bioethanol including imported fuels such as Brazilian sugar cane bioethanol or corn bioethanol from the US. Per tonne of bioethanol, the BIOLYFE fuel shows e.g. medium greenhouse gas emission savings

(Fig. 4-13). Yet, the use of limited agricultural land is a decisive factor for this comparison, too. BIOLYFE bioethanol from wheat straw clearly succeeds in this regard because its provision does not require additional agricultural land. For other biofuels, Fig. 4-13 has to be interpreted carefully because the comparison of agricultural land occupation in different climatic zones can only serve as a rough indicator of system properties but not as a basis for comparative assertions. Furthermore, the direct land use does not include indirect land use effects of by-products. For example, some by-products from 1st generation bioethanol production can be used as high quality feedstuff because of their high protein content. In that case, alternative feedstuff is replaced and agricultural land elsewhere becomes available (potentially also in different climatic zones), which reduces the net area occupancy of the respective bioethanol production. As these indirect effects are also dependent on changeable market mechanisms, they are however hard to quantify ex ante (for details please refer to /Rettenmaier et al. 2008/). Nevertheless, BIOLYFE bioethanol still shows high land use efficiency if agricultural biomass is used instead of residues.

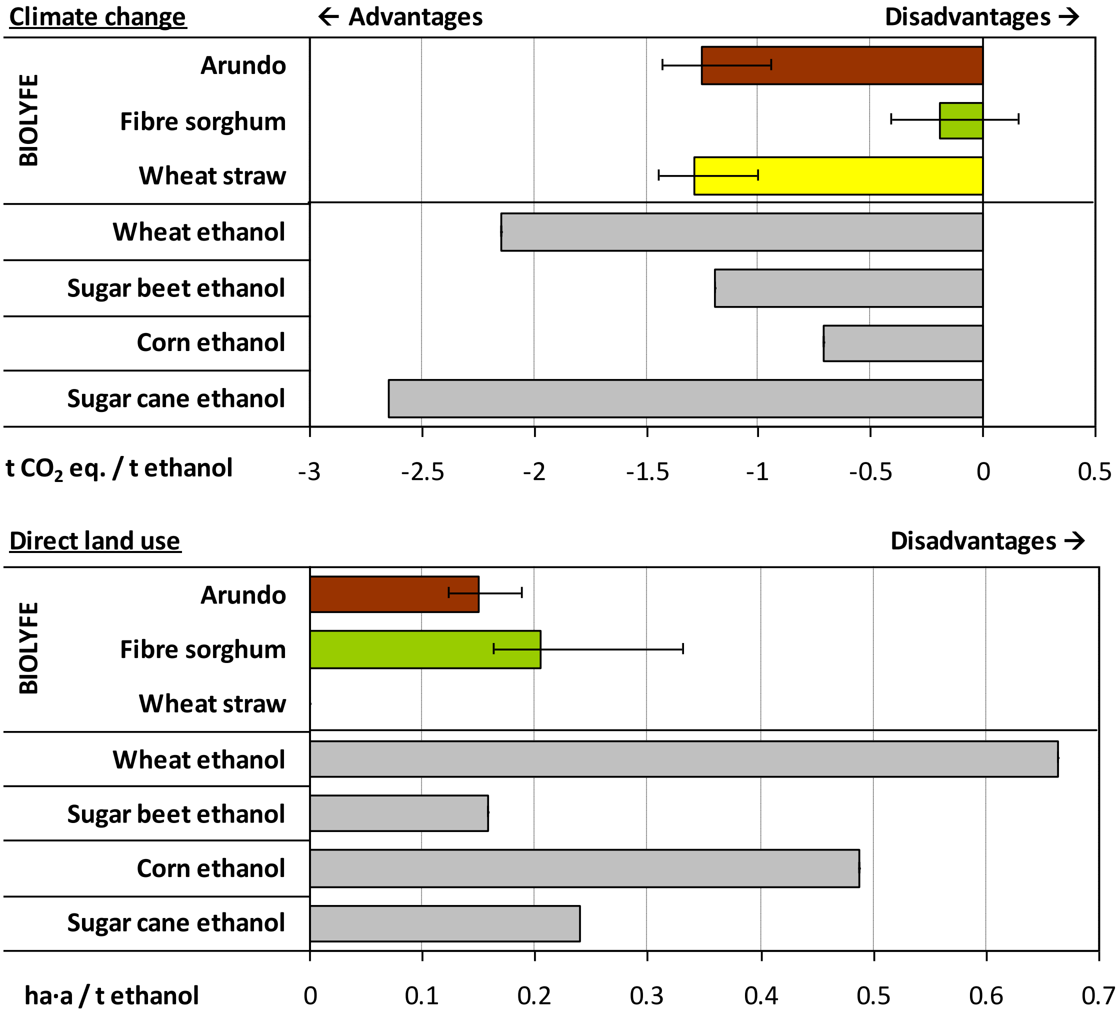


Fig. 4-13 Comparison of BIOLYFE bioethanol to alternative ways of producing bioethanol including imported fuels

4.1.9 Summary

The results of the screening LCA (life cycle assessment) on BIOLYFE bioethanol production as compared to fossil fuels and currently available biofuels can be summarised as follows:

Principal result: Compared to gasoline, BIOLYFE bioethanol introduces both environmental benefits and drawbacks viewed across the entire life cycle comparison, based on the feedstocks Arundo donax (giant reed), fibre sorghum and wheat straw, depending on the impact studied. In general terms, the pattern of benefits and drawbacks follows that known from established biofuels: Under most conditions, BIOLYFE bioethanol contributes to conserving non-renewable energy resources, just as many established biofuels do, as well as to mitigating climate change and photochemical ozone formation (summer smog). However, it also presents additional burdens in relation to acidification, nutrient input to soil and water bodies, stratospheric ozone depletion and particulate matter emissions. Conversely, there may be a few exceptions under extreme boundary conditions: For example, under certain conditions the use of fibre sorghum as a feedstock can lead to a neutral greenhouse gas balance or even to additional climate burdens compared to gasoline.

Optimisation potentials: The overall results comprise the expenses associated with the BIOLYFE bioethanol process and the credits for avoided expenses relating to gasoline production and use. The quantity of ethanol produced and thus the quantity of replaced gasoline are therefore decisive in the balance. The expenses are dominated to varying degrees by the individual life cycle phases, depending on the environmental impact. However, some life cycle phases are particularly relevant to numerous environmental impacts and therefore represent important starting points for optimising bioethanol production. These include a reduction in fertiliser demand, primarily nitrogen fertiliser, and a reduction in enzyme requirements. Especially for Arundo and Fibre sorghum, which are relatively new crops in Europe, there should be a higher potential for optimisation through crop management and breeding compared to well established crops as e.g. wheat. Despite enormous recent improvements, the potential for improvement of enzyme production and performance is even more pronounced because of the very innovative technology involved.

Another variable to be optimised is energy efficiency. In principle, it should be possible for future ethanol production to be energy self-sufficient. This means that the entire process energy can be provided by combustion of the process by-products (primarily lignin), so that neither additional electricity nor heat is required and no surplus energy is produced. However, if it is seen in future that additional energy is required, as is the case when utilising fibre sorghum as a raw material, the results are substantially poorer – and in extreme cases may even lead to additional greenhouse gas emissions instead of a corresponding saving. Similarly, however, considerable positive effects can be anticipated, if surplus electricity can be generated as a result of optimisation.

Excursus: Use of BIOLYFE bioethanol as a chemical feedstock: An alternative use of ethanol as a feedstock for the production of biochemicals such as bio-based polyethylene, for example, compared to its use as a fuel, displays no clear results in terms of its environmental balance: a higher saving in non-renewable energy sources, slightly lower greenhouse gas emissions and otherwise similar environmental impacts.

Comparison of BIOLYFE bioethanol to other biofuels I: The lignocellulosic biomass used for BIOLYFE can also be used for what is known as BTL (biomass-to-liquid, Fischer-Tropsch diesel). On the one hand, more fuel can be produced using the PROESA® process, but substantial surplus electricity or heat can be achieved in some BTL processes by incinerating by-products. Here, it can be seen that producing BIOLYFE bioethanol from wheat straw and Arundo leads to similar environmental results compared to BTL; large differences, both positive and negative, are possible depending on the method used and its exact design. Because the situation varies from case to case, a conclusive evaluation cannot be made. A trend towards benefits for BIOLYFE bioethanol compared to BTL cannot be recognised in the case of fibre sorghum.

Comparison of BIOLYFE bioethanol to other biofuels II: Alternative to the cultivation of feedstocks for BIOLYFE bioethanol, other biomass can be cultivated on existing agricultural land, which can also be utilised for biofuel production, such as wheat or sugar beet for ethanol production.

- Arundo: There is a tendency toward higher savings of non-renewable energy sources and greenhouse gases for bioethanol produced from Arundo than for the competing options of bioethanol produced from wheat, sugar beet and rapeseed biodiesel, as well as biomethane produced from corn. In terms of other environmental impacts, e.g. acidification and eutrophication, BIOLYFE bioethanol produced from Arundo displays environmental impacts in part several times higher than for other biofuels. A conclusive evaluation is not possible given these contradictory results.
- Fibre sorghum: In contrast to this, BIOLYFE bioethanol produced from fibre sorghum displays overall poorer results. This is due to several factors including a lower conversion yield, a higher net energy demand and higher agricultural inputs. Annual crops such as Fibre sorghum typically require higher agricultural inputs compared to perennial crops such as Arundo.
- Wheat straw: Wheat straw does not require any additional cultivation areas and is therefore preferable in terms of the limited availability of agricultural land.

Results on land use effects: BIOLYFE bioethanol can demonstrate a considerable environmental benefit in terms of direct land use: Because wheat straw is an agricultural residue, no additional farmland is occupied due to its use. Direct land use for Arundo is in the same range as for ethanol produced from sugar beet and considerably less than for other bioethanol types such as those produced from wheat, corn and sugar cane. However, it should be noted that some indirect land use savings can be achieved in conjunction with established bioethanol types by using by-products as fodder. Such by-products are not available from BIOLYFE bioethanol production.

Additional positive land use effects may be achieved if it proves possible to cultivate Arundo or fibre sorghum on idle land even if the soil should be less fertile. The area used may then be larger, but does not compete with traditional cultures. Because the environmental impacts per tonne of bioethanol on low fertility soil do not differ substantially from those on normal agricultural land, idle land should be preferentially used in terms of land use competition, even if the soil is less fertile.

In summary: Because possible additional environmental impacts from indirect land use changes are avoided by the use of straw and the cultivation of feedstocks on idle (abandoned) land, in addition to the benefits described above, these two options represent two of the most important options for environmentally friendly feedstock provision for BIOLYFE bioethanol.

Conclusion: From an overall environmental perspective, it can be seen that BIOLYFE bioethanol is not fundamentally better in all cases than conventional gasoline or other biofuels. However, there is an extremely high potential for producing environmentally friendly BIOLYFE biofuel. This primarily involves the production of bioethanol from wheat straw or Arundo, in particular from idle (abandoned) land. Environmental performance improves relative to how well the complete process energy or even surplus energy can be generated through combustion of the process by-products during biomass conversion and by increasing enzyme efficiency.

4.2 Environmental assessment: site-specific impacts

As a precondition for the identification of local environmental impacts, it is assumed that in case of implementing a biorefinery sufficient land is available for feedstock provision as well as sufficient biomass, both for feed and food production. Direct competition for land or for different types of biomass is excluded. The idea is to concentrate on the impacts arising from feedstock production and the implementation of a biorefinery on the environmental factors, as land use items would overlay the expected impacts. Secondary effects would affect the comparability of a concept and its transferability to other regions in Europe, although land use change can have both environmental and social implications.

4.2.1 Biomass provision

The cultivation of energy crops includes both risks as well as opportunities, dependent on the type of crop. The assessment of crop specific impacts primarily depends on the comparison with alternative uses i.e. on the reference system. Alternative types of use could be e.g. rotational or non-rotational set-aside land, forest areas or areas reserved for nature conservation. Since energy crops are mostly cultivated on arable land, the reference system for the assessment of the annual crops (e.g. Sorghum) is rotational set-aside land. For perennial crops like Arundo, non-rotational set-aside land is chosen as reference system.

In addition to the BIOLYFE feedstocks, a number of other perennial and annual crops are investigated for later comparison (see chapter 4.2.1.3).

4.2.1.1 Perennial crops

Arundo donax

Arundo is a perennial crop with undemanding and robust plants. Low impacts are expected on soil compaction. Due to the cultivation time of about five years and therefore less maintaining cycles, low impacts are expected on soil compaction. High Arundo yields can only be reached if enough water is available. Thus, high water use could have negative impacts on the availability of groundwater. The impacts on plants / biotopes are expected to be negative, since a shortage of water induced by Arundo cultivation might lead to a loss of species and induce a development in the surrounding vegetation towards drought resistance. The impacts of an Arundo donax plantation on landscape in comparison to non-rotational set-aside could be both negative and positive because this is dependent on the local environmental conditions. An Arundo plantation in a flat arable area might be a disturbance of the landscape. However, it can also increase the structural variety of a monotonous landscape and offer additional habitats for special types of plants and animals, e.g. deer, birds or carbide beetles. Depending on the surrounding area, this might either lower or increase biodiversity.

Due to high water consumption and transpiration rates, Arundo plantations could increase the local humidity. Tab. 4-1 summarises the risks associated with cultivation of Arundo in comparison with non-rotational set-aside-land.

Tab. 4-1 Risks associated with the cultivation of Arundo donax compared to the reference system non-rotational set-aside 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 compac-tion	neutral[1]	neutral[1]		neutral[1]	neutral[1]				**positive / negative[2]**
Loss of soil organic matter	neutral[1]			neutral[1]	neutral[1]				neutral[1]
Soil chemistry / fertiliser	neutral[1]	neutral[1]	neutral[1]						
Nutrient leaching	neutral[1]	neutral[1]							
Eutrophi-cation	neutral	neutral	neutral	neutral	neutral				neutral
Water demand		negative	negative	negative					**negative / positive**
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral
Loss of landscape elements				**negative / positive**	**negative / positive**	**negative / positive**	**negative / positive**	**negative / positive**	**negative / positive**
Loss of habitat types				neutral	neutral	neutral	neutral	neutral	neutral
Loss of species				negative[2]	**negative / positive**				**negative / positive**

1: Regarding the total cultivation period of the crop; slightly negative in the first year
2: Negative due to risk of permanent impact on arable plants

Other perennial crops

For further results regarding other perennial crops see, annex chapter 8.4.1.

4.2.1.2 Annual crops

Sorghum bicolor

As maintenance cycles for the cultivation of annual crops are more frequent, the impact on soil exceeds perennial crops by far. The danger of erosion is high, especially after planting the seeds and after harvesting, when soil cover is low. Due to the annual export of biomass the carbon balance of the soil as well as the balance of nutrients has to be compensated by fertiliser or / and input of organic material / green manuring, which means the potential impact on groundwater by leaking and on superficial water by runoff is quite high. Animals, plants and biodiversity might be impacted as well, as the stress on soil in combination with chemical weed control might cause a decrease in species diversity. The cultivation of Sorghum might lead to a loss of habitats and plant species compared to rotational set-aside land affecting flora, fauna and biodiversity, although the impact could be minimised by providing additional habitats, e.g. nesting areas for birds and hiding places for deer. Therefore, the impact might not be that negative. The impact on the environmental factors climate / air, landscape and human health and recreation is relatively low and compared to the reference system no differences are expected. Tab. 4-2 summarises the risks associated with cultivation of Sorghum on the environmental factors.

Tab. 4-2 Risks associated with the cultivation of Sorghum bicolor compared to the reference system rotational set-aside 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							
Nutrient leaching		negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Water demand		negative		neutral	neutral				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	neutral/ negative				neutral/ negative
Loss of species				neutral/ negative	neutral/ negative				neutral/ negative

Other annual crops

For further results regarding other annual crops see annex chapter 8.4.2.

4.2.1.3 Agricultural residues

Wheat / barley (use of straw)

Wheat / barley straw was used as a feedstock in agriculture ever since e.g. for bedding, feed and in modern times for mushroom cultivation. Harvesting straw goes along with a depletion of soil carbon and in case of farms, the carbon cycle was closed by bringing back straw and manure to the fields. A potential reference system therefore is the conventional use of straw.

In order to maintain carbon levels in the soil, this is still an option as /Panoutsou et al. 2012/ estimate that an export of 40 % of straw in case of wheat and barley is sustainable.

In the reference system of conventional use it is assumed that the greatest part of the straw is left on the field and ploughed in the soil to maintain the soil organic carbon. 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. 60 % residues left on field) 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. Tab. 4-3 summarises the risks associated with cultivation of wheat / barley and no use of straw on the environmental factors.

Tab. 4-3 Risks associated with the cultivation of wheat / barley and the use of straw compared to the reference system "conventional use" of straw

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

4.2.1.4 Comparison

An advantage of perennial crops is the reduced exposure of soil, based on lower maintenance cycles as well as on reduced application of fertiliser and pesticides for weed control. Due to lower leaching rates, the cultures show less impact on water quality basically on groundwater. Species and habitat diversity would benefit from perennial crops like Arundo, offering additional habitat types for invertebrates e.g. insects and vertebrates like deer or birds. Regarding biodiversity impacts from annual crops can be both positive and negative, depending on the surrounding landscape and the potential changes to be expected.

The cultivation of annual crops in general results in higher impacts on the environment especially due to the intensive field works. The risk of soil compaction and erosion is higher than in the reference system of rotational set-aside land, whereas the differences between the crops are quite low.

Tab. 4-4 Crop specific environmental impacts and reference scenarios

	Perennial crops		Annual crops				Residues
Feedstock	**Arundo donax**	**Sugar cane***	**Rapeseed**	**Sorghum**	**Sugar beet**	**Cereal**	**Cereal straw**
Reference scenario / **Type of risk**	non rsl	cerr.	rsl	rsl	rsl	rsl	conv. use
Soil erosion	B	C	C	C	E	C	C
Soil compaction	A	D	C	C	E	C	C
Soil organic matter	B	E	D	D	E	D	C
Soil chemistry / fertiliser	C	D	D	D	E	D	C
Nutrient leaching, Eutrophication	B	D	D	D	D	D	C
Water demand	D	D	C	D	E	C	C
Weed control / pesticides	B	E	E	E	E	E	C
Loss of habitat / species diversity	C	E	C	D	D	D	C
Loss of landscape elements	C	C	C	C	C	C	C

Impacts are ranked into five comparative categories (A, B, C, D, E); “A” is assigned to the best options concerning the factor, “E” is assigned to unfavourable options concerning the factor;

*: imported crops

Reference scenarios:

non rfl	non-rotational set-aside land, no cropping	Arundo donax
rfl	rotational set-aside land, no cropping	Rapeseed, Sorghum, Cereal, Sugar beets
conv. use	conventional use, straw left on field (ploughed in)	Cereal straw
cer.	cerrado (topical savannah)	Sugar cane

High risk of erosion results on the one hand from the part time coverage of the soil during the growing season. On the other hand the relatively wide distance between the rows especially in the cultivation of sugar beet (see annex, chapter 8.4.2.2) increases the risk compared to Sorghum and cereals. The risk on groundwater and superficial water is increased due to leaching of nutrients. Catch crop as well as undersown crops would help to minimise risks from lacking soil coverage. Compared to the reference system of leaving the residues on the field (and ploughing them in) no differences are expected. There might be a development towards long-stalked varieties as straw could become a marketable product in case of further biorefinery deployment. The impact on soil will increase if unsustainably high yields of straw are taken out. A decrease of soil organic matter and an increased use of fertiliser would be potential consequences, thus increasing the risk of adverse effects on ground and surface water. Leaving a sustainable portion of straw on the fields in case of a biorefinery (approx. 60 %) would result in a balanced carbon level comparable to the reference system.

Tab. 4-4 shows a clear difference between perennial and annual crops, indicating a lower impact of perennial crops on the environment than annual crops. The least impact is expected from perennial crops like Arundo donax compared to non-rotational set-aside. An increased impact is expected for the production of annual crops compared to rotational set-aside land (e.g. wheat, sugar beet), whereas impacts from the use of cereal straw basically do not differ from conventional use.

4.2.2 Material inputs

Following an LCA approach, the provision of fertiliser, pesticides and fuel for agricultural vehicles has to be taken into consideration as well.

Fertiliser

Essential factors for soil fertility in agricultural soils used for intensive feedstock production are carbon, nitrogen and phosphorus as well as calcium, potassium, magnesium and sulphur. Micronutrients contribute to the health of feedstock plants as well and can generally be provided with the application of mineral fertiliser.

The most important factor for soil fertility in intensive agriculture is carbon, which has to be provided in form of biomass, either as

- harvesting residues
- manure from livestock farming
- green manure in form of cover crops (e.g. legumes)
- residues from biological conversion processes e.g. vinasse from sugar cane and sugar beets or residues from anaerobic digestion. Organic fertiliser has the advantage to cover parts of other essential nutrients as well.

In intensive agricultural areas, additional application of fertiliser is necessary, providing e.g. nitrogen, phosphorus, potassium and calcium. This can either be provided as mineral fertiliser coming from the chemical industry (e.g. nitrogen fertilisers via the Haber-Bosch-process) or from mining (phosphorus in form of Apatite [e.g. from Morocco], nitrogen in form of potassium nitrate [e.g. from China]). Especially due to long-term changes in landscape affecting soil, water, flora, fauna and biodiversity the application of mineral fertiliser has negative implications on the environment.

Pesticides

Intensive agricultural production goes along with establishing monocultures, in order to minimise efforts for maintenance and harvesting. Agricultural profits are often impacted by different kinds of pests, either herbal diseases (fungi, bacteria, virus) or herbivorous animals (beetles, moths, etc.). In order to minimise damage from diseases or any kind of pests, various pesticides are available. Especially due to long-term changes in landscape affecting soil, water, flora, fauna and biodiversity, the application of pesticides has negative implications on the environment.

Fuel

Fuel is necessary to move agricultural vehicles. The provision of petroleum-based fuels has negative implications on the environment. Tab. 4-5 summarises potential impacts from value chains of providing fertiliser, pesticides and fuel for feedstock production. As an additional option, potential impacts from the provision of organic fertiliser and green manure were added.

Tab. 4-5 Potential impacts on the environment related with the value chains of material inputs for feedstock provision

Element / Source / Type of risk	Organic fertiliser / Green manure Agriculture	Mineral fertiliser Mining	Mineral fertiliser Chemical industry	Pesticides Chemical industry	Fuel Crude oil refinery
Prospection	-	C	-	-	C
Drilling / Mining	-	E	-	-	E
Waste production	A	D	D	D	D
Demand of water	A	C	D	D	D
Emissions (exhaust fumes, water, metal)	B	C	D	D	D
Land requirements	A	E	C	C	D
Demands for steel (equipment)	A	C	B	B	D
Transportation	C	D	D	D	D
Refining / processing	-	D	E	E	D
Accident (e.g. traffic, leakage, etc.)	B	C	C	E	E

Impacts are ranked in five comparative categories (A, B, C, D, E); “A” is assigned to the best options concerning the factor, “E” is assigned to unfavourable options concerning the factor; reference scenario: “no action”-alternative

Least impacts are to be expected from the use of organic fertiliser and green manure, respectively. Insignificant types of risks might arise from transportation, potential accidents and from gaseous emissions (odours, possibly laughing gas). The highest impacts on the environment are expected from the provision of mineral fertiliser, both from mining and the chemical industry, pesticides and fuels.

Due to spatial segregation of providing fertiliser, pesticides and fuel for agricultural vehicles on the one hand and feedstock production on the other hand, the local impacts resulting from the value chains mentioned above are low, although local implications at the point of provision are high. This might become clearer from a LCA point of view.

4.2.3 Transport and logistics

Impacts of logistics are expected from

- Transportation infrastructure
- Fuel efficiency
- Storage facilities

Transportation infrastructure

Transportation and distribution of feedstock will most of all be based on trucks, which need roads. Depending on the location of a potential 2G bioethanol plant 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).

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 wide-scale-emissions and high traffic loads of industrial areas will be below detection limits. In sensitive areas, mitigation measures might be necessary (e.g. reduced speed for transportation traffic).

Storage facilities

A prospected biorefinery needs a guaranteed feedstock supply, provided either by onsite storages (e.g. foil-covered piles) or by storage facilities in the refinery, to facilitate short-term feedstock supply and protection against weather impacts. Especially in case of annual crops as well as straw a huge storage capacity is necessary to minimise damage due to humidity (mould) or vermin as feedstock can only be harvested once a year. Additional buildings cause sealing and compaction of soil, loss of habitats (plants, animals) as well as reduced groundwater infiltration.

4.2.4 Conversion

Feedstock processing and provision of the product portfolio is done in a biorefinery. The local environmental impact assessment is 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.

Impacts can be

1. related to the construction phase
2. project-related: buildings, infrastructure and installations
3. related to the operation phase.

Following the LCA-approach, the expected impacts are 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: as 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 set-aside land.
- Brownfield scenario: 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.

The environmental issues potentially affected by these factors are summarised in the following tables Tab. 4-6 (Greenfield scenario) and Tab. 4-7 (Brownfield scenario).

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 buildings, infrastructure and installations differ from the location of a potential plant. In case of a Brownfield scenario, lower impacts are expected than in a Greenfield scenario, where additional land has to be sealed.

Tab. 4-6 Technology related impacts expected from a BIOLYFE 2G bioethanol plant 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 trans-mission 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

→ **Indirect impacts due to the interaction of environmental factors**

Tab. 4-7 Technology related impacts expected from a BIOLYFE 2G bioethanol plant 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
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			P2.1	A2.1				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 trans-mission 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
→ **Indirect impacts due to the interaction of environmental factors**

Further details of potential impacts expected from conversion and use are provided in annex chapter 8.5, valid for industrial plants in general as well as in particular for a biorefinery.

4.2.5 Alternatives to BIOLYFE

4.2.5.1 Feedstock provision

Following the LCA-approach, it is not only necessary to compare potential impacts of different feedstock scenarios in order to determine the most appropriate feedstock for a potential biorefinery. An additional issue is to compare the technology of a biorefinery with a reference technology. Outstanding is an assessment of the value chains for conventional reference systems, which in case of BIOLYFE are natural gas provision and crude oil provision. This is related with different types of risks causing potential impacts on the environment.

Impacts of crude oil / natural gas provision are expected to affect all environmental factors negatively. The impacts are classified as unfavourable for the environment. Both value chains bare a high risk of environmental impacts related with accidents, which in case of crude oil provision might exceed the risks of natural gas provision by far (see /wikipedia/ for a list of spills). Tab. 4-8 summarises potential impacts on environmental factors on the value chains for both crude oil provision and natural gas provision.

Tab. 4-8 Impacts on the environmental factors related with the value chains of crude oil / natural gas provision

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
Drilling	negative	negative	negative				negative		
Waste (oil based and water based mud)	negative	negative	negative		negative				
Demand of water (process water)		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	negative			negative	negative	negative	negative	negative	negative
Refining / processing	negative	negative		negative	negative		negative	negative	negative
Accidents (traffic, pipeline leakage)	negative	negative	negative	negative	negative		negative	negative	negative

4.2.5.2 Conversion

Impacts from implementing a refinery for conversion and use of conventional (fossil) feed-stock 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 4.2.4).

Other impact 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.

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, release of GMO

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.

4.2.6 Comparison: BIOLYFE systems vs. alternatives

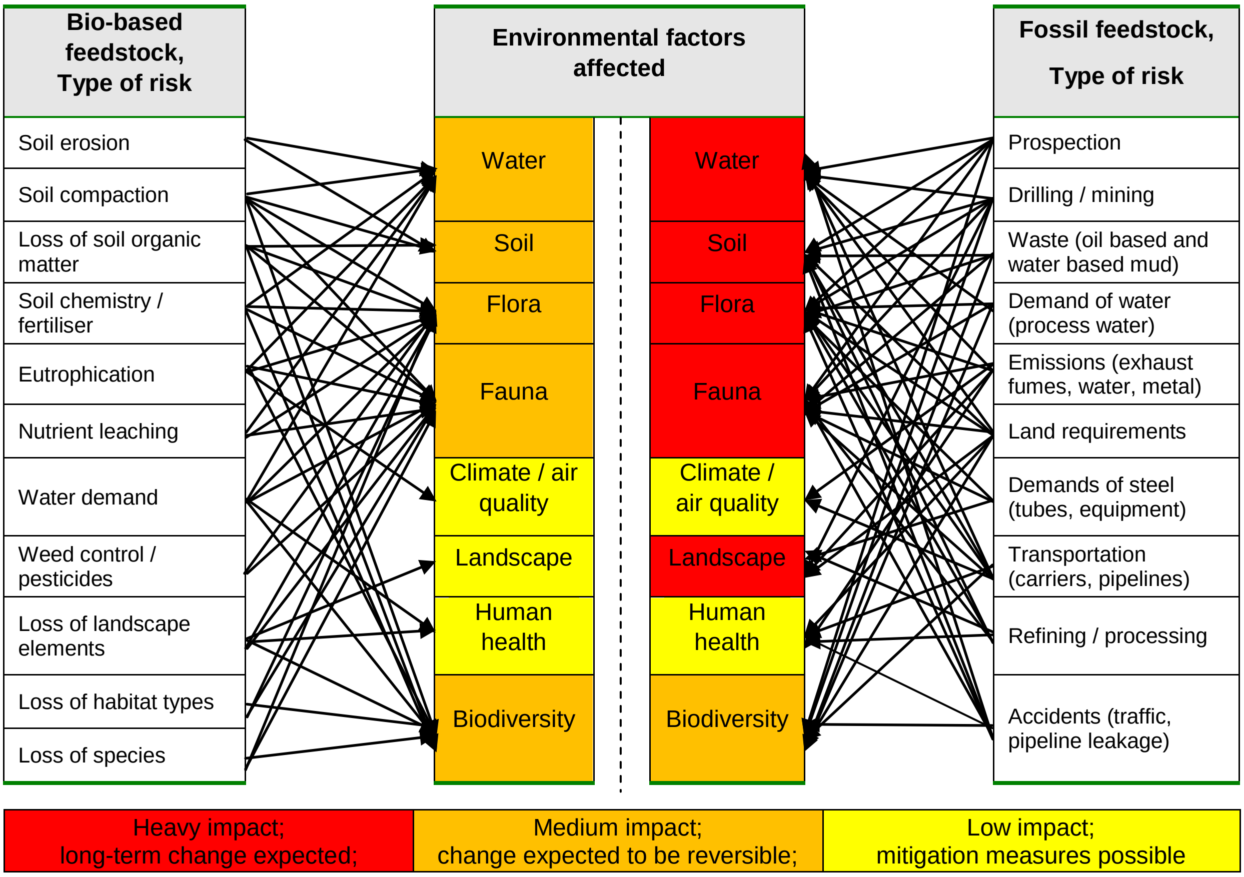
4.2.6.1 Feedstock provision

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 conventional, non-renewable feedstock are fundamentally different and in general are based on extraction technologies focussing on components below the surface. Regeneration normally is not possible.

As types of risks associated with these technologies are completely different in quality and quantity, a direct comparison is not possible. Nevertheless, Tab. 4-9 summarises 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.

Tab. 4-9 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 with the provision of bio-based feedstock are expected to be mostly reversible. For instance the depletion of soil organic matter (SOM) 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 factors 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.

4.2.6.2 Conversion

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

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

Significant impacts are expected from buildings, infrastructure and installations due to sealing and compaction and during operation, e.g. due to risk of explosions and fire in the plant or the storage areas. Depending on the location of the plant additional impacts might occur because of

- drain of water resources for production (environmental factor: water)
- waste water production and treatment (environmental factor: water).

The comparison of conversion technologies in different types of biorefineries and conventional refineries (crude oil / natural gas) on technological related factors with the reference scenario “no action”-alternative is summarised in the following table.

Tab. 4-10 Potential impacts on the environment related to different technologies regarding feedstock conversion and transport

Technology related factor / product	BIOLYFE	Anaerobic digestion	Fermentation 1st generation	Trans-esterification	Gasification	Crude oil refinery	Gas refinery
	Ethanol	Methane	Ethanol	Fatty Acid Methyl Ester (biodiesel)	FT Diesel	Fuel	Methane
Impacts resulting from construction phase							
Construction works	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]
Impacts related to operational phase							
Emission of noise (refinery)	D	D	D	D	D	D	D
Emission of gases and fine dust (refinery)	C	C	C	C	C	E[6]	D
Emission of light (refinery)	C	C	C	C	C	C	C
Drain of water resources for production (refinery)	D	D	D	D	D	D	D
Waste water production and treatment (refinery)	D	D	D	D	D	D	D
Traffic (collision risk, emissions)	C	C	C/E[3]	C/E[3]	C/E[3]	E[3]	E[3]
Electromagnetic emissions from high-voltage transmission lines	C	C	C	C	C	D[6]	D[6]
Risk of accidents - explosion - fire in the plant - fire in the storage areas - release of GMO	C/D[4]	C/D[4]	C/D[4]	C/D[5]	C/D[5]	E[1, 5, 6]	E[1, 5, 6]

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”-alternatives

Foot notes:

1: No significant impacts expected in a Brownfield scenario
2: Significant impacts expected in a Greenfield scenario
3: Increase of 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

4.2.7 Summary

Methodological approach

The assessment of local environmental impacts within the BIOLYFE system is based on a combination of elements of environmental impact assessment (EIA) and life cycle assessment (LCA), which are merged into the so-called life cycle environmental impact assessment (LC-EIA). Whereas standard EIA assesses the local impacts on environmental factors arising from construction and production or use, an LCA takes into account the whole life of a product (cradle to grave) and uses reference scenarios to evaluate e.g. feedstock production and conversion in BIOLYFE in comparison to conventional, both bio-based and fossil-based, systems as summarised in the following Tab. 4-11 indicating the strength of a LC-EIA as a comprehensive qualitative approach especially helpful in an early stage of a project.

Tab. 4-11 Efficiency of different environmental assessment tools

Process	EIA	LCA	LC-EIA
Upstream processes (e.g. provision of basic materials and fertiliser, transportation)	-	+ qt	(+) ql
Feedstock provision	-	+ qt	+ ql
Construction of bioethanol plant	+ qt	(+) qt	+ ql
Provision of infrastructure around a plant	+ qt	(+) qt / sc	+ ql
Conversion	+ qt	+ qt	+ ql
Use	-	+ qt	-
Downstream processes (e.g. end-of-life treatment, recycling and final disposal)	-	+ qt	(+) ql

+ = applicable, (+) = partial applicable, - = not applicable;
qt =quantitative analysis, ql = qualitative analysis, sc = scenario analysis

As the assessment was not applied for a specific location, a generic approach was chosen to facilitate the transferability to other regions in Europe.

Biomass provision

Main scenarios for feedstock provision were the cultivation of Arundo donax (perennial crop), Sorghum bicolor (annual crop) and cereal straw (residue). Regarding impacts on environmental factors, <u>perennial crops</u> show a clear advantage due to reduced exposure of soil, based on lower maintenance cycles as well as on reduced application of fertiliser and pesticides for weed control. Due to lower leaching rates, the cultures show less impact on water quality, basically on groundwater, but also on natural and artificial water bodies. In an arable area, species and habitat diversity would benefit from additional habitat types for invertebrates e.g. insects and vertebrates like deer or birds.

The cultivation of annual crops in general results in higher impacts on the environment, especially due to intensive field works. The risk of soil compaction and erosion is higher, whereas the differences between the crops are quite low.

High risk of erosion results from the low soil coverage during the growing season (e.g. Sorghum) and relatively wide distance between crop rows (e.g. sugar beet). The risk on groundwater and superficial water is increased due to leaching of nutrients.

Risks from the provision of wheat / barley straw are expected to be comparable to the reference system of ploughing the straw in, as long as harvesting is done in a sustainable way, leaving about 60 % of the residues on the fields. Risks from cultivating annual crops will remain.

Additional material input

Following the life cycle oriented approach, additional material input for feedstock provision is resulting from value chains of providing organic and mineral fertiliser, pesticides and fuel. Least impacts are expected from the provision of organic fertiliser and green manure with low risks resulting from transportation, potential accidents and from gaseous emissions (odours). Highest impacts on the environment are expected from the provision of mineral fertiliser, both from mining and the chemical industry, pesticides and fuels. Although local effects from provision can be high, e.g. in phosphate mining, additional local impacts from the use of fertiliser, pesticides or fuel are low.

Further impacts are expected from the provision of additional transportation infrastructure, the efficiency of fuel (ethanol < fossil fuels) and the need of storage facilities necessary to guarantee a sufficient feedstock supply for a biorefinery throughout the year.

Conversion

According to standard EIA procedure, potential impacts result from construction works, from buildings, infrastructure and installations on-site as well as from the operation of a prospective plant. Impacts from implementing a refinery are site-specific and very much dependent on the location / surroundings. In case of a Brownfield scenario less impacts are expected than in a Greenfield scenario, where additional land has to be sealed.

BIOLYFE systems versus alternatives

In comparison with other systems impacts from the provision of bio-based feedstock are mostly reversible (e.g. depletion of soil organic matter due to agricultural cultivation, depletion of water due to use of fertiliser and pesticides). Impacts from conventional fossil feedstock provision especially on water, soil, flora, fauna and landscape are expected to be long-term changes and non-reversible.

Potential impacts from implementing different types of conversion plants show little differences on a generic level. In all technologies, significant impacts are expected from buildings, infrastructure and installations due to sealing and compaction. Differences might occur during operation, e.g. due to risk of explosions and the handling of potential hazardous substances. Depending on the vicinity of the plant, additional impacts might occur due to drain of water resources for production as well as wastewater production and treatment.

4.3 Economic assessment

There are several drivers for using non-food lignocellulosic materials as feedstocks for fuels and chemicals. Certainly, environmental sustainability and preservation are important, however equally important is to be competitive in the market for the production of bio-based chemicals and fuels. The economic impact of the BIOLYFE system on second generation bioethanol production has been assessed by an economic modelling tool based on a wide number of process and economic parameters (for methodology see chapter 2.3). All the key process and economics parameters considered for every scenario have been summarised in Tab. 4-12. Specific data on the assessed scenarios can be found in the annex (chapter 8.7).

Tab. 4-12 Main output parameters for process and economics analysis

Output	Variable	Unit of measurement
Process output	Biomass consumption	dry tonne / tonne ethanol
	Enzyme solution consumption	relative unit (X-fold)
Economic output	Biomass	€ / tonne ethanol
	Consumables (Chemicals and enzyme)	€ / tonne ethanol
	Fuel	€ / tonne ethanol
	EE exported (-) / purchased (+) to / from grid	€ / tonne ethanol
	Surplus lignin cake sold	€ / tonne ethanol
	Ethanol variable production cost	**€ / tonne ethanol**
	Fixed production cost	€ / tonne ethanol
	Ethanol cash cost	**€ / tonne ethanol**
	Fixed Capital Investment	MM €
	Capital charge	€ / tonne ethanol
	Ethanol production cost	**€ / tonne ethanol**

For every scenario analysed, the study has considered a standard case, that is a system in which the expected performances for a mature technology facility have been estimated, and two different cases in which the system performs better (favourable case) or worse (less favourable case) than the standard.

4.3.1 Main scenario

In this paragraph, the economical evaluation developed for an ethanol facility in Central Europe is presented.

The analysis focuses on the reference case of 100 kt per year dry ethanol plant, in the hypothesis that Arundo donax is used as feedstock for a continuous production system (8,000 hours per year).

The following figure (Fig. 4-14) reports the estimation of cash costs and the detail of variable and fixed production costs estimates.

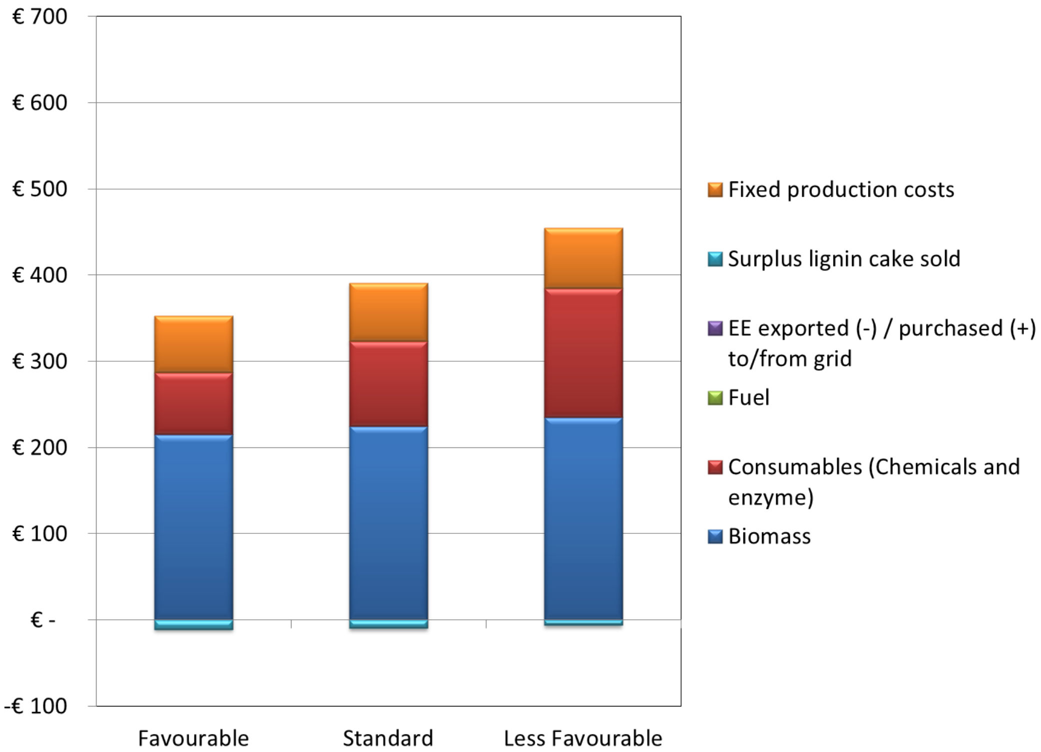


Fig. 4-14 Comparison of the results of cash costs for the main scenario (100 kt / a 2nd generation bioethanol from Arundo). EE: electric energy

Considering the standard case, the total cash cost per tonne of ethanol has been evaluated around 381 €. Impact cost of feedstock, in the Arundo donax ethanol case, represents about 59 % of total operating costs (ethanol cash cost).

In the favourable and less favourable cases the cost of feedstock per tonne of ethanol represents around 63 % and 52 %, respectively on the total cash cost. The different impact of consumables costs must be noted: in favourable case, the cost of consumables is about half of one less favourable case per tonne of ethanol.

The impact of utilities costs has not been reported since the plant can be energy self-sufficient, due to the exiting stream that can be used for energy integration (exhaust steam, lignin and concentrated stillage to be burnt). In fact, net electricity and natural gas consumption are assumed to be zero, being the energy required to satisfy utilities demand taken from the energy produced by burning lignin rich stream and concentrated stillage in an dedicated co-generation unit.

If the energy obtained burning the total amount of lignin is higher than one required from the plant, the extra amount of lignin is exported and it is assumed to be sold OSBL. In the standard case this profit is around 10 € / tonne of ethanol.

For what regards CAPEX, the resulting Fixed Capital Investment (FCI) in the standard case is 89 million €. It comprises the Direct Capital Costs (DCC) for the reference plant and the Indirect Capital Costs (ICC): these include installation, equipment insulation, supervision and scaffolding for construction plus civil work and site preparation. The resulting Fixed Capital Investment (FCI) has been considered in the determination of production costs as Capital Charge, calculated assuming the repayment of the FCI in a period of 15 years with an annual interest rate of 8 %.

The following figure (Fig. 4-15) reports the estimation of total production costs and the detail of capital charge costs estimates.

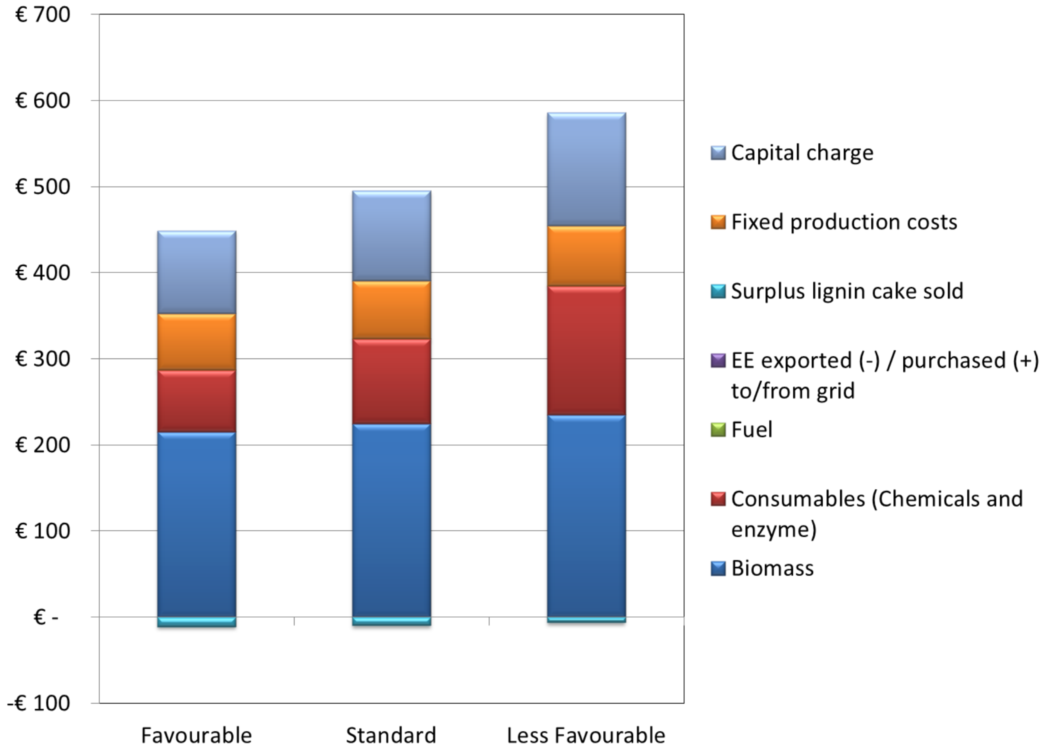


Fig. 4-15 Comparison of the results of total production costs for the main scenario (100 kt / a 2nd generation bioethanol from Arundo). EE: electric energy

4.3.2 Additional scenarios: feedstock

The aim of this paragraph is to show the main difference from an economical point of view between the main scenario and alternative scenario with the use of different feedstocks, such as wheat straw and fibre sorghum.

The analysis has been driven by the same process and economic assumptions that have been made for the main scenario.

Fig. 4-16 shows the differences in the ethanol cash cost (standard case) between the three different biomasses considered.

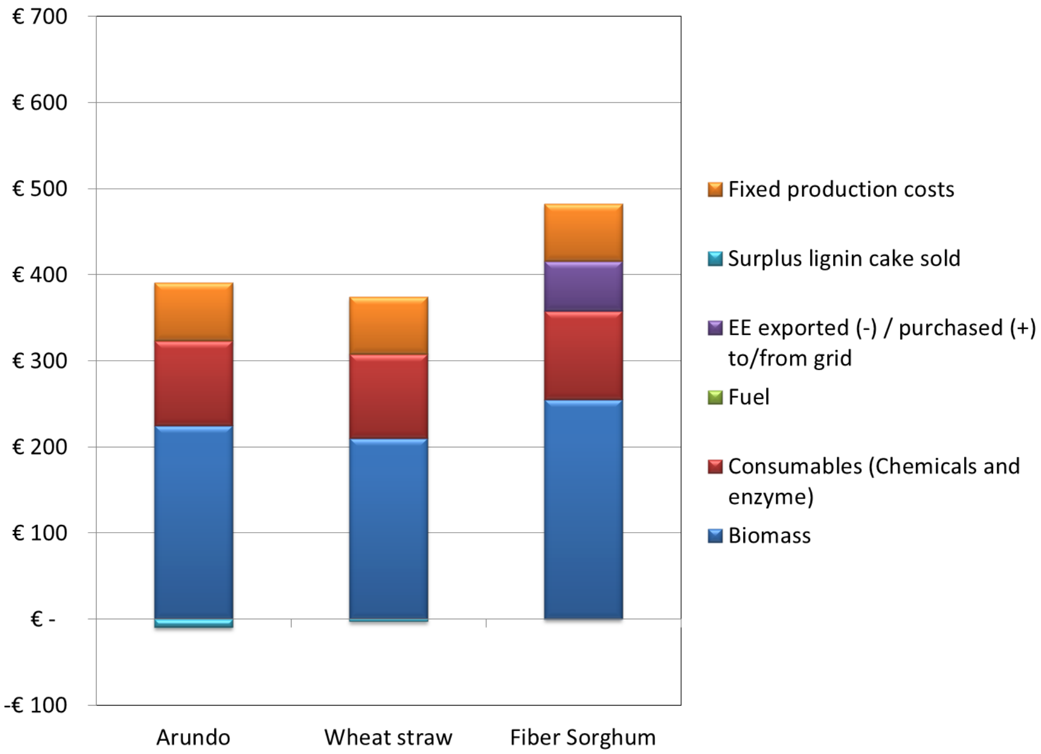


Fig. 4-16 Comparison of the results of total cash cost for different feedstocks (100 kt / a 2nd generation bioethanol from Arundo, wheat straw and fibre sorghum) for the standard cases. EE: electric energy

Considering the different feedstocks, the cash cost per tonne of ethanol has been evaluated around 371 € for a wheat straw plant and 482 € for a fibre sorghum plant. Impact cost of feedstock, in the wheat straw ethanol case, is comparable with that obtained with Arundo, while for fibre sorghum has a higher slice of cost, mainly due to the lower amount of potentially fermentable sugars in the initial biomass.

While the impact of utilities costs has not been considered in Arundo and wheat straw cases, for fibre sorghum the plant isn't energy self-sufficient and, for this reason, an adequate import of electricity has been included. The impact of these extra amount of energy purchased has been estimated around 58 € per tonne of ethanol.

Considering also the FCI and its accountable depreciation, the differences between the total production costs of ethanol for the three cases are shown in Fig. 4-17 below.

The impact of Capital Charge on ethanol cost is comparable for the first two cases (around 104 € for Arundo and wheat straw), while it is around 120 € per tonne of ethanol from fibre sorghum. This reflects the FCI resulting in the third case (around 103 million €) that is a 15-20 % higher than in the first two investment plans.

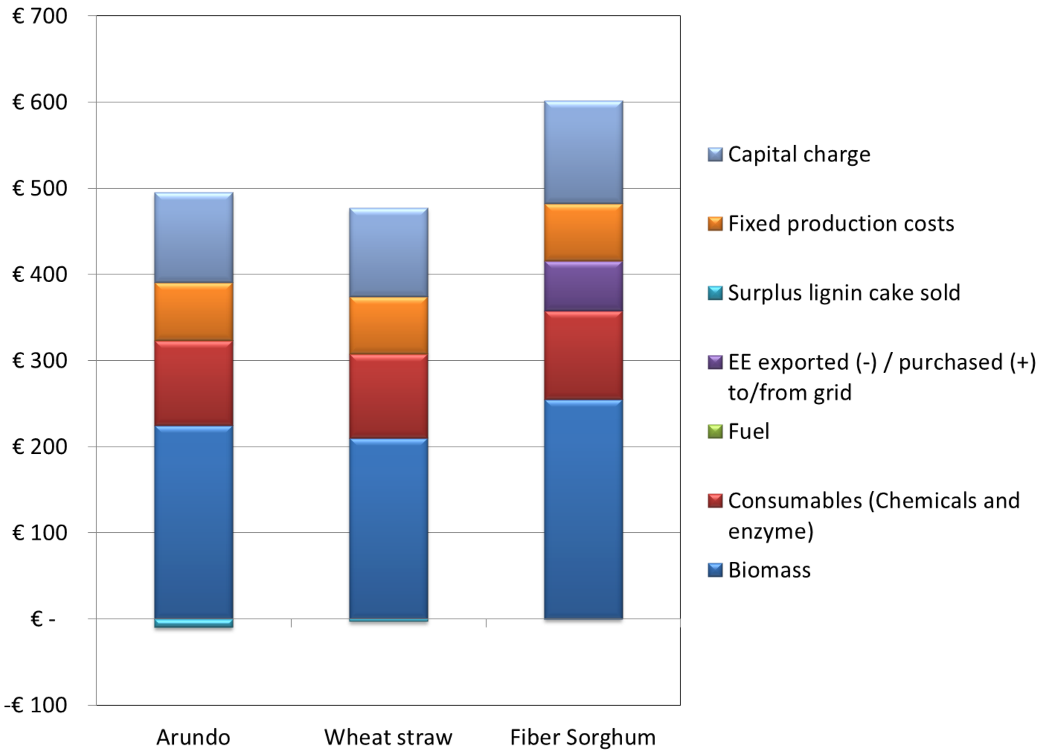


Fig. 4-17 Comparison of the results of total production costs for different feedstocks (100 kt / a 2nd generation bioethanol from Arundo, wheat straw and fibre sorghum) for the standard cases. EE: electric energy

4.3.3 Additional scenario: product use options

In this paragraph, an overview on the economical comparison between ethylene from petroleum derivatives and bio-ethylene is presented.

Ethylene and bio-ethylene are chemically identical, so existing equipment and production units can indifferently use both to produce plastics or other downstream products.

Bio-ethylene is produced from bio-ethanol trough a catalytic process using an alumina or silica-alumina catalyst, once bio-ethanol has been produced and purified to chemical grade. One tonne of bio-ethylene requires 1.74 tonnes of (hydrated) bio-ethanol /Kochar et al. 1981/. Conversion yields of 99 % with 97 % selectivity to ethylene have been achieved /Chematur n.d./. The reaction is endothermic and requires a minimum theoretical energy use of 1.6 gigajoules (GJ) per tonne of bioethylene. While the ethanol-to-ethylene (ETE) process is relatively simple, it has scarcely been used in the last decades.

Tab. 4-13 provides an overview of the capacity of current and planned facilities where bio-ethylene or its downstream products are produced through ETE technology.

Tab. 4-13 Overview of current and planned plants for ethylene production from bioethanol (Source: /IEA-ETSAP & IRENA 2013/)

Location	Company	Start-up year	Bio-ethylene capacity, kt / a	Final product	Biomass feedstock type
			Operational		
India	India Glycols Ltd.	1989	175b	Bio-EG	Molasses
Brazil	Braskem	2010	200	Bio-PE	Sugarcane
			Under construction		
Brazil	Solvay Group	2011	60	PVC	Sugarcane
Taiwan	Greencol Taiwan Corporation	2011	100	Bio-EG	Sugarcane (from Brazil)
Brazil	Dow / Mitsui	2013	350 (expected)	Bio-PE	Sugarcane
			Status unknown		
China	Sinopec	1980s	9	Bioethylene	
China	BBCA group	2004	17	Bioethylene	
China	Yongan Pharma-ceuticals	2011	42b	Bio-EO	
China	Jilin Bohai	2012	63b	Bio-EO	
China	Heyang Bio Ethanol Co.	2013	80b	Bio-EO / EG	
China	Sinopec Sichuan Vinylon Works		10	Bioethylene	Cassava

The current production capacity is about 375 kt per year, of which 200 kt / a are used for producing polymers (bio-PE) and the remaining part for producing bio-based ethylene glycol (EG). Most of the capacity under construction also focuses on production of non-polymer ethylene derivatives, such as EG and ethylene oxide (EO), which could later be used in polymers production.

Bio-ethylene production based on sugarcane is estimated to save about 60 % of fossil energy compared to petrochemical production as the process can also produce electricity.

Tab. 4-14 presents an overview of bioethylene production costs in different regions. Productions from starchy and sucrose feedstock are based on IRENA analysis, whereas productions from ligno-cellulosic biomass are based on other literature sources.

According to the IRENA analysis, the production costs of sugarcane bio-ethylene are very low in Brazil and India (i.e. around $ 1,200 / t bio-ethylene). Chinese production based on sweet sorghum is estimated at about $ 1,700 / t. Higher costs are reported in the United

States (from corn) and in the European Union (from sugar beets) at about $ 2,000 / t and $ 2,600 / t, respectively. At present, the cost of ligno-cellulose-based production is estimated at $ 1,900-2,000 / t in the U.S. In comparison, the cost of petrochemical ethylene is substantially lower (i.e. $ 600-1,300 / t), depending on the region with a global average of $ 1,100 / t. The current production cost of bio-ethylene is between 1.1-2.3 times higher than the global average petrochemical ethylene, but ligno-cellulosic bio-ethylene is expected to reduce the gap in the near future.

Tab. 4-14 Overview of estimated production cost for bio-ethylene, (all costs in 2009 $ / tonne) (Source: /IEA-ETSAP & IRENA 2013/)

Location	**Feedstock type**	**Ethylene production cost**	
		Mean	Range
	IRENA estimates – starch- and sucrose-containing feedstocks		
U.S.	Corn	2,060	1,700 – 2,730
Brazil	Sugarcane	1,190	970 – 1,630
India	Sugarcane	1,220	1,000 – 1,670
EU	Sugar beets	2,570	2,180 – 3,380
China	Sweet Sorghum	1,650	1,340 – 2,180
	Other sources – lignocellulosic feedstocks		
U.S.	2012 state-of-the-art estimate (biochemical)	1,190	1,820 – 2,080
U.S.	Corn residue (thermochemical)	2,000	1,900 – 2,170
	IRENA estimates – reference production routes		
U.S.	Target of USD 1 / gallon bio-ethanol	1,080	980 – 1,250
Global	Steam cracking (petrochemical ethylene)	1,100	600 – 1,300

4.3.4 Sensitivity analysis: biomass costs

While from an environmental point of view, some aspects like cultivation input, land or transport distance are fundamental for the determination of the sustainability of the system, from an economical point of view it has only to be considered the total biomass production cost.

Total biomass production cost results from the sum of costs related to biomass farming (land preparation, seeding, chemicals and utilities use, …), harvesting, collection and transportation to the ethanol plant and it is a parameter that strongly influences the operative costs. This parameter also depends on market trends, location of the plant, period of the year and many other factors.

Biomass production costs considered in the main scenario have been estimated on the basis of data from the M&G-Biochemtex experimental farm in the north-west of Italy and have been adapted to the selected scenario taking into account factors like climate, rainfall, percentage of area suitable for intensive farming, costs related to agricultural operations and chemicals in Central Europe with respect to Italy.

As reference case, it has been considered the standard main scenario (100 kt per year dry ethanol plant from Arundo donax).

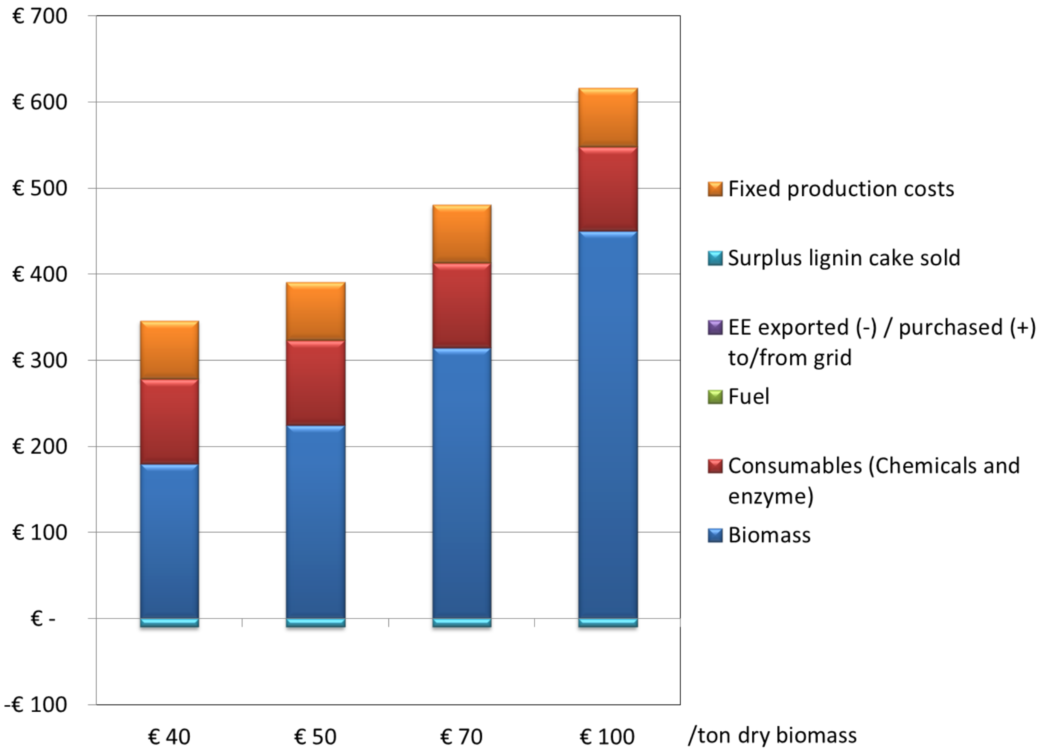


Fig. 4-18 Comparison of total cash costs resulting varying the biomass specific cost. EE: electric energy

As it is shown in Fig. 4-18, a situation in which the biomass cost is around 100 € / tonne dry of feedstock could not be considered a competitive business. This is essentially because in this last case the impact of biomass cost on total cash cost is around 450 €.

4.3.5 Sensitivity analysis: enzymes

The enzyme impact on the final production cost of one tonne of ethanol is one of the most important parameters to be considered in the sensitivity analysis. It basically depends on the enzyme dosage, performance and price.

The enzyme cost impact has been normalised on the basis of a standard value (set according to Biochemtex experience) which is expressed as "1X". It is expected that this value can be reduced, as a consequence of enzymes performance and / or process improvements. This assumption is based on several forecasts of suppliers who expect to overcome the issue with new generations of enzymatic formulations in a few years.

Five scenarios are considered, centred on the reference case (1X). As shown in Fig. 4-19, the effect of enzyme input is important for operative expenses due to the intrinsic cost of enzyme.

Enzyme cost is not under direct control of Biochemtex, but it can be reasonable to assume a decrease considering the market growth in this field for the next years. In order to not introduce an additional uncertainty factor, the simulation does not assume any variation of the specific price of the enzyme between the different scenarios.

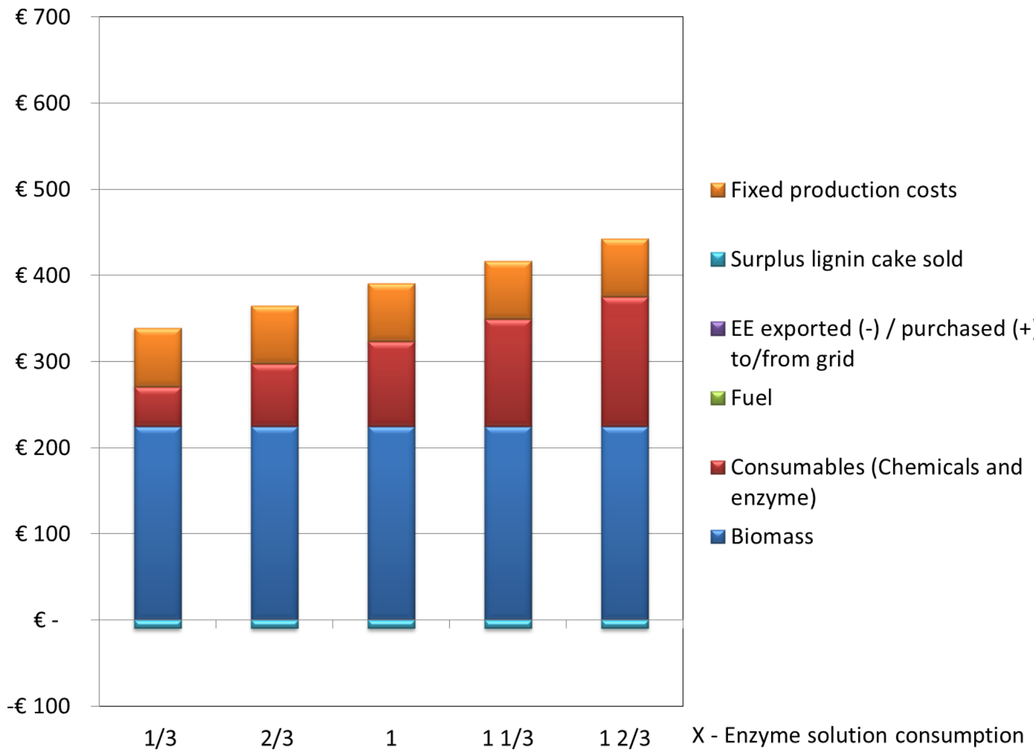


Fig. 4-19 Comparison of total cash cost resulting by varying enzyme input parameters. EE: electric energy

Considering the results obtained by varying only the enzyme input parameters for the standard case, the best total cash cost per tonne of ethanol has been evaluated around 329 €, for the scenario in which the enzyme has ⅓ dosage input compared to the reference one. The worst case considers an ethanol cash cost standing at around 433 €. In the favourable and less favourable cases, the cost of enzyme per tonne of ethanol impacts around 14 % and 35 %, respectively on the total cash cost.

No additional considerations have been done for what concerns the impact of different hydrolysis yields, different residence times and, as a consequence, of lower energy requirements (in particular due to the lower demand for stirring in the hydrolysis step).

Considerations about the probably decrease in capital cost investment directly attributable to lower reactors volume size for enzymatic hydrolysis reactors have also been skipped due to the complexity of these kind of predictions, which are strictly related to specific enzyme formulation performances and improvements.

4.3.6 Other sensitivity analyses: regional variability

The regional variability influence on the economics of the standard case of main scenario (100 kt per year dry ethanol plant from Arundo donax) has been studied in terms of costs of labour and maintenance of the plant.

The economic impact of fixed production costs in different European location has been estimated by changing the hourly labour cost and the maintenance / fixed capital investment cost ratio with respect to a reference standard value (based on Biochemtex experience).

The following figure (Fig. 4-20) reports the estimation of total cash costs assuming three different European locations.

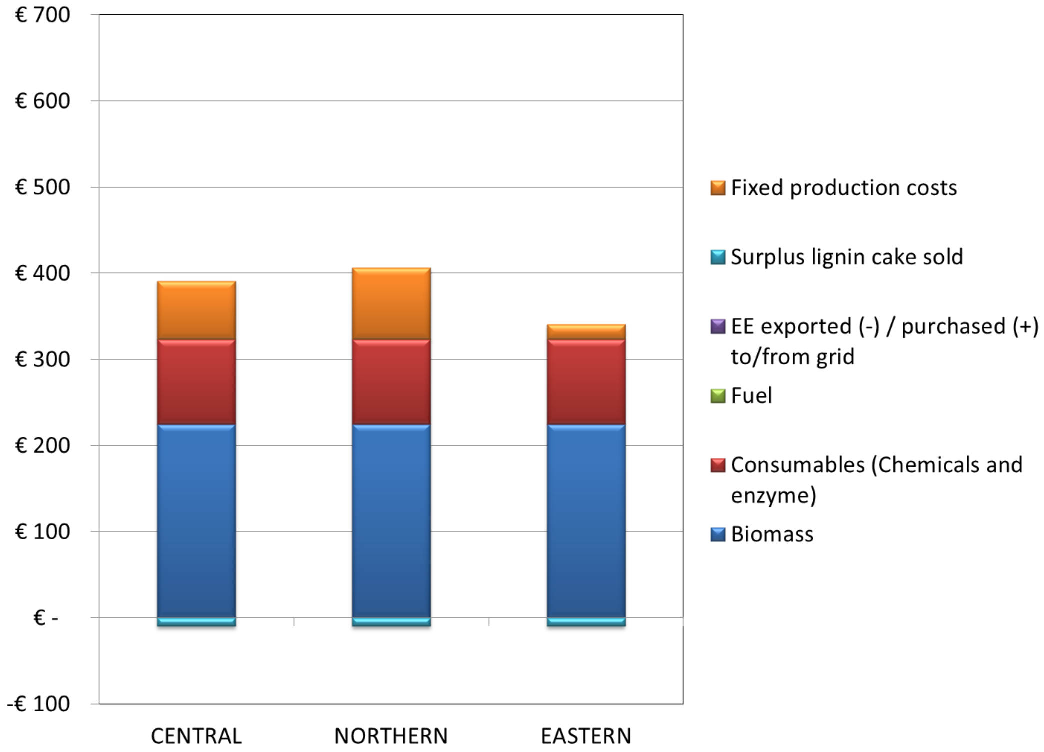


Fig. 4-20 Comparison on total cash cost in three different European locations. EE: electric energy

From these preliminary and partial estimates, the Eastern Europe appears as the most convenient location to build plants. Anyway, additional evaluations on capital investment cost and many other factors are absolutely necessary to drive future business plan.

4.3.7 Alternatives to BIOLYFE: BTL

Two main categories of processes have been object of research and development activities aimed to the production of 2nd generation biofuels from lignocellulosic biomasses: biochemical and thermochemical processes.

While PROESA® technology is a biochemical route, based on the conversion of cellulose and hemicellulose to bioethanol through the action of enzyme and yeast, many different thermochemical processes (characterised by severe temperature conditions and the use of chemicals) are under development for the conversion of lignocellulosic biomasses to fuel compounds (also known as synfuels) which are similar to fossil-derived gasoline and diesel fuels. The latter kinds of processes are also defined as Biomass to Liquid processes (BTL) and include, as examples, Methanol to Gasoline processes (MTG), Fischer-Tropsch based processes.

The expected production costs of synfuels from BTL processes have been compared to the standard case defined for the PROESA® technology. Literature data relative to the production costs of synfuels show a large range of values, due to methodological aspects (e.g. system boundaries and completeness, allocation methods, financial models) and process assumptions (e.g. technology choices, feedstock, plant efficiencies and yields, investment cost estimations).

In order to compare fuels with different characteristics in terms of energy content and vehicle efficiency, results have been reported on a gallon_ethanol_equivalent_efficiency (ge_ef) basis, according to the conversion factors summarised in Tab. 4-15. The ge_ef unit here defined represents the amount of a fuel that is necessary to cover the same distance that can be covered with one gallon of fuel ethanol.

Tab. 4-15 Energy content and vehicle efficiency factors for different fuels

		Diesel	Gasoline	Ethanol
LHV	[MJ / gal]	135.5	122.5	80.5
Vehicle efficiency	[km / MJ]	0.38	0.32	0.34

The projected production costs of synfuels for the Nth BTL plant fall between 0.7 and 1.4 € / litre, equivalent to 2.5 - 5 $ / ge_ef. More in detail, /Sunde et al. 2011/ report a projected production cost for synfuels between 0.7 and 1.12 € / litre, equivalent to 2.5 - 4 $ / ge_ef. A second study made by /Haarlemmer et al. 2012/ aimed to estimate the economics of different BTL pathways described in literature, highlights a synfuel production cost of 1 - 1.4 € / litre (equivalent to 3.6 - 5 $ / ge_ef).

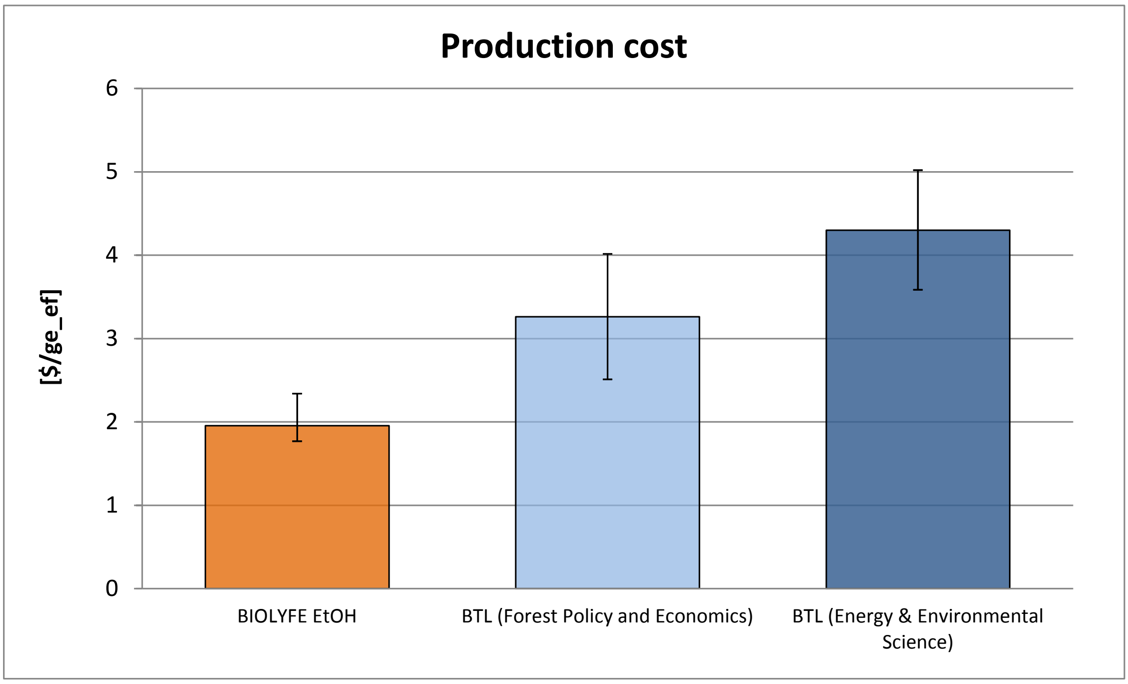


Fig. 4-21 Production costs comparison between PROESA® bioethanol from Arundo donax and BTL fuels

The comparison with PROESA® bioethanol production cost (Arundo donax as feedstock) shows that PROESA® technology is characterised by an average production cost far below that of BTL synfuel (-40 % and -55 % for central values, depending on the reference for BTL) (see Fig. 4-21).

Another important aspect is the narrower range of variation, resulting from process assumptions, of PROESA® production costs when compared to BTL technologies: a factor that can play an important role when relevant investments have to be planned.

4.3.8 Alternatives to BIOLYFE: 1st generation biofuels

2nd generation biofuels are coming up beside 1st generation ones as renewable energy source in transport sector and are expected to play a role more and more important in the next years.

Despite a production process that is in general simpler with respect to 2nd generation biofuels, the further expansion of 1st generation biofuels market have to face up to some main issues, such as the use of feedstock in competition with food and / or feed markets, with possible impacts on their price (and a consequent impact also on the biofuel production cost) and on land use.

PROESA® technology allows to produce bioethanol without entering into competition with the food and feed sectors for what concerns feedstock and land use (e.g. using agricultural residues, as wheat straw, or lignocellulosic crops which can grow on marginal or degraded land, as Arundo donax).

The production costs of PROESA® bioethanol and many 1st generation processes have been compared: literature data have been collected for sugarcane, sugar beet, corn and wheat bioethanol, rapeseed biodiesel and biomethane from maize. In many cases, the cost of feedstock has been updated to current values, in order to obtain a more fair comparison between these different production scenarios.

As in the previous paragraph, results have been reported to a gallon_ethanol_equivalent_efficiency (ge_ef) basis, in order to take into account the different energy contents of the fuels (on a Lower Heating Value basis) as well as their different vehicle efficiencies (in terms of MJfuel / km), as summarised in Tab. 4-15.

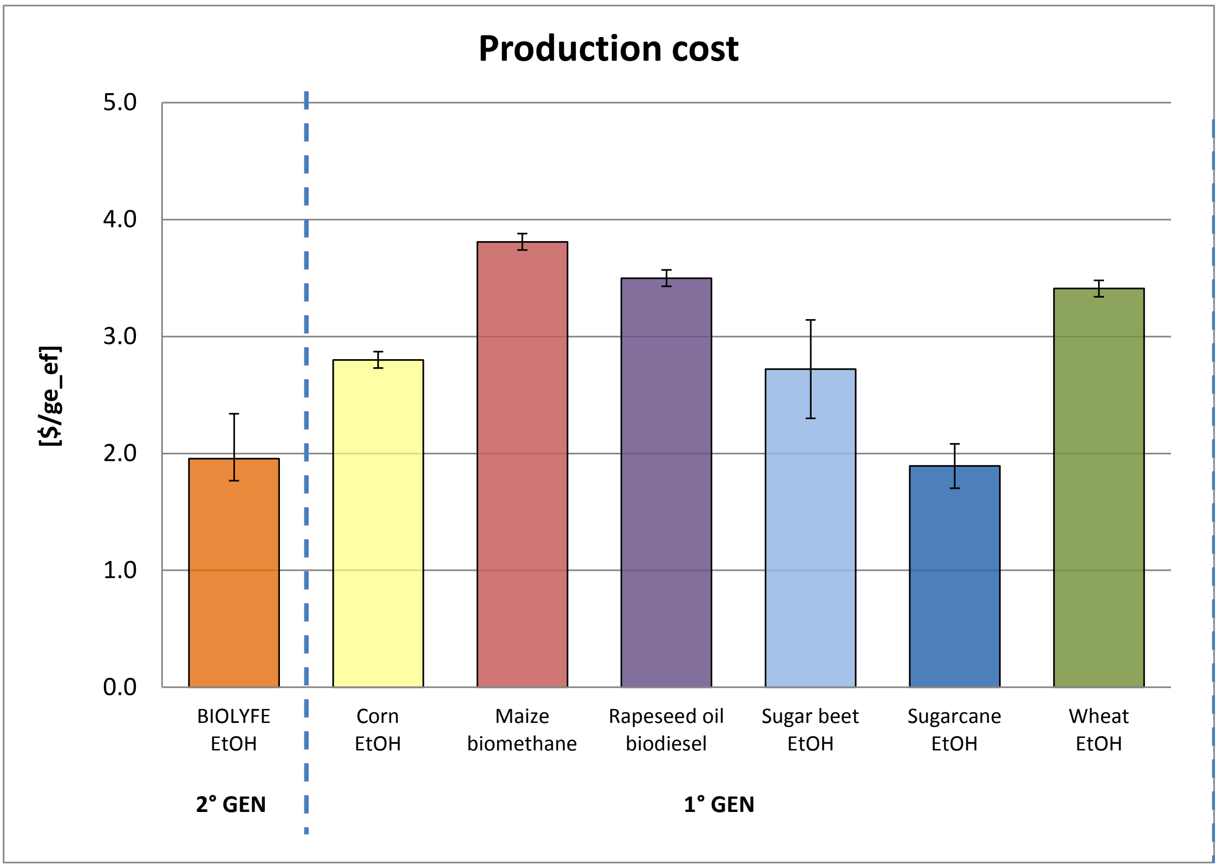


Fig. 4-22 Production costs comparison between PROESA® bioethanol from Arundo donax and 1st generation biofuels from different feedstock and processes

The comparison shows the advantages that PROESA® bioethanol offers with respect to first generation technologies in terms of production cost, with a reduction that in many cases can exceeds 40 %.

4.3.9 Summary

The previous sensitivity analysis allows to predict effects of process configuration and conditions on ethanol process yield and cash cost.

The integration of PROESA® and BIOLYFE results economically sustainable, under many different scenarios, which are expected to be characterised by a competitive bioethanol cash cost (under 350-400 € per tonne of ethanol).

Feedstock type and cost, enzymes load and cost, energy integration process and location are the parameters considered in the analysis. Main results from the sensitivity analysis are summarised by key parameters:

- **Feedstock type:** both Arundo donax and wheat straw result as promising biomasses for ethanol production. Due to their higher potential sugar content, they ensure a lower tonne of biomass / tonne of ethanol produced ratio.
- **Feedstock cost:** depending on the location, costs related to biomass cultivation and farming, can show a relevant variability. To better illustrate this effect on bioethanol cash cost, it could be considered that at a biomass cost of 70 € / dry tonne, ethanol could have a cash cost around 470 € / tonne.
- **Enzymes load:** it is expected that the dosage value can be reduced in the next future due to possible enzymes performance and / or process improvements. The best case considered (at ⅓ dosage) brings to a reduction of ethanol cash cost of about 13 % compared to standard dosage scenario.
- **Enzyme costs:** this variable cannot be directly controlled by Biochemtex. It can be reasonable to consider a sensitivity scenario with a 20 % enzyme cost reduction, in light of the expected market growth in this field in the next years. This consideration could bring to a reduction of the enzyme impact cost that in standard case has been estimated to be around the 20 % of total bioethanol cash cost.
- **European location:** although more detailed studies are needed to analyse the cost of capital investment and other cost factors, the preliminary estimations reported show how the Eastern Europe appears as the most convenient location to build new ethanol plant: the fixed production costs have a reduction of about 75 % compared to the reference case.

4.4 SWOT analysis, social impacts and biomass competition

The SWOT analysis (strengths, weaknesses, opportunities and threats) assesses the whole life cycle of BIOLYFE bioethanol production and use. Sustainability aspects, which are covered neither in the environmental nor in the economic assessment, were found for two life cycle steps: biomass provision (chapter 4.4.1) and biomass conversion (chapter 4.4.2). These SWOT matrices were discussed with stakeholders and experts at an international workshop held in Madrid. The points raised there are summarised in chapter 8.8.5 in the annex. Further issues on social impacts and competition about biomass are analysed in chapters 4.4.3 and 4.4.4, respectively.

4.4.1 SWOT analysis of biomass provision

The sustainability of biomass provision can be discussed with a focus on various aspects. General arguments for and against lignocellulosic fuels are discussed in chapter 4.4.1.1 and specific arguments for the main BIOLYFE feedstock Arundo donax are subject of chapter 4.4.1.2. Additional SWOT matrices can be found in the annex on the alternative feedstocks fibre sorghum (chapter 8.8.1) and wheat straw (chapter 8.8.3), cultivation methods for all crops (chapter 8.8.2) and on feedstock mixtures versus single feedstocks (chapter 8.8.4).

4.4.1.1 Cultivation of lignocellulose crops for the production of 2nd generation bioethanol in general

The following table shows general strengths, weaknesses, opportunities and threats for the cultivation of herbaceous lignocellulose crops as energy crops for the production of 2nd generation bioethanol. The strengths, weaknesses, opportunities and threats are mainly defined in comparison to fossil based fuels (status quo). But success and failure factors compared to 1st generation biofuels made of domestic crops (e.g. ethanol from sugar beet, biodiesel from rapeseed) or imported 1st generation biofuels are also considered.

Tab. 4-16 SWOT analysis for cultivation of lignocellulose crops for the production of 2nd generation bioethanol

Strengths	Weaknesses
• S1: **Renewable resource**: can be used as alternative to fossil fuels. Contribution to **energy security.** • S2: Can contribute to **rural development** by creating new income opportunities in rural areas if cultivated on former fallow land. • S3: Can contribute to **climate change mitigation** (at least if land use change is avoided). • S4: Introduction of new crops offers the **chance to increase crop species diversity** and reduce pest pressures caused by mono-cropping systems.	• W1: **Need for arable land** (in some cases: marginal land) to cultivate the crops → land becomes an increasingly scarce resource. There is increasing demand for the limited arable land *(indirect competition for food and feed!)*. • W2: New crops in most regions**: farmers lack knowledge** and experience regarding cultivation of lignocellulose crops for energy. • W3: **Infrastructure and logistics for lignocellulosic (=low density) biomass supply not fully developed** in regions with high biomass potential.

Tab. 4-16 (continued) SWOT analysis for cultivation of lignocellulose crops for the production of 2nd generation bioethanol

Strengths	**Weaknesses**
• S5: Compared to 1st generation biofuels: **No direct competition to food**, because lignocellulose is not digestible for humans. • S6: Most lignocellulose crops are **easy to grow and high yielding** → high energy and land use efficiency.	• W4: **Storage facilities not yet available.** • W5: **Lignocellulose processing approaches are considered commercial only at large scale**. The large amount of feedstock needed for large processing units is difficult to be organised within an acceptable distance without compromising sustainability. • W6: In most cases higher eutrophication, acidification and ozone depletion compared to fossil fuels.
Opportunities	**Threats**

• O1: **Rising market opportunities for biofuels** as fossil fuels become scarcer. The trend of increasing fossil fuel prices increases competitiveness of biofuels. Subsidies for 2nd generation biofuels may rise because of their lower competition to food production.
• O2: New crops that have shortly entered into the focus of agricultural research → **still high potential for enhancement of the currently available genetics and management practices**, overcoming existing agricultural weaknesses and limitations.
• O3: Robust plants could be **cultivated on land with lower productivity** not suitable for other purposes (poor soil, dry area, remote areas).
• O4: Global sustainability **certification schemes** for biofuels are established or under development (GBEP, RSB), facilitating a proof of sustainability to positively influence public perception.
• O5: Involving **farmers as shareholders** could facilitate cooperation and increase feedstock availability.
• O6: Close cooperation with **farmers unions and regional institutions** can facilitate cooperation and increase feedstock availability.
• O7: **Cooperations of farmers** could make the biomass provision more efficient (shared infrastructures and logistics).
• O8: **Support of exchange of experience** amongst European farmers by EU and industries could facilitate successful cultivation.
• O9: **Training and subsidies for farmers** supported by industries and policy makers could minimise farmers' burdens.
	• T1: **Market price might be too low** compared to production costs:
	    • Competition with other energy carriers, in particular fossil fuels and electric mobility.
	• T2: Rising **land scarcity** can lead to unsustainable biomass provision.
	    • T2a: There will be less surplus land available for bioenergy production at global scale because of **rising demand for food and feed**. A rapid increase in demand for bioenergy can **bring food prices up and increase hunger**.
	    • T2b: Increased **risk of harvest failures** because of extreme weather events going align with climate change.
	    • T2c: With a rapid increase in demand for bioenergy, farmers have incentive to clear natural ecosystems. This **poses a risk for endangered species and can increase greenhouse gas emissions**, leading in some cases to net CO_2 emissions.
	• T3: **Farmers might prefer to stay with food crops** because they are used to these crops and they can be used as food in times of food scarcity.
	• T4: **High bureaucracy** (RED) efforts for farmers reduce willingness to grow certified bioenergy crops.

4.4.1.2 Arundo donax

Arundo donax is the main feedstock for BIOLYFE. The strengths, weaknesses, opportunities and threats for Arundo cultivation are defined in comparison to other agricultural crops that are common in Europe and can be used for energy purposes (wheat, sugar beet, rapeseed, etc.). The aim of the analysis is to identify success and failure factors and help farmers and biorefining companies to decide on suitable feedstocks.

Tab. 4-17 SWOT analysis for Arundo donax as energy crop

Strengths	Weaknesses

• S1: Arundo is a **perennial crop**:
  • S1a: No seeding and tillage needed except in the first year.
  • S1b: Lowers erosion risk compared to cultivation of most annual crops.
• S2: **Arundo is a particular robust crop, suitable for low input cultivation and cultivation on low fertility soil**:
  • S2a: Does not require large amounts of fertilisers.
  • S2b: Low demand for pesticides and herbicides. High resistance against pest because of noxious chemicals in stems.
  • S2c: Resistant to stagnant moisture (but: with lower yields).
  • S2d: Tolerant to salinity, even marshlands (but: with lower yields).
  • S2e: Established plant is drought resistant.
  • S2f: Giant reed can survive low temperatures when dormant (i.e. in winter).
• S3: Fast growing and **high yielding** (up to 40 t dm / ha) → efficient land use; high return of energy per invested energy unit.
• S4: **Flexible harvesting time** → less storage capacities needed (but: harvesting time affects yields and biomass properties).
• S5: **Existing harvesting technologies** can be used with minor adaptations.
	• W1: Arundo is a **perennial crop:**
	  • W1a: Binds the farmer for many years to his decision.
	  • W1b: Low yields in the first 2 years → other material has to be used as additional feedstock.
	• W2: Arundo is a **new cultivar → lack of knowledge and experience**
	  • W2a: **Few if any commercially available cultivars.**
	  • W2b: **Necessary nutrient input not yet well researched**. In US, fertilisation comparable to maize silage is recommended.
	  • W2c: **Farmers lack knowledge and experience** in Arundo production for energy.
	  • W2d: **Large scale cultivation of Arundo does not exist at the moment** → lack of knowledge.
	  • W2e: **Few production cost data available** because Arundo is a new crop.
	  • W2f: **Lack of knowledge on Arundo genome** → has to be studied first before breeding strategies can be developed.
	• W3: Freshly harvested Arundo b**iomass has some weak properties:**
	  • W3a: moisture at harvesting time too high for storage→ **drying needed.**
	  • W3b: Arundo donax biomass has **high ash and chlorine content**.
	• W4: **Risks for environmental sustainability**
	  • W4a: Arundo is **invasive to natural ecosystems** by dispersal from agricultural fields.
	  • W4b: Arundo is suspected **to alter hydrological regimes** in semi-arid areas because of high transpiration.

Tab. 4-17 (continued) SWOT analysis for Arundo donax as energy crop

	Weaknesses

	• W5: **Difficulties in cultivation**
	  ◦ W5a: **Sensitive to frost damage after the start of spring growth** (while still a seedling).
	  ◦ W5b: Arundo can become a **weed in following crops** that is very hard to remove.
	• W6: High expenditure for planting: Large amount of rhizomes or nodes needed (about 20 000) with partly high costs (literature values: up to 1 € per rhizome?).
	• W7: Sterile plant → lack of sexual reproduction – low genetic variability and genetic improvement more difficult.

Opportunities	**Threats**

• O1: **High gross margins** for farmers because of high yields and low expenditures.
• O2: **Development of new varieties and agricultural practices**
  ◦ O2a: to overcome the agricultural weaknesses, in particular invasiveness and high water demand.
  ◦ O2b: Development of management practices to overcome the risk of invasiveness. (e.g.: Ploughing for a distance of 3 m once a year)
  ◦ O2c: Development of propagation techniques / seeding techniques that lower costs
• O3: High ability to remove pollutants from water and soil → can be used for **phytoremediation** purposes. A. donax is a plant only slightly affected by the presence of metals (such as cadmium, nickel, arsenic and lead) in the rhizosphere. (BUT: suitability of biomass with higher salt content for ethanol production not demonstrated).
	• T1: **Low acceptance because Arundo donax is known as invasive** in some regions. Arundo has bad reputation amongst farmers as being a weed.
	• T2: **New pests** may occur if Arundo donax is cultivated in large scale.

4.4.2 SWOT analysis of the BIOLYFE biomass conversion process

Tab. 4-18 SWOT analysis for the biomass conversion in a BIOLYFE 2nd generation bio-ethanol plant and the use of bioethanol as fuel

Strengths

General aspects

- S1: Contributes to independence from fossil fuels (energy security).
- S2: **Technology for 2nd generation bioethanol in general is advanced and ready to be implemented** on industrial scale, pilot plants exist.
- S3: Biomass based fuels are **politically supported** by EC (RED → creating high demand).
- S4: Second generation ethanol from lignocellulose (which is not digestible for humans) is **not directly competitive to food** → higher acceptance.
- S5: The bioethanol plant is **relatively flexible** in respect to the feedstock.
- S6: For fermentation, **biomass does not have to be dry** as it is for thermochemical conversion or combustion → suitable for biomass with higher moisture content at harvest.
- S7: **Lower hazard risk compared to thermochemical conversion** because no high temperature and pressure processes are involved.
- S8: The technologies for the production of second generation bioethanol **could be adapted to alternative processes more easily** than gasification and anaerobic digestion that pose constraints in terms of gas cleaning and upgrading before utilisation.
- S9: **Numerous processes for the conversion of the C5 and C6 sugars into value added chemicals are already available**. This facilitates a flexible utilisation of the plant, not only for the production of second generation bioethanol but also for numerous chemicals, thus facing any market oscillation.

Pre-treatment and viscosity reduction

- S10: The pre-treatment method used **(w/o acids)** allows cheaper construction.
- S11: **Low concentration of inhibitors** in Biochemtex two-step steam explosion process.
- S12: **High viscosity reduction** in continuous mode processing could be achieved.

Weaknesses

General aspects

- W1: **Insecurity of feedstock supply**: limited availability of sustainably extractable agricultural residues (straw) and sustainably cultivated energy crops (Arundo, sorghum) in Europe. Other ligno-cellulosic biorefinery concepts compete for the same biomass (i.e. thermochemical biorefineries, biogas production).
- W2: At the current stage of technological development, lignocellulose ethanol production is considered to be **economic only at large-scale industrial facilities** → risk of insufficient or unsustainable feedstock supply.
- W3: **High investment costs** provide a barrier for the implementation of further commercial lignocellulose ethanol plants.
- W4: Use of **GMO** yeasts: Security requirements, residue treatment needed.

Pre-treatment and viscosity reduction

- W5: **Mild pre-treatment conditions** lower the sugar yield after enzymatic hydrolysis.

SSF process

- W6: **Still high costs for enzymes**, even though remarkable cost savings and efficiency increase could be achieved by using CTec3 instead of conventional cellulases.

Solid-liquid separation, distillation & dehydration

- W7: **Product separation is energy intensive** → lowers economic and environmental performance.

Side streams and process integration

Final product, use and distribution

- W8: E85 **not suitable for all types of engines**.
- W9: **Infrastructure and flex-fuel-fleet not yet well developed in Italy**.

Tab. 4-18 (continued) SWOT analysis for the biomass conversion in a BIOLYFE 2nd generation bioethanol plant and the use of bioethanol as fuel

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Strengths

SSF process

- S13: **Simultaneous fermentation** of C5 and C6 sugars by one GMO yeast strain → high efficiency.
- S14: **High conversion efficiency:** A big part of the feedstock (both C6 and C5 sugars) can be converted into ethanol.

Solid-liquid separation, distillation & dehydration

- S15: Process can run at **high dry matter contents** in SSF, giving lower separation costs.

Side streams and process integration

- S16: Lignin use for **green electric power generation → additional earnings**.

Final product, distribution and use

- S17 E**thanol** can be used as replacement for gasoline in most car engines.

Final product, distribution and use

- S18: Ethanol can also be **used for chemical industry** (e.g. as basis for ethylene production with a potential large market in the polymer industry.
- S19: **Infrastructure for distribution of low blend ethanol is easily implemented** in existing infrastructure. There are good examples for the successful development of a complete infrastructure for bioethanol blends (e.g.: E85 in Sweden).
- S20: **Lower greenhouse gas emissions and lower primary energy demand compared to fossil gasoline** (At least for Arundo and wheat straw as feedstocks).

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Opportunities

Social, legal, political and economic opportunities

- O1: Biomass based products are considered particularly environmental friendly by some → eventually willingness to pay **bio-based premium**.
- O2: **Growing market** for all kinds of alternative fuels, including bioethanol, expected as a result of decreasing petroleum reserves / increased cost of production of these fuels and increasing worldwide demand for fuels. Flex-fuel care might become more common and hence the market for ethanol as fuel in Europe may increase.
- O3: **Funding is available** for research and development for lignocellulose ethanol plants in Europe.
- O4: Acceptance could be increased by establishing **sustainability certification schemes**.

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Threats

Social, legal, political and economic threats

- T1: **Uncertain development of oil price** and hence of biofuel prices.
- T2: **Low acceptance of bioethanol**
  - T2a: by some car drivers because they fear damage to the engine.
  - T2b: by some car drivers because of food vs. fuel issues.
  - T2c: Low acceptance of the use of genetic engineering to improve the performance of microorganisms (yeasts, bacteria for enzyme production).
  - T2d: acceptance can be negatively influenced by competing interest groups (e.g. some car manufactures, NGOs because of fears for the environment).

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Tab. 4-18 (continued) SWOT analysis for the biomass conversion in a BIOLYFE 2nd generation bioethanol plant and the use of bioethanol as fuel

Opportunities	Threats
• O5: 2nd generation bioethanol plants can contribute to **rural development** by creation of jobs, income and added value in rural areas. **Technical opportunities** • O6: **Advances in biotechnology** (enzymes as well as yeast) may increase the yield in the future. • O7: All **process energy** could be produced internally if CHP is used. • O8: The production of second generation bioethanol can be **coupled with the production of additional chemicals** such as furans and phenols (biorefinery), thus making the plants much more profitable. In particular processing of lignin to high value added products may increase economic performance. • O9: Development and propagation of **combined production of fuels and feed** (e.g.: 1st generation ethanol provides a protein rich feed as by-product). • O10: Integration of 1st and 2nd generation bioethanol possible and maybe economically advantageous. • O11: 2nd generation ethanol production is technically feasible for **decentralised processing**. Technological development might make 2nd generation ethanol process also economic at smaller scale and hence lower the risk of a too high and unsustainable regional biomass withdrawal. • O12: Development of technologies and processes suitable for a wide range of feedstocks: This will enable **multifeedstock processing,** thus reducing the risk of feedstock scarcity.	• T3: The **economic crisis in Europe** may cause difficulties to acquire the capital needed to establish large-scale lignocellulose ethanol plants. • T4: Biofuels are **competing with alternative energy sources for mobility** (electromobility etc.). • T5: **Infrastructure for ethanol fuels (e.g. E85) not a high priority** on the European level in comparison to other alternative fuels, such as natural gas. • T6: Some car companies (e.g. Volkswagen) do not give **guarantees** for use of biofuels. **Technical threats** • T7: The industrial plant may show a **weaker performance than the models predicted**.

4.4.3 Social implications of BIOLYFE biorefining systems

The following table (Tab. 4-19) shows the main outcomes of a “hot spot” analysis for BIOLYFE biorefineries in Europe based on the sLCA stakeholder categories and the related indictor-subcategories.

The table clearly shows that most indicators are either of low relevance for EU27 because of the legal and political situation (e.g.: child labour or forced labour has a very rare occurrence in the EU) or depend on the management of the specific company and hence cannot be assessed for the BIOLYFE concept as such. In the following, the evaluation is shortly explained.

Workers

Workers are the employees of BIOLYFE biorefineries. The geographical frame for BIOLYFE sustainability assessment is the European Union. Hence, the EU legal and political situation applies. It can be assumed that BIOLYFE biorefineries comply with EU law. Because of the legal framework, severe violations of human rights and labour rights such as child labour and forced labour are not relevant any more in the European Union. All other indicators depend on management of the specific plant; there is no specific risk of the technology for low indicator values.

Consumers

Consumers are the buyers and users of E85 made of BIOLYFE 2nd generation ethanol. End-of-life indicators are not relevant for consumptive goods as fuels. Feedback, privacy and transparency depend on the management and are not specifically influenced by technology used in this context. Transparency could be considered higher compared to fossil fuels because of the regional supply chain, but regionality alone is not sufficient to achieve transparency.

Local community

In this category, the farmers supplying the biomass are included. This stakeholder category is most strongly affected by the installation of a BIOLYFE biorefinery. Both positive and negative impacts were identified. Increased income opportunities and access to education and highly qualified jobs on the positive side. On the negative side, a change in landscape and an increased land scarcity are to mention. Changes in landscape might also be evaluated positive by the some local stakeholders and do most likely not lead to severe social impacts. But land scarcity can in the worst case lead to severe human rights violations. Land scarcity could induce indirect land use changes. Land use change can even lead to delocalisation and violation of indigenous rights by putting traditional informal land rights under pressure. Delocalisation and migration as well as violation of indigenous rights are in most cases linked with severe negative impacts on the people's welfare.

Society

The society as such profits from BIOLYFE plants, because the BIOLYFE concept contributes to innovation, a shift to a green economy and added value generation.

Value chain actors

In this category, competing companies, customer companies and suppliers except farmers were summarised. No specific social hot spots were identified.

Summary

The "hot spot" analysis shows that the BIOLYFE concept offers social advantages for the society by contributing to economic and technological development and a shift to a green economy, but that some risks for the local community and the biomass suppliers have to be considered. To avoid harms to farmers and local populations, avoidance of indirect land use change is of high importance. As personal preferences highly influence the social relevance of different indicators and impacts, community engagement and thereby the integration of the personal value choices of the affected people is an indispensable prerequisite for a final assessment on social impacts beyond basic human rights.

Tab. 4-19 Qualitative assessment of selected sLCA indicators in BIOLYFE. Indicators shaded in green: BIOLYFE has a positive impact. Indicators shaded in red: BIOLYFE has a direct negative impact. Indicators shaded in orange: relevant risk of indirect negative impacts.

Stakeholder category	Sub categories	BIOLYFE Assessment
Worker	Freedom of Association and collective bargaining	Depend on management, no specific effects
	Child Labour	Not relevant in EU27
	Fair salary	Depend on management, no specific effects
	Working hours	Depend on management, no specific effects
	Forced labour	Not relevant in EU27
	Equal opportunities / discrimination	Depend on management, no specific effects
	health and safety	Depend on management, no specific effects
	Social benefits / social security	Depend on management, no specific effects
Consumer	Health and safety	No remarkable differences to fossil reference
	Feedback mechanism	Depend on management, no specific effects
	Consumer Privacy	Depend on management, no specific effects
	Transparency	Depend on management, ev. higher compared to fossil fuels because of local supply chain
	End of life responsibility	Not relevant for fuels
Local community	Access to material resources	Increased land scarcity
	Access to immaterial resources	Creation of highly qualified jobs increases access to education
	Delocalisation and Migration	Might occur in developing countries in case of indirect land use changes
	Cultural Heritage	Change in landscape by changing cultivation patterns
	Safe & healthy living conditions	Depend on construction side, only general effects of industrial sides
	Respect of indigenous rights	Negative impacts may occur in case of indirect land use change effects
	Community engagement	Depend on management, but high importance for acceptance
	Local employment	Income opportunity for farmers and jobs in rural areas
	Secure living conditions	No relevant direct impact
Society	Public commitments to sustainability issues	Biofuel companies support shift to a green economy
	Contribution to economic development	Biofuel companies create added value
	Prevention & mitigation of armed conflicts	Not relevant in EU27
	Technology development	Biofuel companies contribute to development of new technologies
	Corruption	Depend on management, no specific effects
Value chain actors	Fair competition	Depend on management, no specific effects
	Promoting social responsibility	Depend on management, no specific effects
	Supplier relationships	Depend on management, but high importance for acceptance
	Respect of intellectual property rights	Depend on management, no specific effects

4.4.4 Biomass competition issues

The availability of a sufficient amount of sustainably produced biomass is a key issue for successful 2nd generation bioethanol production. Therefore, the issue of biomass competition was analysed separately to complement the outcomes of SWOT analysis, economic assessment and environmental assessment. Main findings are summarised in the following.

The land availability for bioenergy crop production in Europe was calculated several times, coming to estimates of between 20 and 30 Mha (Tab. 4-20). 20 Mha would be enough to feed the remarkable amount of more than 2500 BIOLYFE plants (calculated with an average biomass yields of 20 t DM per ha). According to /Fischer et al. 2010/, this amount could be set free even under consideration of high environmental standards. The ethanol producible in these plants would equal about 74 Mtoe.

Nevertheless, it has to be considered that biomass transport over long distances is costly, and hence bioethanol plants will be built most likely in regions with high local biomass potential. Within these regions, the demand for additional biomass can increase land scarcity for other uses (food crops, nature protection or recreation).

Tab. 4-20 Summary of estimated land availability for growing bioenergy feedstocks in Europe by 2030 (Note: Figures from Fischer et al. are without Ukraine)
Source: /Kretschmer et al. 2013/

SUMMARY	Estimated land availability for bioenergy crops by 2030	Additional land from pastures etc.
/EEA 2006/ EU22	19.3 Mha	5.9 Mha
/Fischer et al. 2010/ Base scenario, EU27 + Switzerland & Norway	30.5 Mha	----
/Fischer et al. 2010/ Environment scenario, EU27+ Switzerland & Norway	20.4 Mha	----
/Fischer et al. 2010/ Energy scenario, EU27 + Switzerland & Norway	30.5 Mha	15 Mha
/Krasuska et al. 2010/ EU27	26.3 Mha	-----

Furthermore, the figures calculated above do not consider the global arable land demand. According to /Bringezu et al. 2012/ the Europeans require 0.31 ha of the world's cropland per capita for their overall consumption of agricultural goods. In global average, 0.23 ha of land is cultivated per capita. A remarkable extension of cropland on a global scale is not likely. Even though there are some areas suitable for agriculture but currently not in use, the increasing soil sealing and soil degradation put pressure on cropland resources. /Bringezu et al. 2012/

estimates the cropland availability in 2030 of 0.2 ha per capita. The current EU consumption of about 0.31 ha per capita clearly exceeds the globally available cropland for each world citizen. Therefore, using land in Europe for bioenergy can have negative indirect effects on food availability in developing countries by increasing land scarcity on a global scale.

4.5 Integrated assessment

The integrated assessment of sustainability is a structured way of comparing several sustainability aspects into a holistic picture with the aim to provide decision support to politicians and stakeholders. The integrated assessment of sustainability consists of the following steps:

- Selection of relevant scenarios and indicators from individual assessments (chapter 4.5.1)
- If applicable, addition of suitable conflict mitigation indicators such as CO_2-avoidance costs (chapter 4.5.2)
- Comparisons to suitable benchmarks (chapter 4.5.3)
- Overall comparison and discussion of results (chapter 4.5.4)

4.5.1 Overview of scenarios and indicators

The overall sustainability assessment covers what is often termed the three pillars of sustainability: Environment, economy and society. Furthermore, several technological aspects are included as a separate category because they can have significant impacts on the overall sustainability but are not covered in other categories. Indicators for all aspects of sustainability are taken from the individual assessments in chapter 4.1 to 4.4. The categories society and technology are not analysed in a dedicated assessment in this project. Therefore, those aspects were covered by the SWOT analysis.

Several indicators were chosen for each of the categories / pillars of sustainability (Fig. 4-23). Quantitative environmental and economic indicators originate from screening LCA (chapter 4.1) and economic assessment (chapter 4.2). The economic indicator “production costs” was additionally expressed in form of the comparative indicator “cost difference compared to gasoline” based on an oil price of 70 $ / barrel to reflect the concept of life cycle comparisons. Furthermore, this variant of the indicator is needed for the calculation of avoidance costs (see also chapter 4.5.2). As the oil price and other developments influencing the gasoline price cannot be predicted for 2020, this comparative indicator is of much lower certainty than the original “production costs” indicator. Thus, it can serve as a rough guideline when interpreted carefully, e.g. in a political context, but not as a basis for economic decisions.

	Indicator	Unit	Arundo	Fibre sorghum	Wheat straw	Biopolymers (Arundo)	High enzyme demand (Arundo)	Low enzyme demand (Arundo)	Low fertility soil (Arundo)	BTL 1 (Arundo)	Wheat ethanol	Beet ethanol	Corn ethanol (US)	Cane ethanol (Brazil)	Rape seed biodiesel	Maize biomethane
			Standard conditions							Standard conditions						
			BIOLYFE scenarios							Alternatives to BIOLYFE						
Technology	Maturity	-	- -	-	-	- -	- -	- -	- -	- -	0	0	0	0	0	0
Technology	Availability of infrastructure	-	- -	- -	-	- -	- -	- -	- -	- -	0	0	0	0	0	0
Technology	Use of GMOs	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0
Technology	Toxicity risks	-	+	0	+	+	+	+	+	0	0	0	0	+	0	0
Technology	Risk of explosions and fires	-	0	0	0	0	0	0	0	0	+	+	+	+	+	+
Environment	Resource depletion: energy	GJ / t ethanol (eq.)	-21	-8	-22	-28	-18	-23	-21	-25	-34	-14	-14	-34	-39	-34
Environment	Climate change	t CO_2 eq. / t ethanol (eq.)	-1.3	-0.2	-1.3	-1.6	-1.1	-1.3	-1.2	-1.6	-2.1	-1.2	-0.7	-2.7	-1.9	-1.2
Environment	Acidification	kg SO_2 eq. / t ethanol (eq.)	9	17	8	9	10	8	9	5	3	0	9	12	12	15
Environment	Terrestrial eutrophication	kg PO_4 eq. / t ethanol (eq.)	1.0	2.2	0.9	1.0	1.1	1.0	1.0	0.9	0.9	0.2	1.6	1.5	2.7	2.6
Environment	Aquatic eutrophication	kg PO_4 eq. / t ethanol (eq.)	2.1	7.6	3.2	2.0	2.2	2.1	2.0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Environment	Photochem. ozone formation	kg ethene eq. / t ethanol (eq.)	-1.1	-1.0	-1.2	-1.0	-1.1	-1.1	-1.1	-0.9	-1.6	-1.2	-1.3	-0.3	-0.2	-0.7
Environment	Ozone depletion	g CFC-11 eq. / t ethanol (eq.)	28	52	28	29	29	28	28	13	12	-7	33	16	52	37
Environment	Respiratory inorganics	kg PM10 eq. / t ethanol (eq.)	6	12	5	6	7	6	6	2	0	0	4	11	5	7
Environment	Direct agricultural land use	ha·a / t ethanol (eq.)	0.15	0.20	0.00	0.15	0.15	0.15	0.23	0.20	0.66	0.16	0.49	0.24	0.94	0.33
Environment	Water	-	- -	-	0	- -	- -	- -	-	- -	0	-	-	-	-	-
Environment	Soil	-	0	-	0	0	0	0	- -	0	-	- -	- -	0	- -	- -
Environment	Fauna	-	0	-	0	0	0	0	- -	0	-	-	-	-	-	-
Environment	Flora	-	-	-	0	-	-	-	- -	-	-	- -	- -	-	-	- -
Environment	Landscape	-	0	0	0	-	-	-	0	0	0	0	0	-	0	0
Economy	Production costs	€ / t ethanol (eq.)	485	602	474	485	537	459	485	900	850	670	690	470	860	940
Economy	Cost difference to gasoline*	€ / t ethanol (eq.)	-115	-232	-104	N/A	-167	-89	-115	-530	-480	-300	-320	-100	-490	-570
Economy	Fixed capital investment	Million €	89	103	88	89	89	89	89	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Society	Local community and farmers															
Society	Access to land	-	- -	- -	0	- -	- -	- -	-	- -	- -	- -	- -	- -	- -	- -
Society	Access to jobs & income	-	+	+	++	+	+	+	++	+	+	+	+	0	+	+
Society	Acceptance	-	- -	+	++	- -	- -	- -	++	- -	+	+	+	+	+	+
Society	General society															
Society	Acceptance	-	-	- -	-	-	-	-	-	-	- -	- -	- -	- -	- -	- -
Society	Contribution to innovation	-	++	+	+	++	++	++	++	++	0	0	0	0	0	0

Fig. 4-23 Overview of all indicators from the assessments of individual aspects of sustainability under standard conditions. Relative quantities are expressed per tonne of ethanol or equivalent amount of fuel (t ethanol eq., based on distance driven in a car). Quantitative indicators were categorised like the qualitative indicators where possible (advantageous: green, neutral: yellow, disadvantageous: red), for categorisation of land use, see text. N/D: no data. *: Cost differences to gasoline are based on an oil price of 70 $ / barrel. Data on bandwidths of BIOLYFE scenarios and further BTL data can be found in chapter 8.9 in the annex.

The multitude of qualitative indicators resulting from the LC-EIA (chapter 4.2) was aggregated into five indicators reflecting the affected environmental factors. In a similar approach, important aspects from the SWOT analysis were introduced as indicators for the categories society and technology. The criteria for the selection of all qualitative indicators were the coverage of aspects that

- show significantly different results between the assessed scenarios and
- are relevant for decisions.

After selecting suitable indicators, data was collected from all individual assessments (Fig. 4-23).

Quantitative indicators were categorised to support a subsequent overall comparison. However, this is only possible for comparative indicators (like “cost difference to gasoline”) but not for absolute indicators (like “production costs”) without the introduction of further benchmarks. Deviating from the general pattern, the use of land with low fertility soil was categorised differently from the use of other agricultural land because of an additional qualitative difference.

4.5.2 Additional conflict mitigation indicators

In some cases, there are conflicts between different goals and thus between indicator results reflecting these goals. For example, most biofuel scenarios lead to a mitigation of climate change but to higher costs compared to the use of fossil fuels. If the respective indicators are quantitative, it is possible to state how big these conflicts are. That way, additional conflict mitigation indicators such as “CO_2 avoidance costs” can be defined to support a management of these conflicts (Fig. 4-24, see also chapter 2.5.2). Besides the well-known indicator “CO_2 avoidance costs”, similar indicators can be defined for other conflicts such as “energy resource savings costs”.

Several limitations have to be taken into account regarding the applicability of such indicators. First, they express how efficiently a certain goal can be reached by accepting potentially worse results regarding a different goal. Thus, avoidance costs are not defined if there is no avoidance. For example, BIOLYFE bioethanol from fibre sorghum does not achieve a mitigation of climate change under standard conditions. Therefore, this goal cannot be reached no matter how much the production of BIOLYFE bioethanol from fibre sorghum would be supported economically or politically (without changing the conditions and thus the scenario). Second, avoidance costs are not robust if avoided burdens are close to zero. In that case, avoidance costs tend towards infinity and are very sensitive to changes within the range of the given uncertainty. In those cases, avoidance costs are not given in the overview tables (N/A). This also applies to energy savings costs for fibre sorghum under less favourable conditions (see chapter 8.9 in the annex).

	Indicator	Unit	Arundo	Fibre sorghum	Wheat straw	Biopolymers (Arundo)	High enzyme demand (Arundo)	Low enzyme demand (Arundo)	Low fertility soil (Arundo)	BTL 1 (Arundo)	Wheat ethanol	Beet ethanol	Corn ethanol (US)	Cane ethanol (Brazil)	Rape seed biodiesel	Maize biomethane
			Standard conditions: BIOLYFE scenarios							Standard conditions: Alternatives to BIOLYFE						
Environment	Resource depletion: energy	GJ / t ethanol (eq.)	-21	-8	-22	-28	-18	-23	-21	-25	-34	-14	-14	-34	-39	-34
Environment	Climate change	t CO_2 eq. / t ethanol (eq.)	-1.3	-0.2	-1.3	-1.6	-1.1	-1.3	-1.2	-1.6	-2.1	-1.2	-0.7	-2.7	-1.9	-1.2
Environment	Acidification	kg SO_2 eq. / t ethanol (eq.)	9	17	8	9	10	8	9	5	3	0	9	12	12	15
Environment	Terrestrial eutrophication	kg PO_4 eq. / t ethanol (eq.)	1.0	2.2	0.9	1.0	1.1	1.0	1.0	0.9	0.9	0.2	1.6	1.5	2.7	2.6
Environment	Aquatic eutrophication	kg PO_4 eq. / t ethanol (eq.)	2.1	7.6	3.2	2.0	2.2	2.1	2.0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Environment	Photochem. ozone formation	kg ethene eq. / t ethanol (eq.)	-1.1	-1.0	-1.2	-1.0	-1.1	-1.1	-1.1	-0.9	-1.6	-1.2	-1.3	-0.3	-0.2	-0.7
Environment	Ozone depletion	g CFC-11 eq. / t ethanol (eq.)	28	52	28	29	29	28	28	13	12	-7	33	16	52	37
Environment	Respiratory inorganics	kg PM10 eq. / t ethanol (eq.)	6	12	5	6	7	6	6	2	0	0	4	11	5	7
Economy	Production costs	€ / t ethanol (eq.)	485	602	474	485	537	459	485	900	850	670	690	470	860	940
Economy	Cost difference to gasoline*	€ / t ethanol (eq.)	-115	-232	-104	N/A	-167	-89	-115	-530	-480	-300	-320	-100	-490	-570
Economy	CO_2 avoidance costs	€ / t CO_2 eq.	91	N/A	81	N/A	151	67	93	323	224	250	450	38	263	456
Economy	Energy resource savings costs	€ / GJ	5	27	5	N/A	9	4	6	21	14	22	22	3	12	17

Fig. 4-24 Indicator table supplemented by the conflict mitigation indicators CO_2 avoidance costs and energy resource savings costs. t ethanol eq.: amount of fuel equivalent to 1 t ethanol based on distance driven in a car); N/A: not applicable (no savings); N/D: no data; *: cost differences to gasoline are based on an oil price of 70 $ / barrel. Data on bandwidths of BIOLYFE scenarios and further BTL data can be found in chapter 8.9 in the annex.

4.5.3 Benchmarking

In theory, that scenario is best, which is clearly better than all other scenarios in all indicators under all conditions. However, such a scenario does not exist for the provision of transportation fuels. Thus, each candidate scenario for the provision of a sustainable fuel has some disadvantages compared to several alternatives. These conflicts are important to know for decision makers but not immediately available from the extended results table in Fig. 4-24. For this purpose, candidate scenarios are compared to all other scenarios in a benchmarking process. In this process, suitable benchmarks (candidate scenarios) and a comparison metric is identified. This metric should provide information on:

- whether a scenario is better or worse than the benchmark regarding a certain indicator
- whether this holds true under favourable or less favourable conditions, too
- whether the differences are robust.

The metric is described in detail in chapter 2.5.3. It provides the following results from very advantageous (++) to very disadvantageous (--) compared to the benchmark. As the reference always is a biofuel, which was selected as benchmark, the rating does not state whether advantages compared to fossil fuels occur. For example, a (-) for corn ethanol compared to Arundo ethanol in Fig. 4-26 means that corn ethanol is worse than Arundo ethanol regarding the achieved mitigation of climate change (per tonne of ethanol), although both achieve considerable mitigations compared to gasoline.

Benchmark: Arundo 2.5 % threshold, Product basis		**BIOLYFE scenarios**							**Alternatives to BIOLYFE**						
	Indicator	**Arundo**	Fibre sorghum	Wheat straw	Biopolymers (Arundo)	High enzyme demand (Arundo)	Low enzyme demand (Arundo)	Low fertility soil (Arundo)	BTL 1 (Arundo)	Wheat ethanol	Beet ethanol	Corn ethanol (US)	Cane ethanol (Brazil)	Rape seed biodiesel	Maize biomethane
Technology	Maturity		++	++	0	0	0	0	0	++	++	++	++	++	++
	Availability of infrastructure		0	++	0	0	0	0	0	++	++	++	++	++	++
	Use of GMOs		0	0	0	0	0	0	++	++	++	++	++	++	++
	Toxicity risks		--	0	0	0	0	0	--	--	--	--	0	--	--
	Risk of explosions and fires		0	0	0	0	0	0	0	++	++	++	++	++	++
Environment	Resource depletion: energy		--	**0**	++	-	+	0	++	++	--	--	++	++	++
	Climate change		--	**0**	+	-	+	0	++	++	0	--	++	++	**0**
	Acidification		--	+	0	-	+	0	++	++	++	0	--	--	--
	Terrestrial eutrophication		--	+	+	0	0	0	++	+	++	--	--	--	--
	Aquatic eutrophication		--	--	0	0	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	Photochem. ozone formation		--	+	-	0	0	-	--	++	+	++	--	--	--
	Ozone depletion		--	0	0	0	0	0	++	++	++	--	++	--	--
	Respiratory inorganics		--	+	+	-	+	0	++	++	++	++	--	++	-
	Direct agricultural land use		-	++	0	0	0	N/A	-	--	0	--	--	--	--
	Water		++	++	0	0	0	++	0	++	++	++	++	++	++
	Soil		--	0	0	0	0	0	0	--	--	--	0	--	--
	Fauna		--	0	0	0	0	0	0	--	--	--	--	--	--
	Flora		0	++	0	0	0	0	0	0	--	--	0	0	--
	Landscape		0	0	0	0	0	0	0	0	0	0	-	0	0
Economy	Cost difference to gasoline		--	0	N/A	-	+	0	--	--	--	--	+	--	--
	Fixed capital investment		--	0	0	0	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	CO_2 avoidance costs		N/A	**0**	N/A	-	+	0	--	-	--	--	+	--	--
	Energy resource savings costs		N/A	0	N/A	-	+	0	--	--	--	--	+	-	--
Society	Local community and farmers														
	Access to land		0	++	0	0	0	++	0	0	0	0	0	0	0
	Access to jobs & income		0	++	0	0	0	0	0	0	0	0	--	0	0
	Acceptance		++	++	0	0	0	++	0	++	++	++	++	++	++
	General society														
	Acceptance		--	0	0	0	0	0	0	--	--	--	--	--	--
	Contribution to innovation		--	--	0	0	0	0	0	--	--	--	--	--	--

Fig. 4-25 Results of benchmarking process with the main BIOLYFE scenario (Arundo) as benchmark and a threshold of 2.5 %. The scenarios are compared on a product basis (per tonne of ethanol equivalent). N/A: some comparisons are not applicable (land use on low fertility soil is qualitatively different, costs for biopolymers cannot be compared to gasoline, avoidance costs are only defined in case of robust avoidances). N/D: no data available.

No difference (0) between two scenarios means for quantitative indicators that the difference is smaller than a certain percentage of the overall range of results among all scenarios. Depending on the question asked, different percentages are useful to determine the thresholds. Fig. 4-25 and Fig. 4-26 shows the benchmarking process for Arundo as a benchmark with a 2.5 % and 10 % threshold, respectively. The 2.5 % threshold can provide distinctions between similar scenarios such as variations of the Arundo scenario. For example, a reduction of greenhouse gas emissions of more than 2.5 % of the range of greenhouse gas emissions by any kind of biofuel is significant if it arises just from the reduction of the enzyme demand. In this case, all other conditions and causalities are identical and thus the uncertainty is low.

Benchmark: Arundo 10 % threshold, Product basis		**BIOLYFE scenarios**							**Alternatives to BIOLYFE**						
	Indicator	**Arundo**	Fibre sorghum	Wheat straw	Biopolymers (Arundo)	High enzyme demand (Arundo)	Low enzyme demand (Arundo)	Low fertility soil (Arundo)	BTL 1 (Arundo)	Wheat ethanol	Beet ethanol	Corn ethanol (US)	Cane ethanol (Brazil)	Rape seed biodiesel	Maize biomethane
Technology	Maturity		++	++	0	0	0	0	0	++	++	++	++	++	++
	Availability of infrastructure		0	++	0	0	0	0	0	++	++	++	++	++	++
	Use of GMOs		0	0	0	0	0	0	++	++	++	++	++	++	++
	Toxicity risks		- -	0	0	0	0	0	- -	- -	- -	- -	0	- -	- -
	Risk of explosions and fires		0	0	0	0	0	0	0	++	++	++	++	++	++
Environment	Resource depletion: energy		- -	0	+	0	0	0	+	++	-	-	++	++	++
	Climate change		- -	0	0	0	0	0	+	++	0	-	++	++	0
	Acidification		- -	0	0	0	0	0	++	++	++	0	-	-	- -
	Terrestrial eutrophication		- -	0	0	0	0	0	0	0	++	- -	- -	- -	- -
	Aquatic eutrophication		- -	- -	0	0	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	Photochem. ozone formation		0	0	0	0	0	0	-	++	0	+	- -	- -	- -
	Ozone depletion		- -	0	0	0	0	0	++	++	++	0	++	- -	-
	Respiratory inorganics		- -	0	0	0	0	0	++	++	++	++	- -	0	0
	Direct agricultural land use		0	++	0	0	0	N/A	0	- -	0	- -	0	- -	- -
	Water		++	++	0	0	0	++	0	++	++	++	++	++	++
	Soil		- -	0	0	0	0	0	0	- -	- -	- -	0	- -	- -
	Fauna		- -	0	0	0	0	0	0	- -	- -	- -	- -	- -	- -
	Flora		0	++	0	0	0	0	0	0	- -	- -	0	0	- -
	Landscape		0	0	0	0	0	0	0	0	0	0	-	0	0
Economy	Cost difference to gasoline		- -	0	N/A	0	0	0	- -	- -	- -	- -	0	- -	- -
	Fixed capital investment		- -	0	0	0	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	CO_2 avoidance costs		N/A	0	N/A	-	0	0	- -	-	-	- -	+	-	- -
	Energy resource savings costs		N/A	0	N/A	-	0	0	- -	-	- -	- -	0	-	- -
Society	Local community and farmers														
	Access to land		0	++	0	0	0	++	0	0	0	0	0	0	0
	Access to jobs & income		0	++	0	0	0	0	0	0	0	0	- -	0	0
	Acceptance		++	++	0	0	0	++	0	++	++	++	++	++	++
	General society														
	Acceptance		- -	0	0	0	0	0	0	- -	- -	- -	- -	- -	- -
	Contribution to innovation		- -	- -	0	0	0	0	0	- -	- -	- -	- -	- -	- -

Fig. 4-26 Results of benchmarking process with the main BIOLYFE scenario (Arundo) as benchmark and a threshold of 10 %. The scenarios are compared on a product basis (per tonne of ethanol equivalent). N/A, N/D: see Fig. 4-25.

A threshold of 10 % provides a more differentiated picture when comparing very different scenarios such as BIOLYFE bioethanol to 1st generation biofuels as in this case the uncertainties of the comparison are also higher. However, this threshold cannot reflect aspects of uncertainty arising from data quality issues. In this regard, all comparisons between biofuels regarding the impacts on aquatic eutrophication, photochemical ozone depletion and ozone formation have to be interpreted carefully. These impacts strongly depend on few input parameters, which are associated with a relatively high uncertainty.

The benchmarking procedure is independent of the reference unit of the comparison. It can be performed on a product basis (per tonne of ethanol equivalent) but also e.g. on an area basis (per hectare of occupied agricultural land).

4.5.4 Overall comparison

The overall comparison provides comprehensive and at the same time intuitive overview tables as a basis for a verbal argumentative discussion of all results of this sustainability assessment. In this chapter, the line of thoughts followed in chapter 5.1 (conclusions) is introduced without discussing all information provided by the comprehensive charts. A detailed discussion including distinct properties of individual scenarios and the conclusions and recommendations based on it can be found in detail in chapter 5.

The following generalising overall statements can be made without detailing exceptions and distinctions of individual scenarios at this point:

- BIOLYFE bioethanol and alternative biofuels show a similar pattern of global and regional environmental impacts (quantitative environmental indicators) as well as economic impacts (Fig. 4-23). In contrast, there are pronounced differences regarding technology.
- High savings of non-renewable energy resources, high mitigations of climate change and low production costs often correlate within groups of similar biofuels (e.g. within 1st generation bioethanols) because high greenhouse gas emissions and costs are associated with energy consumption. Furthermore, biofuel price differences to gasoline vary much more than greenhouse gas or energy savings. Thus, avoidance costs are dominated by differences in costs. Therefore, the indicators CO_2 avoidance costs and energy resource savings costs provide limited additional information compared to the indicator “cost differences to gasoline” (Fig. 4-24).
- Promising optimisation options for the PROESA® process can be clearly identified (Fig. 4-25, e.g. see “+” for “Low enzyme demand”).
- BIOLYFE bioethanol from wheat straw is advantageous or comparable to BIOLYFE bioethanol from Arundo regarding almost all indicators. For any other scenario, there are no clear preferences because advantages in some aspects are associated with pronounced disadvantages in other aspects.

Benchmark: Arundo 10 % threshold, Area basis	Indicator	BIOLYFE scen.: Arundo	BIOLYFE scen.: Fibre sorghum	Alternatives to BIOLYFE: BTL 1 (Arundo)	Alternatives to BIOLYFE: Wheat ethanol	Alternatives to BIOLYFE: Beet ethanol	Alternatives to BIOLYFE: Rape seed biodiesel	Alternatives to BIOLYFE: Maize biomethane
Technology	Maturity		++	0	++	++	++	++
	Availability of infrastructure		0	0	++	++	++	++
	Use of GMOs		0	++	++	++	++	++
	Toxicity risks		- -	- -	- -	- -	- -	- -
	Risk of explosions and fires		0	0	++	++	++	++
Environment	Resource depletion: energy		- -	0	- -	-	- -	-
	Climate change		- -	0	- -	0	- -	-
	Acidification		0	++	++	++	++	++
	Terrestrial eutrophication		0	++	++	++	++	0
	Aquatic eutrophication		- -	N/D	N/D	N/D	N/D	N/D
	Photochem. ozone formation		-	-	- -	0	- -	- -
	Ozone depletion		0	++	++	++	++	++
	Respiratory inorganics		0	++	++	++	++	++
	Direct agricultural land use		0	0	0	0	0	0
	Water		++	0	++	++	++	++
	Soil		- -	0	- -	- -	- -	- -
	Fauna		- -	0	- -	- -	- -	- -
	Flora		0	0	0	- -	0	- -
	Landscape		0	0	0	0	0	0
Economy	Cost difference to gasoline		0	- -	0	- -	+	- -
	Fixed capital investment		-	N/D	N/D	N/D	N/D	N/D
	CO_2 avoidance costs		N/A	- -	-	-	-	- -
	Energy resource savings costs		N/A	- -	-	- -	-	- -
Society	Local community and farmers							
	Access to land		0	0	0	0	0	0
	Access to jobs & income		0	0	0	0	0	0
	Acceptance		++	0	++	++	++	++
	General society							
	Acceptance		- -	0	- -	- -	- -	- -
	Contribution to innovation		- -	0	- -	- -	- -	- -

Fig. 4-27 Results of benchmarking process with the main BIOLYFE scenario (Arundo) as benchmark. Selected scenarios are compared on an area basis (per hectare of direct agricultural land use). N/A, N/D: see Fig. 4-25.

- A comparison of biofuels on a product basis (per tonne of ethanol equivalent) with Arundo bioethanol as a benchmark shows an especially important conflict: Pronounced global and regional environmental advantages (upper eight environmental indicators) of some 1st generation biofuels often come along with pronounced disadvantages regarding direct agricultural land use (Fig. 4-26). As the limiting factor for overall achievable environmental benefits is not the amount of fuel that can be used in the EU, but the area of land that is available for its production, a comparison on a product basis cannot provide answers to which biofuel is most sustainable.
- A comparison on an area basis of biofuels that require the use of additionally agricultural land provides insights on important advantages and disadvantages (Fig. 4-27). In case there is no wheat straw available for bioethanol production, Arundo bioethanol is a very good option regarding mitigation of climate change, savings of non-renewable energy and price difference to gasoline based on calculations by Biochemtex. Nevertheless, other biofuels are advantageous in other aspects, which makes any further decision dependent on value-based choices.

5 Conclusions and recommendations

The following chapter 5.1 merges the conclusions of all previous analyses based on a summary of the most important results into an overall assessment of the sustainability of BIOLYFE bioethanol. Specific recommendations for policy makers, researchers, companies and farmers based on these conclusions are given in chapter 5.2.

5.1 Conclusions

Background and objective

The provision of sustainably produced fuels from renewable resources is an important social goal and is also reflected in EU policy. Important objectives include reducing greenhouse gas emissions, reducing the dependency on fossil fuels and generating sources of income in rural areas. Biofuels currently on the market are predominantly produced from crops that can also be utilised as foodstuffs. Their life cycle greenhouse gas emissions are generally lower than those of fossil fuels are, but partially still substantial. Moreover, awareness is increasing that these fuels may be accompanied by some considerable drawbacks, because of both the competition with foodstuffs and the negative impacts on other environmental factors such as eutrophication and acidification.

Alternative biogenic fuels are therefore currently being developed to increase benefits and reduce drawbacks. A very promising option here is the conversion of lignocellulosic (woody and fibrous) biomass to bioethanol. A consortium formed for this purpose worked in a common project named BIOLYFE ("Second generation bioethanol process: demonstration scale for the step of lignocellulosic hydrolysis and fermentation"). The project developed technologies allowing an increased and economically viable utilisation of the lignocellulosic feedstock for the production of second generation bioethanol. In order to achieve this objective, the BIOLYFE project focuses on hydrolysis and fermentation steps. BIOLYFE started in January 2010 and lasted for 4 years. The project is co-funded by the European Commission in the 7th Framework Programme (Project No. FP7-239204). In the BIOLYFE framework was launched what is currently the world's largest lignocellulose-bioethanol facility in Crescentino, Italy.

An integrated sustainability assessment of the realisation of 2nd generation ethanol biorefineries in Europe in the period 2014-2020 is also performed as part of this project. It analyses whether a future, large-scale dissemination of the BIOLYFE 2nd generation ethanol process using mature technology provides benefits from environmental, economic and social perspectives compared to the use of existing biofuels or fossil fuels. This comprehensive analysis investigates scenarios[2], which model various possible future implementations of this

[2] This study does not make prognoses or predictions on the technological development but examines the effects of plausible developments depicted in scenarios supplemented by sensitivity analyses where critical variability exists.

technology and its whole life cycle integration, from the provision of raw materials to the energy utilisation of the bioethanol, and a variety of optimisation options.

Assessment approach

This study supplements established assessment methodologies such as the environmental life cycle assessment (LCA) and cost-benefit analysis from a business perspective by innovative approaches to cover and integrate all sustainability-related aspects of future BIOLYFE biorefineries. In respect to the environment, LCA methodology primarily covers global and regional impacts but is still under development regarding local and site-specific impacts. To still provide reliable decision support, it is extended by a new qualitative, life cycle based assessment of local aspects termed life cycle environmental impact assessment (LC-EIA), which uses methods originating from environmental impact assessment (EIA). Furthermore, a SWOT analysis (strengths, weaknesses, opportunities, threats) qualitatively examines all sustainability aspects not covered by environmental and economic assessment. Besides several particular aspects, the SWOT analysis focusses in this study on social impacts and competition about biomass. The used innovative approach for an integrated sustainability assessment includes harmonisation of settings for all individual assessments beforehand and a later joint evaluation of results using multi-dimensional comparison metrics and a structured transparent discussion. This way, the integrated sustainability assessments helps decision makers to manage complexity instead of hiding it. The application of this innovative assessment approach proved useful to provide balanced and specific recommendations. These relate not only to the bioethanol process itself but also to its integration into a whole life cycle and even to its potential role in a competitive future bio-economy taking into account risks of shifting burdens from one sustainability aspect to another.

BIOLYFE bioethanol: Some principal results

General results: In general terms, the pattern of benefits and drawbacks of BIOLYFE bioethanol follows that known of established biofuels. BIOLYFE bioethanol can contribute to environmental benefits in terms of climate change, saving non-renewable energy resources and photochemical ozone formation (summer smog). However, other negative environmental impacts such as acidification or nutrient input into ecosystems must be taken into account – like for first generation biofuels, too. Unlike European first generation biofuels, BIOLYFE bioethanol can be produced from perennial crops, which can be cultivated with relatively low local environmental impacts especially on soil and fauna. Land use competition may occur, in particular if cultivated biomass such as Arundo or other energy crops are used as a feedstock. In contrast to first generation biofuels, this risk can and should be minimised within the BIOLYFE supply chain by exploitation of agricultural residues (e.g. wheat straw) where feasible and combination of their use with possible dedicated crop cultivation – preferentially on idle (abandoned) land. According to Biochemtex calculations, from a market prospective, BIOLYFE bioethanol production costs are more competitive than first generation biofuels, and depending on oil price, they can even aim at competing with conventional fossil fuels. Thus, BIOLYFE bioethanol can also contribute to farmers' income and generate permanent jobs in both industry and agriculture.

BIOLYFE bioethanol presents an option for helping to achieve the sustainability goals of climate protection, energy security and promoting rural development. Advantages in these aspects can be seen in comparison to fossil fuels – as it is the case for many other biofuels. In many cases, nevertheless, BIOLYFE bioethanol can also show important advantages compared to other biofuels under certain conditions as discussed in the following paragraphs. Please note that quantitative results presented in those paragraphs are greatly influenced by the agreed methods used, boundary conditions and technology development depicted in the scenarios. Thus, comparisons are only valid within the same framework of setting, which are uniformly applied to all scenarios within this study.

Specific technological aspects: There are some important differences between BIOLYFE bioethanol and established bioethanol types in the specific characteristics of their impacts. First, there are obviously large differences in the adopted technology. 2nd generation biofuel technology is less tested to date and is associated with high capital costs. However, it does provide an innovation gain for society and is more readily accepted (currently at least) by society than traditional biofuels. This is, because agricultural residues such as straw can be used as feedstock, whereas 1st generation ethanol is based on cultivated crops, which can compete with food. Nevertheless, it is noteworthy to mention, that concerning innovation, this assessment is based on assumptions for full mature technology. In contrast, today the development is at the stage of an industrial demonstration plant. Therefore and because of the innovation gain and, secondly, because BIOLYFE bioethanol can help to achieve the sustainability goals of climate protection, energy security and promoting rural development specified above, this technology should continue to be tested on large scale and to be further optimised. The BIOLYFE bioethanol facility itself is characterised by being capable of energy self-sufficient operation utilising Arundo and wheat straw. Local environmental impacts due to its construction and operation do not differ significantly from those impacts of any industrial plant. However, enzymes that are relatively complex to produce must be purchased and barely any or no usable by-products result from the integrated concept.

The second general difference relates to feedstocks. Because feedstocks, which have not previously been used, or only on a relatively small scale, are employed in BIOLYFE bioethanol facilities, the infrastructure and logistics paths, including for storage, still need optimisation. Moreover, acceptance among farmers for cultivating innovative perennial cultures such as Arundo donax (giant reed) is still low and may require incentives such as coverage of risks to develop. However, perennials also provide benefits in terms of lower agricultural expenditures and lower local environmental impacts on soil and fauna. Additionally, these cultures generally yield more ethanol per hectare in combination with the applied BIOLYFE ethanol second generation technology than first generation biofuels.

Altogether, this means that there is a tendency for some remarkable benefits in terms of feedstock supply compared to most established biofuels, which contrasts on the other hand with conversion requiring higher expenditures.

Costs: The economic analysis by Biochemtex reveals that BIOLYFE bioethanol produced from wheat straw and Arundo can be cheaper in future than bioethanol produced from fibre sorghum and cheaper than most established biofuels of today. Nevertheless, lignocellulosic ethanol, similarly to other advanced biofuels, will depend on suitable framework policies steering instruments such as directives for a certain transition period.

Alternatives and risks: Compared to the production of alternative innovative biofuels such as certain types of BTL (biomass-to-liquid, via the Fischer-Tropsch process) from the same biomass, the BIOLYFE bioethanol process displays cost benefits. Depending on the BTL production process and its way of implementation, BIOLYFE bioethanol produced from Arundo and wheat straw can lead to substantially higher or substantially lower quantitative environmental impacts compared to estimation for the BTL route. It must be taken into account that today no BTL process from renewables has been developed at industrial demo scale like in the case of BIOLYFE. Thus, while lignocellulosic ethanol is assessed at industrial scale, all BTL routes are estimations and expectations, still to be confirmed at production scale similar to the Crescentino plant. Since the situation additionally varies from case to case, a conclusive evaluation on the environmental performance of BIOLYFE bioethanol relative to BTL cannot be made. In terms of technological risks, a mixed picture with numerous highly fuel-specific aspects emerges in a comparison of all analysed fuels. All the risks appear manageable, but must continue to be monitored and critically assessed.

Resource efficiency of BIOLYFE bioethanol and alternative biofuels

Biofuel production is primarily limited by the availability of biomass and agricultural land[3]. Additional important factors include the availability of investment capital and the price difference compared to fossil fuels. These latter factors can be influenced to a far greater extent by political decisions than the availability of biomass and agricultural land. This can be very easily observed using the example of non-renewable energy sources, the prices of which are maintained within a politically desirable range, partially by enormous subsidies or other policy steering instruments. Therefore, the total attainable effects are determined by the benefits per hectare of land used. The political decision of whether BIOLYFE bioethanol produced from Arundo or wheat straw should be preferred against established biofuels should thus be considered on the basis of agricultural land use.

Here, straw presents an enormous benefit, because it does not require any additional cultivation areas. BIOLYFE ethanol can lead to savings of about 5 GJ of non-renewable energy and 300 kg of greenhouse gases (GHG) for each tonne of straw under standard conditions. Additionally, the ethanol production costs from straw are comparable to those for Arundo, but no new cultivation methods are required. Therefore, wheat straw, where available under consideration of long-term soil fertility, should be the first choice as feedstock for BIOLYFE bioethanol. This also means that BIOLYFE bioethanol produced from straw should be preferred against established biofuels for these reasons. If it proves possible to cultivate Arundo on idle (abandoned) land – this is land where food cannot be economically cultivated – it basically does not compete with traditional cultures. With this, it is worth to mention, that depending on the local situation, this can cause further negative or positive local environmental effects such as destruction of successional vegetation with negative impacts on soil, fauna and flora or prevention of erosion with positive impacts. Therefore, agricultural practices should be applied and monitored to minimise the negative impacts and strengthen the positive ones.

[3]Although there are parts of the EU in which the area of idle (abandoned) agricultural land is increasing (e.g. Italy), the demand for agricultural land exceeds its availability in the EU in general, which is compensated for by product imports.

Alternatively, Arundo cultivation on existing managed farmland may be justifiable, because under suitable conditions land use efficiencies can be achieved that are greater than for the majority of established, first generation biofuels. Per hectare, Arundo-based BIOLYFE ethanol can typically save e.g. 140 GJ of non-renewable energy and 8 t of GHG, whereas wheat grain based ethanol accounts for roundabout 50 GJ and 3 t of GHG and rape seed biodiesel 40 GJ and 2 t GHG. At the same time, cultivation conditions for Arundo have a considerably lower impact on the soil. However, here it is essential to consider the respective local conditions, because among other things, the Arundo yield depends greatly on water availability. Thus, there is a certain danger of water mismanagement with regard to nature and the population in areas of low water availability unless cultivation practice is focussed on avoiding irrigation, as it is the case for the integrated agricultural strategy of Biochemtex for the 2nd generation bioethanol plant in Crescentino.

The integrated assessment shows that fibre sorghum presents limited benefits as a feedstock for ethanol production compared to other kinds of biomass, e.g. potentially regarding water use, and drawbacks in other aspects. Under less favourable conditions, bioethanol from fibre sorghum can even lead to higher greenhouse gas emissions than gasoline.

Optimisation options for BIOLYFE bioethanol facilities

In addition to the choice of feedstock used, optimisation of the BIOLYFE bioethanol process on the basis of the sustainability analysis performed here can primarily produce benefits from an environmental and economic perspective. It has been shown that in particular optimised enzyme efficiency promises great benefits. This can be provided by both improved enzyme performance (specific activity) under production conditions and more efficient enzyme production. For environmental and cost reasons this should be brought about by intensive optimisation work. Although BIOLYFE bioethanol production can provide the entire process energy needed from the by-products lignin and stillage concentrate, further energy efficiency optimisation provides benefits. Substantial additional reductions in environmental impacts can be achieved by exporting the surplus electricity.

The social effects and public acceptance of new bioethanol facilities depend less on technical processes than on communication with, and involvement of, both the local population and biomass suppliers. This should therefore be actively initiated by the facility operators. In addition, planning security plays an important role for both the facility operators and the farmers as feedstock suppliers. Because BIOLYFE bioethanol's economic competitiveness depends on the highly unpredictable price of crude oil, this planning security should be politically supported by flanking measures during phasing-in and in the optimisation phase, if the market establishment of bioethanol produced from lignocellulose is eventually defined as a social goal.

Conclusive evaluation and integration in the overall context

From an overall environmental perspective, the provision and utilisation of BIOLYFE bioethanol produced from wheat straw and, subordinately, Arundo, in particular from idle land, provides more benefits in some aspects, such as climate change, compared to the majority of established biofuels. In other aspects, it is comparable or associated with only minor drawbacks. Fibre sorghum presents only limited benefits as a feedstock for ethanol production compared to established biofuels and may come along with severe drawbacks. The economic analysis presented here reveals that BIOLYFE bioethanol produced from wheat straw and Arundo is also cheaper than bioethanol produced from fibre sorghum and more competitive compared to established biofuels in future. Similar to other biofuels, BIOLYFE bioethanol will depend on political support for a certain transition period.

In technological terms, further optimisation is still possible and necessary as the Crescentino plant is an industrial demonstration unit. This bioethanol facility, which uses the innovative PROESA® technology, represents a very important step in this direction. Its successful operation will open up opportunities for additional facility construction projects and logistic concepts and can induce positive societal effects in terms of innovations.

Regardless of advantages and further optimisation options, any future biofuel strategy must be integrated in a higher-level biomass and land use strategy. This is because biomass and land demand will probably also increase in the fields of bio-based materials, biogenic chemicals and bioenergy, which also aim at sustainability goals like environmental and employment benefits as well as energy independence. Considerably lower demand is neither envisaged with regard to the production of food and fodder.

If biofuels can be produced from by-products such as straw or from energy crops on idle (abandoned) land, they basically do not compete with foodstuffs or fodder. Whenever dedicated crops from currently managed land are considered, it is advisable to extend this study with additional land use studies specific for the respective geographical situation. Politically, it is required to establish a higher-level biomass and land use strategy to manage competition and local planning based on it in order to take the site-specific benefits and drawbacks of various energy crops into consideration.

BIOLYFE bioethanol has the potential to become an important element in a future bio-based economy, which could be sustainably implemented with the aid of European biomass and land use plans, for example.

5.2 Recommendations

The following recommendations were deduced from the conclusions taking into account all perspectives on sustainability. They are presented for each group of stakeholders.

Policy makers

Policy makers assume a particularly important role when framing future options and in conflict management. Because new technologies such as 2nd generation biorefineries will increase the demand for biomass, the competition between bio-based materials, chemicals, fuels and energy, as well as foodstuffs, fodder and nature conservation centred around biomass or land use represents one of our most important social challenges. This 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, whether greater water demand represents an environmental burden or not, or the quantity of agricultural 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 foodstuffs and fodder.
- Following an initial phase necessary to establish the technology, **support for biorefineries** should be oriented around the reductions in environmental impacts actually achieved.

As an additional measure independent of biomass and land use competition, we recommend:

- Before mature industrial facilities are established on a large scale a **regulatory framework**, which will ensure sustainable production, should be defined. It should comprise a sustainability analysis for each specifically planned large facility, which 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 of the biofuel according to the current European Renewable Energy Directive (RED) after the biorefinery started its operation could be integrated with an analysis about whether the limiting resources biomass and agricultural land are efficiently utilised (for example, a biofuel from residues may be more sustainable than a biofuel from dedicated crops even if greenhouse gas reduction percentages according to RED should indicate the contrary).

Companies

- **Biomass selection** for the bioethanol process should be based on sustainability criteria. Of the biomass types investigated here, wheat straw should be preferentially adopted, then Arundo produced on idle land and only subordinately Arundo produced on managed farmland. Fibre sorghum should be avoided as main feedstock because it does not reach the environmental and economic performance of Arundo or wheat straw – unless further research and development can change this picture.
- The extent to which bioethanol facilities can be designed to provide greater **flexibility** for processing a variety of lignocellulosic **raw materials** (e.g. further residues) needs to be investigated. A variety of different feedstock can then be exploited, which can ensure greater operational security, but also presents additional options for sustainable biomass provision through feedstock diversification.

- The bioethanol facility should be optimised as far as possible in terms of **energy efficiency**. The aim should at least be bioethanol production without purchasing additional electricity or fossil fuels. Otherwise, the results of the life cycle assessment may in part be substantially degraded.
- Companies have to actively **build up trust of society** and local communities. For this, it is necessary to deliver true, profound and transparent information and involve local communities in planning. An indispensable part will be the development of credible strategies to avoid negative impacts. In particular, sustainability criteria and strategies to achieve compliance have to be set up.

Farmers

- Before **shifting to perennial crops**, farmers shall make sure that a market is available in the long run. If possible, farmers shall start with small trials, and as soon as the production is proven successful, they shall try to get long term contracts.
- Farmers should not risk **long term fertility of soils** by extracting too much straw for short term income generation.
- Consider to found **cooperatives** or to become a member of existing ones to optimise the production chain such as facilitating logistics and storage.
- Farmers should **exchange knowledge** and experience with farmers from other regions, which already have more experience in growing bioenergy crops and cooperation with bioenergy companies.
- **Reduction of fertiliser demand**. Especially the use of nitrogen fertilisers to produce agricultural feedstocks generally contributes significantly to the results of life cycle assessments for biofuels. In contrast to the majority of other crops, a lower nitrogen content is a positive and not a negative quality criterion for lignocellulosic biomass. Appropriate optimisation of farming practices and breeding towards low nitrogen content in the harvested biomass as shown for Arundo in field trials can considerably improve the environmental impacts of bio-based products through reduction of fertiliser demand. Thus, efforts should be made to apply this new knowledge in practice wherever possible.

Need for research

There is a need for research and development on the following topics.

- **Recycling nutrients from fermentation residues:** The technical, environmental and economic utility and feasibility of producing biogas from fermentation residues should be examined. Compared to combustion of the fermentation residues, the nitrogen they contain would be retained in the biogas facility's fermentation residues, which could be used as fertiliser. This is only feasible assuming there is no accumulation of harmful substances in the fermentation residues. Considerable additional reductions in environmental impacts may be achieved in this way.
- **Efficient production processes: 'Enzymes'**. Because the production and conversion efficiency of enzymes significantly influence the results of the life cycle assessment, we recommend adopting both aspects as focal points for further development work.

- **Energy efficient production processes: 'purification'**. The purification of ethanol following the fermentation stage is one of the primary single processes determining the results of ethanol production and is therefore regarded as one of the most important focal points either for development and optimisation or for developing alternative treatment processes.
- **Reduction of nitrogen use in agriculture**. Especially the use of nitrogen fertilisers to produce agricultural feedstocks generally contributes significantly to the results of life cycle assessments for biofuels as highlighted in the recommendations to farmers. The optimisation of farming practices and breeding towards low nitrogen contents in the harvested biomass should be continued and extended.
- **Process integration of the whole biorefinery**. The handling of biomass should be further optimised in order to limit waste of resources and energy. This optimisation could also have an impact on the final yield of the whole process. Research on secondary stream and co-product optimisation is just at its starting point and should be better understood and exploited. Last but not least, the scale-up at pre-commercial scale could boost the technology to its complete exploitation potential.

6 Abbreviations and glossary

6.1 Abbreviations

1G / 2G	First generation / second generation
BIOLYFE	Acronym for the project "Second generation BIOethanol process: demonstration scale for the step of Lignocellulosic hY-drolysis and Fermentation"
BTL	Biomass to liquid, a type of synfuel
CAPEX	Capital Expenditure
CFC	Chlorofluorocarbon
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CHP	Combined heat and power plant; co-generation of electricity and heat (air, steam)
CO_2	Carbon dioxide
CO_2 equiv.	Carbon dioxide equivalents, standard unit to aggregate green-house gas emissions for the environmental impact category "climate change"
DCC	Direct Capital Costs
DM	Dry matter
EC	European Commission
EE	Electric energy
EG	Ethylene glycol
EIA	Environmental impact assessment
eLCA	Environmental life cycle assessment
EO	Ethylene oxide
ETE	Ethanol-to-ethylene process
EtOH	Ethanol
EU	European Union
FCI	Fixed Capital Investment
GBEP	Global Bioenergy Partnership
ge_ef	gallon_ethanol_equivalent_efficiency
GHG	Greenhouse gases

GHG em	Greenhouse gas emissions
GMO	Genetically modified organism
GRI	Global reporting initiative for corporate sustainability
GWP	Global warming potential
HCl	Hydrochloric acid
ICC	Indirect Capital Costs
IE	Inhabitant equivalent
ILCD	International Reference Life Cycle Data System
iLUC	Indirect land use change
LCA	Life cycle assessment
LC-EIA	Life cycle environmental impact assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LHV	Lower heating value
MTG	Methanol to gasoline processes
NH_3	Ammonia
N_2O	Nitrous oxide (= laughing gas)
NOx	Nitrogen oxides
OPEX	Operating Expenditure
OSBL	Outside battery limits
PE	Polyethylene
PROESA®	*Produzione di bioetanolo da biomassa lignocellulosica.* Process for bioethanol production from lignocellulosic biomass.
PVC	Poly(vinyl chloride)
RED	European Renewable Energy Directive /EP & CEU 2009b/
RSB	Roundtable on Sustainable Biomaterials
sLCA	Social life cycle assessment
SO_2	Sulphur dioxide
SOM	Soil organic matter
SScF	Simultaneous saccharification and co-fermentation
SWOT	Analysis of strengths, weaknesses, opportunities and threats
WP	Work package

6.2 Glossary

Annual crops	Feedstock plants surviving one vegetation period; germinating, flowering and bearing fruits, planting (harvesting) once a year (e.g. wheat, rapeseed)
Brownfield scenario	Construction / implementation of a potential refinery on a former industrial site, mainly with anthropogenically affected (sealed or / and compacted) soil
Cash cost	The cash cost of 2nd generation ethanol is the sum of variable and fixed production costs excluding capital charge
Construction phase	Impact category in an EIA summarising impacts related the construction phase of a project (e.g. disturbance by working traffic)
Greenfield scenario	Construction / implementation of a potential refinery on unsealed / not compacted soil without major anthropogenic impacts
Marginal land	Agricultural land that is abandoned because foodstuffs cannot be economically cultivated, partially due to low fertility soil
Operation phase	Impact category in an EIA summarising impacts related to the operation of an implemented project (e.g. release of waste water)
Perennial crops	Feedstock plants living more than two years; harvesting is possible several times within the plants' life time (e.g. Arundo)
Production cost	The production cost of 2nd generation ethanol is the sum of variable and fixed production costs including capital charge
Reference product	Conventional product of identical utility, which is compared to an assessed product. It is often but not always made from fossil resources.

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8 Annex

The annex contains various supplementary material including input data, extended methodological descriptions and further results.

8.1 Scenario data

This chapter contains an overview of the most important input data for the sustainability assessment. It contains data on provision of biomass (chapter 8.1.1) and on the scenarios defined to reflect potential implementations of the biorefinery in 2020 using mature technology (chapter 8.1.2).

8.1.1 Agricultural data

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

- Agricultural residues: wheat straw
  The main expenses for cultivating wheat are ascribed completely 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 ascribed to the harvested straw.
  The reference system is ploughing in for wheat straw. 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.
- Agricultural biomass: Arundo and fibre sorghum
  Full expenditures of crop cultivation are ascribed to the harvested crop based on a sustainable cultivation practice. This includes that as many nutrients are replaced by fertilisation as are lost by harvesting and emissions to air and water and exceed the deposition of nutrients from the atmosphere (in case of nitrogen) /Müller-Lindenlauf et al. 2014/.

Provision of biomass is modelled in the screening LCA according to the parameters shown in Tab. 8-1.

8.1.2 Conversion data

For data on the biomass conversion, please refer to chapter 8.7 on the results of process modelling by Biochemtex (see in particular Tab. 8-17 to Tab. 8-22, sections "process output"). Further process data is confidential.

Tab. 8-1 Background data on agricultural processes

	Units (per ha · a)	Arundo donax	Wheat straw	Fibre sorghum
Seedlings / Rhizomes	kg	300*	(none: co-product)	8
Fertiliser[4]				
N	kg	195	14	360
P_2O_5	kg	80	7	125
K_2O	kg	660	33	450
CaO	kg	35	11	35
Crop protection	kg	0.1*	(none: co-product)	5
Diesel fieldwork	l	225	5	105
Yields				
Biomass	t (dry matter)	30	2**	25
Water content	% of fresh matter	50 %	14 %	17 %

*: For establishing the plantation, equally distributed over whole cultivation period.

**: 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. 6 t / (ha • a) apply for questions related to direct agricultural land use and the additional agricultural area occupied due to wheat straw extraction is zero.

8.2 Parameters for LCA

The life cycle impact assessment uses certain characterisation factors to determine the impact of various emissions on the assessed impact categories. These are listed in Tab. 8-2. For details, refer to chapter 2.2.1.1.

[4] The fertiliser demand was calculated as follows: (nutrient content in biomass) * (biomass yield) / (1 - losses through ammonia emissions, denitrification & nitrate leaching) - (atmospheric deposition). Nutrient contents in biomass and biomass yields for Arundo and Fibre sorghum are based on experimental data. Losses are based on model calculations and statistics and atmospheric deposition is based on literature sources /Müller-Lindenlauf et al. 2014/. The following losses were used for nitrogen emissions: Ammonia 3 %, nitrate leaching 15 % for annual crops and 5 % for perennial crops, denitrification losses 10 %. The losses relate to typical agricultural practice expected for 2020. This methodological approach results in higher fertiliser values compared to field trials, but delivers a realistic description of the agricultural practice and allows a consistent comparison between crops.

Tab. 8-2 Indicators, LCI parameters and characterisation factors for the respective impact categories (/CML 2013/, /IPCC 2007/, /Klöpffer & Renner 1995/, /Leeuw 2002/, /Ravishankara et al. 2009/, /IFEU 2013/ on the basis of /IPCC 2007/)

Impact category	Category indicator	Life cycle inventory (LCI) parameter	Molecular formula	Character. factor
Depletion of non-renewable energy resources	Cumulative primary energy use from non-renewable sources	Crude oil	—	—
		Natural gas		
		Hard coal		
		Lignite		
		Uranium ore		
Climate change	CO_2 equivalent (carbon dioxide equivalent)	Carbon dioxide, fossil	CO_2	1
		Nitrous oxide	N_2O	298
		Methane, biogenic*	CH_4	25
		Methane, fossil**	CH_4	27.75
Acidification	SO_2 equivalents (sulphur dioxide equivalent)	Sulphur dioxide	SO_2	1
		Nitrogen oxides	NO_X	0.7
		Ammonia	NH_3	1.88
		Hydrochloric acid	HCl	0.88
Terrestrial eutroph-ication	PO_4 equivalents (phosphate equivalent)	Nitrogen oxides	NO_X	0.13
		Ammonia	NH_3	0.35
Aquatic eutrophica-tion	PO_4 equivalents (phosphate equivalent)	Nitrous oxide	N_2O	0.27
		Nitrogen oxides	NO_X	0.13
		Ammonia	NH_3	0.35
		Phosphate	PO_4^-	1
		Nitrate	NO_3^-	0.1
		Chemical oxygen demand	(various)	0.022
Photochemical ozone formation	C_2H_4 equivalents (ethylene equivalents)	Non-methane hydrocarbons	(various)	1
		Methane	CH_4	0.007
(Stratospheric) Ozone depletion	CFC-11 equivalents	Nitrous oxide (Dinitrogen oxide)	N_2O	0.017
Respiratory inorganics (particu-late matter emissions)	PM_{10} equivalents	Particulate matter	-	1
		Sulphur dioxide	SO_2	0.54
		Nitrogen oxides	NO_X	0.88
		Non-methane hydrocarbons	(various)	0.012
		Ammonia	NH_3	0.64

*without CO_2 effect; **with CO_2 effect

Regarding ozone depletion, an ODP factor for nitrous oxide from a study by /Ravishankara et al. 2009/ is used although it is not yet commonly accepted because it is the only one available.

The required normalisation factors for the EU27 can be found in Tab. 8-3. For details, please refer to chapter 2.2.1.1.

Tab. 8-3 Environmental impacts in the respective categories and the resulting inhabitant equivalent related to inhabitant and year (base year: 2005) (/IFEU 2013/ on the basis of /Eurostat 2007/ and /CML 2013/). Inhabitants EU27 2005: 491,153,644 /Eurostat 2013/

Impact category	Unit	EU27 inhabitant equivalent
Cumulative primary energy demand	GJ / a	82
Climate change	t CO_2 equivalent / a	11
Acidification	kg SO_2 equivalent / a	49
Terrestrial eutrophication	kg PO_4 equivalent / a	6
Aquatic eutrophication	kg PO_4 equivalent / a	38
Photochemical ozone formation	kg C_2H_4 equivalent / a	20
(Stratospheric) ozone depletion	kg CFC-11 equivalent / a	0.069
Respiratory inorganics (particulate matter)	kg PM_{10} equivalent / a	40

8.3 Further results on global / regional environmental impacts

This chapter contains further detailed LCA results, which cannot be shown in chapter 4.1 due to space constraints.

There are further results on:

- Main scenario and additional scenarios on feedstocks (chapter 8.3.1)
- Additional scenario on biopolymers (chapter 8.3.2)
- Alternatives to BIOLYFE (chapter 8.3.3)

8.3.1 Main scenario and additional scenarios on feedstocks

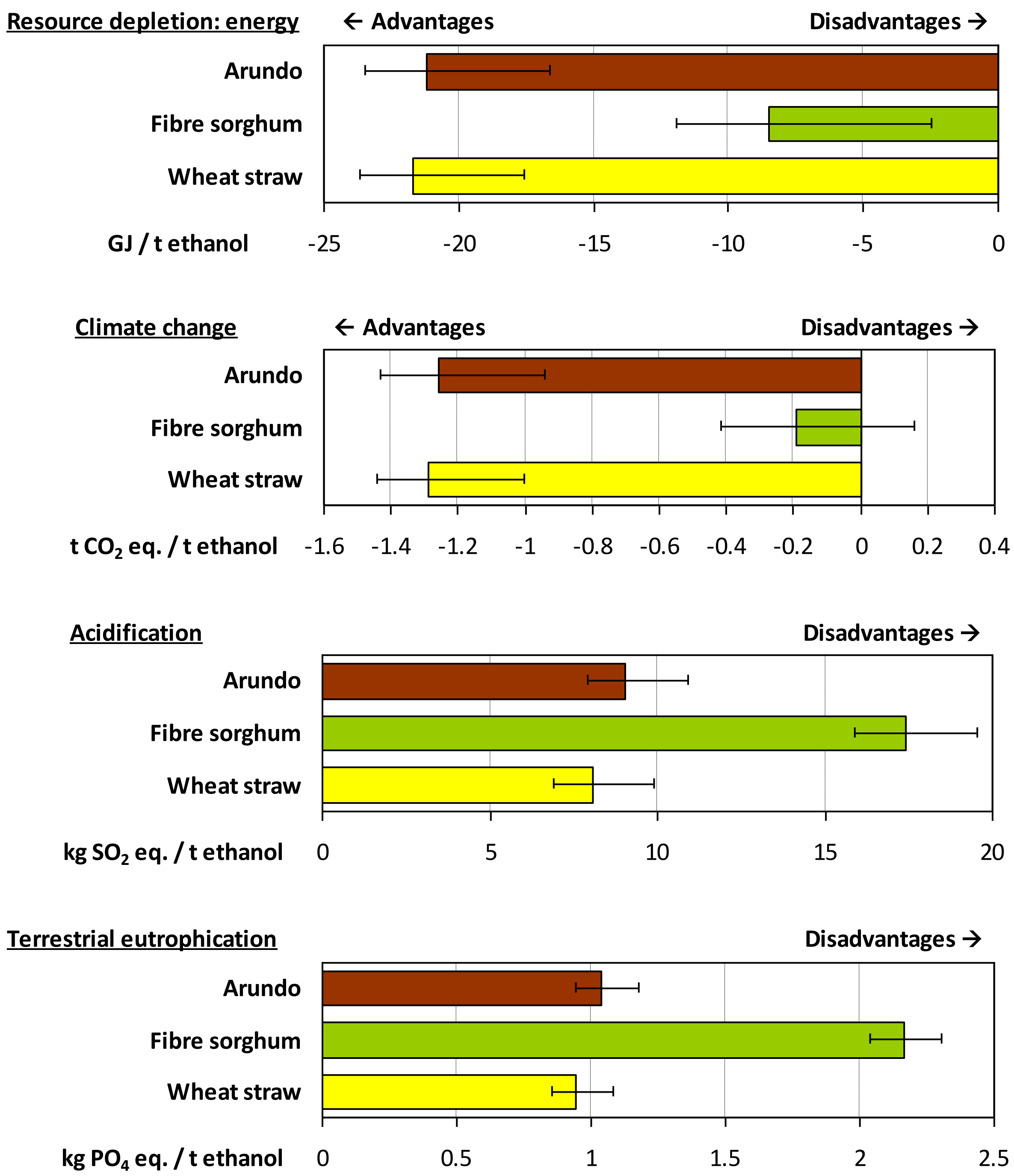


Fig. 8-1 Overview of complete screening LCA results for the main scenario (Arundo) and additional scenarios on feedstocks. Results are shown per tonne of ethanol.

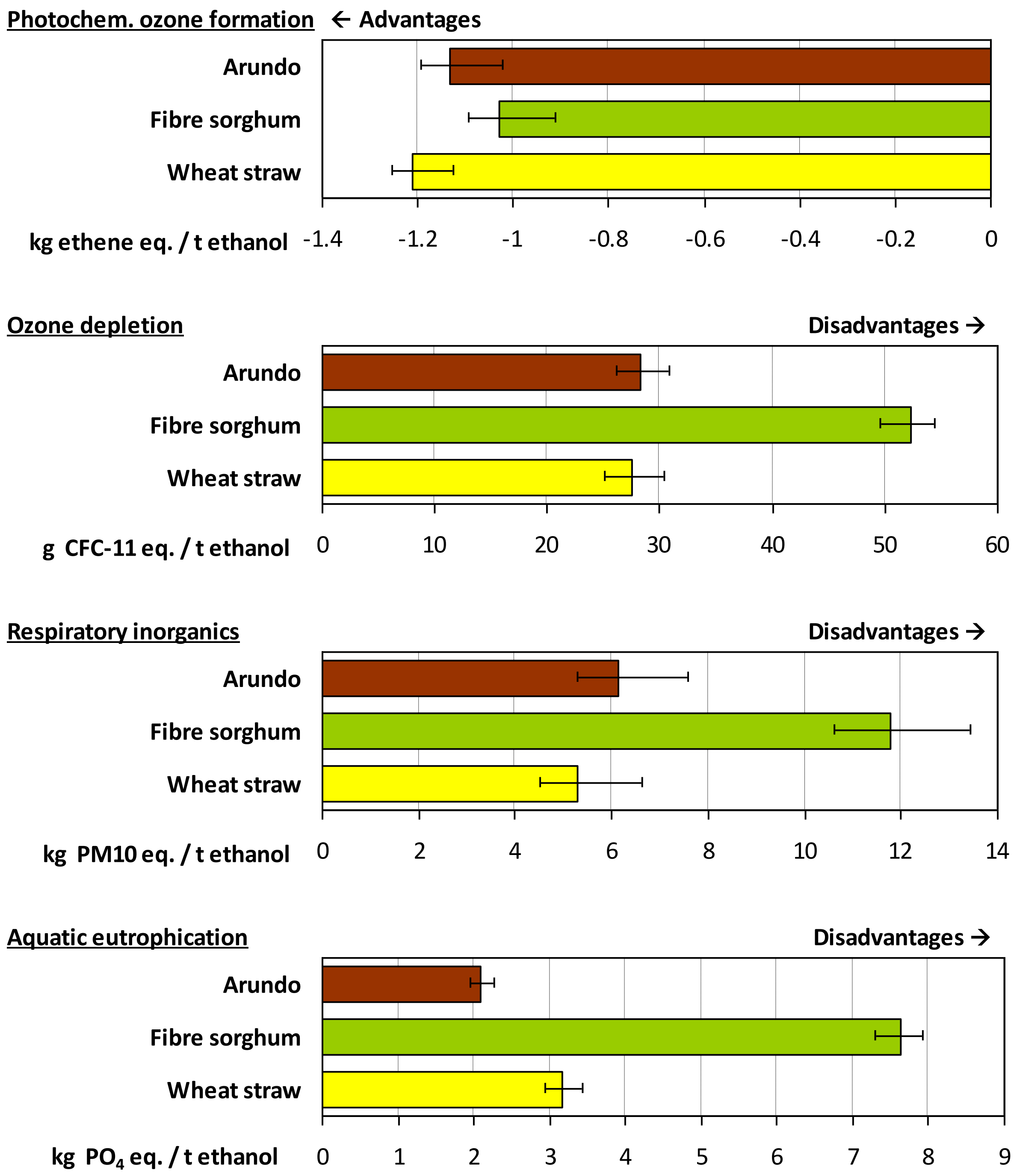


Fig. 8-1 (continued) (Further impact categories)

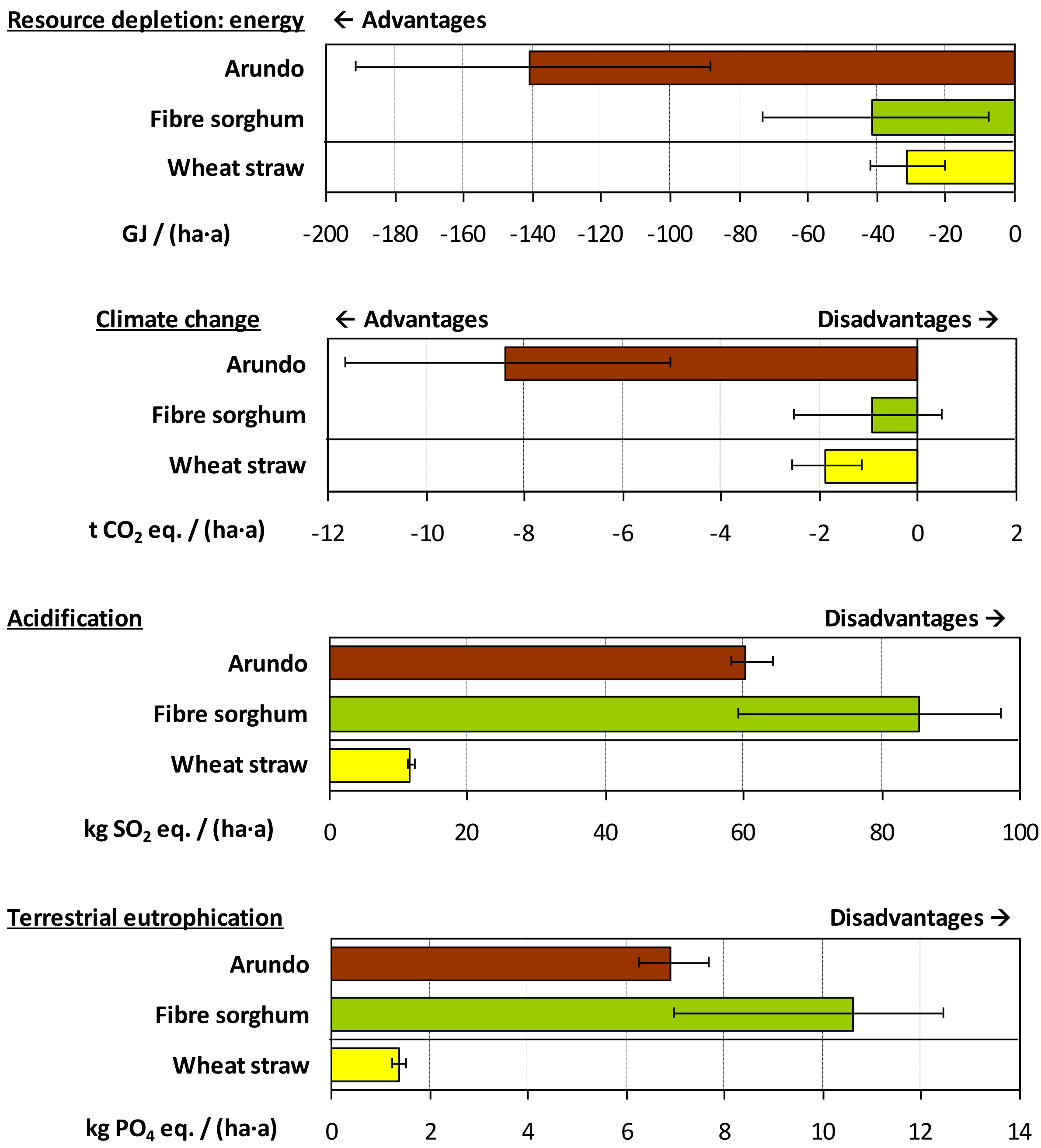


Fig. 8-2 Overview of complete screening LCA results for the main scenario (Arundo) and additional scenarios on feedstocks. Results are shown per hectare and year. Please note that the extraction of wheat straw does not occupy additional agricultural land.

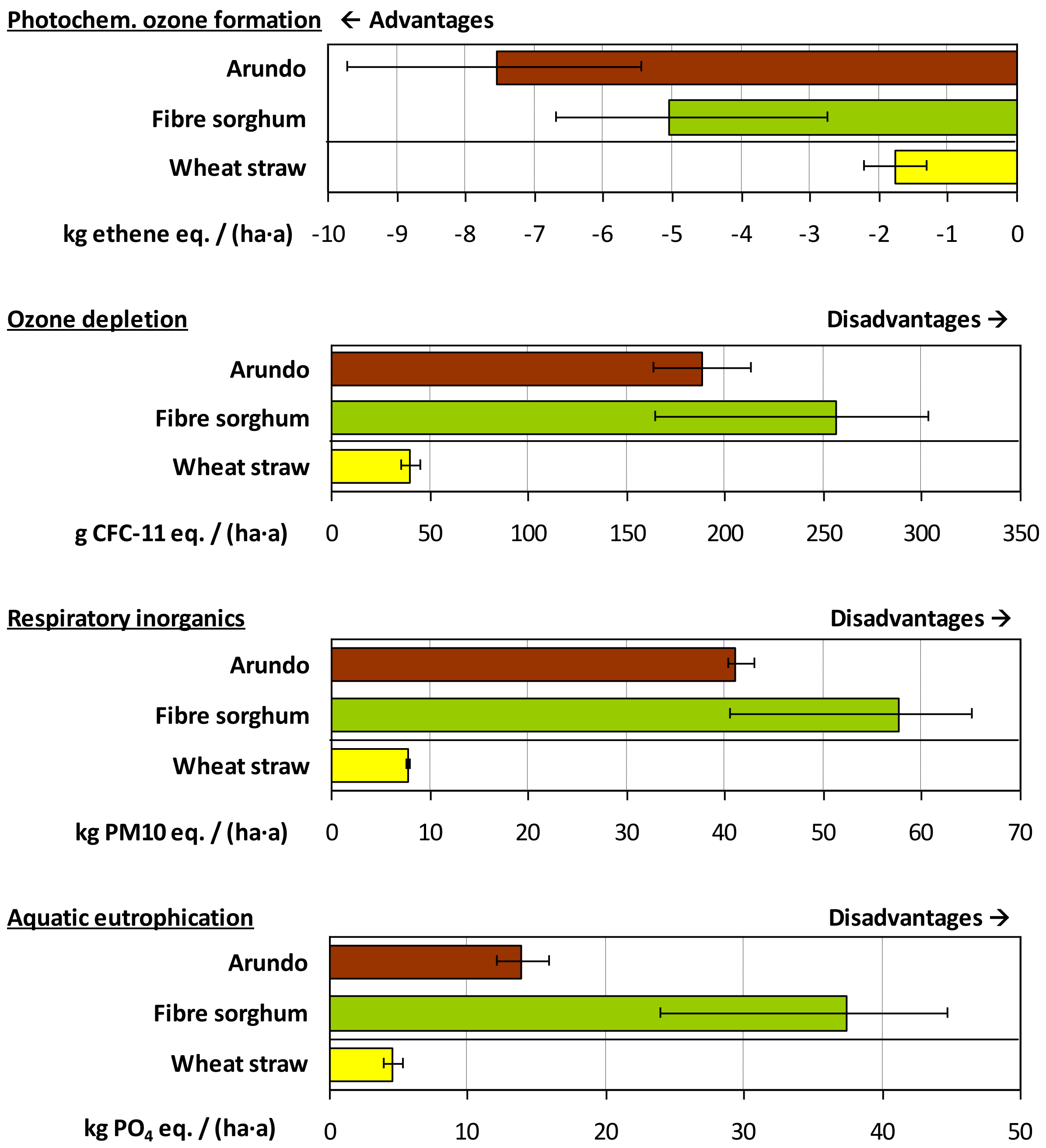


Fig. 8-2 (continued) (Further impact categories)

8.3.2 Additional scenario on biopolymers

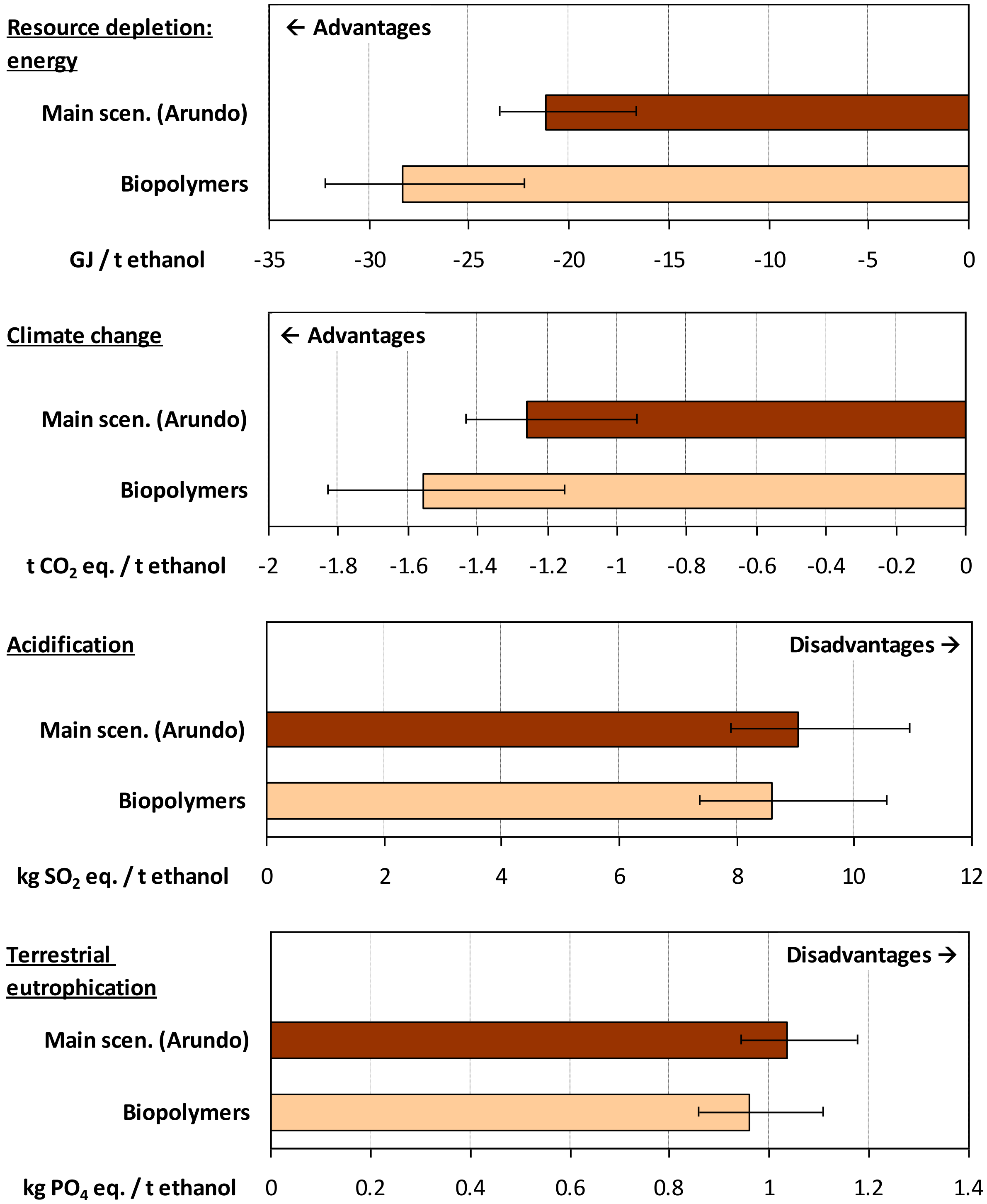


Fig. 8-3 Overview of complete screening LCA results for the additional scenario biopolymers (feedstock: Arundo) in comparison to the main scenario (Arundo). Results are shown per tonne of ethanol.

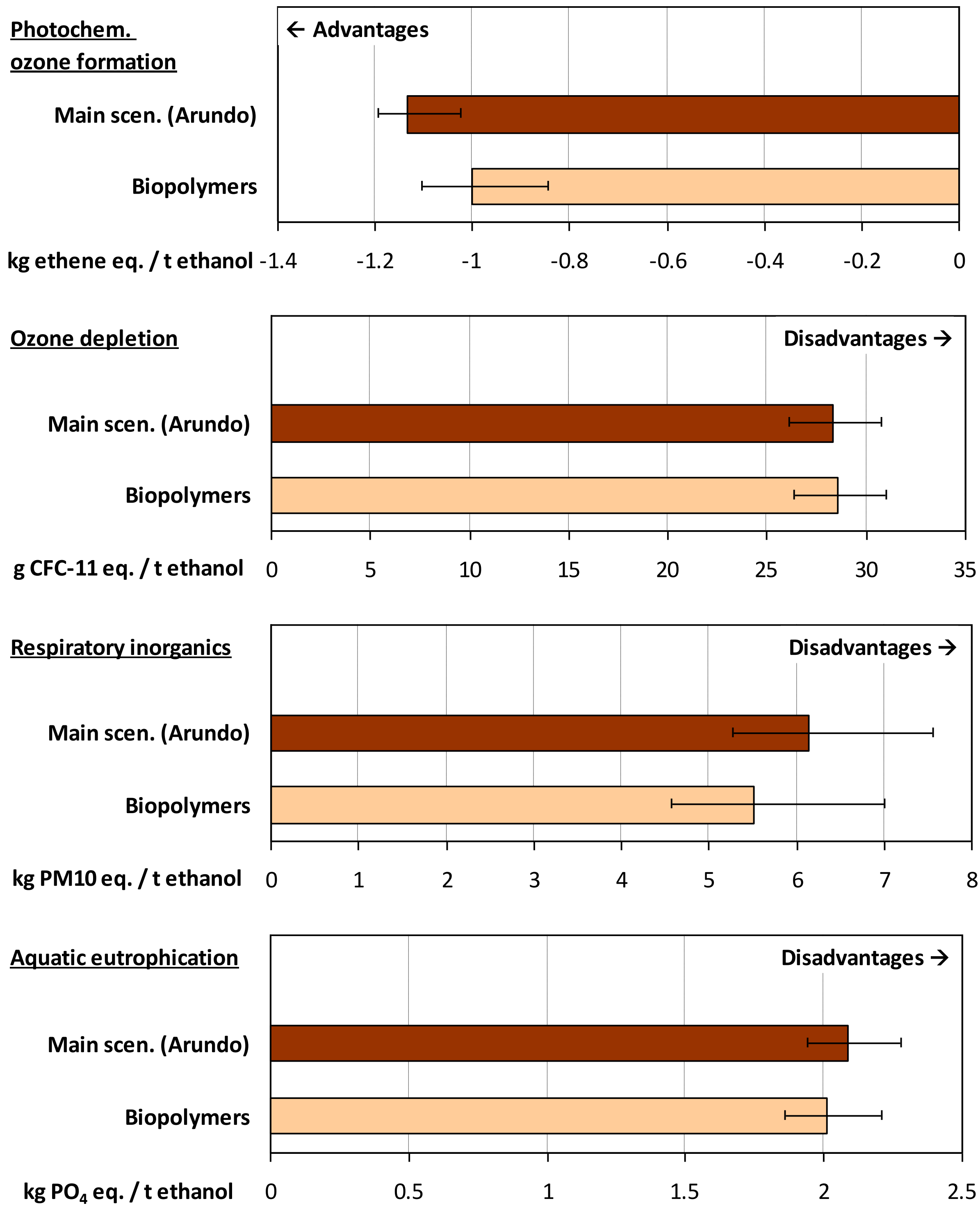


Fig. 8-3 (continued) (Further impact categories)

8.3.3 Alternatives to BIOLYFE

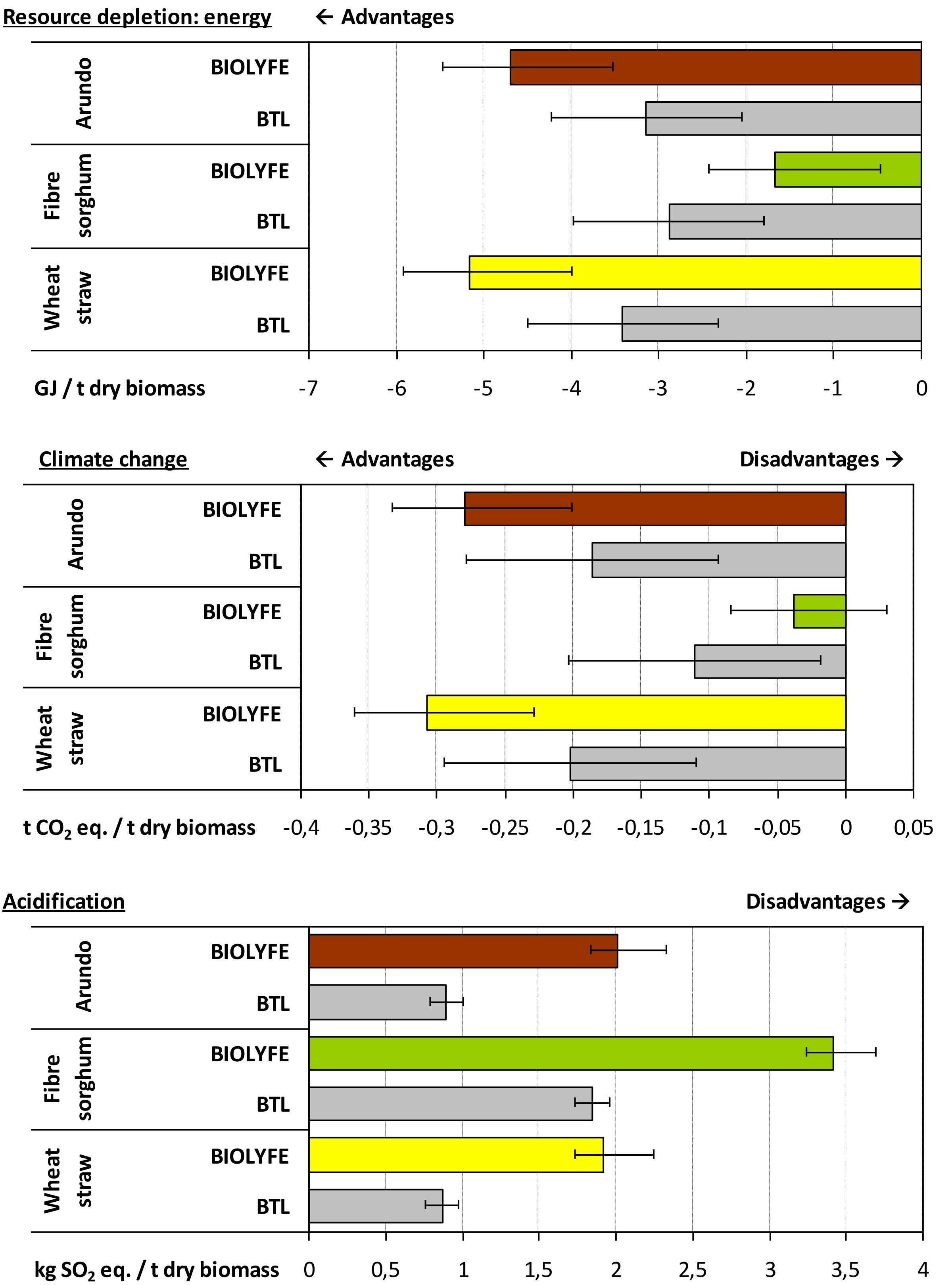


Fig. 8-4 Overview of complete screening LCA results for BTL (biomass to liquid) compared to BIOLYFE bioethanol. Results are shown per tonne of dry biomass.

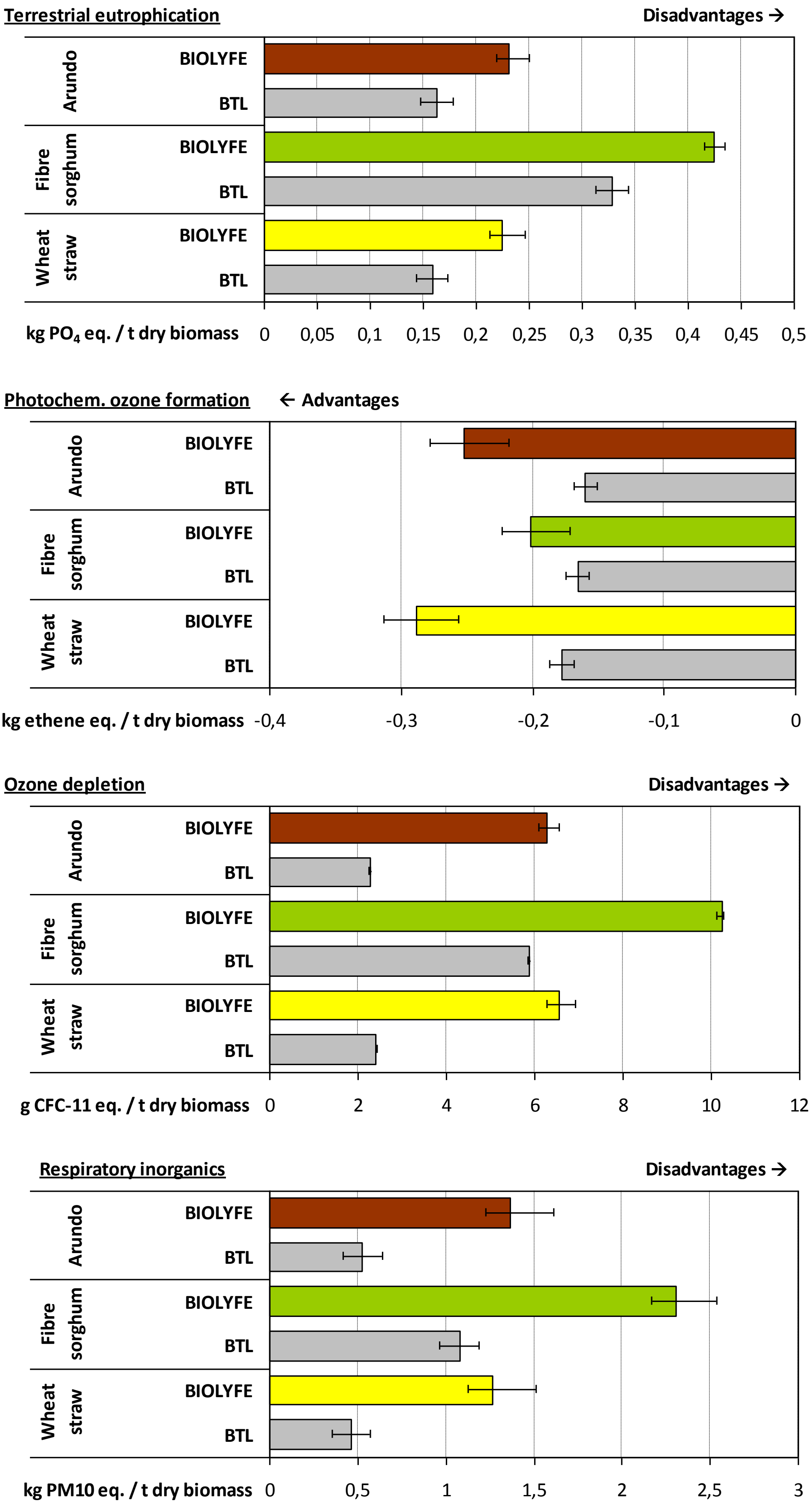


Fig. 8-4 (continued) (Further impact categories)

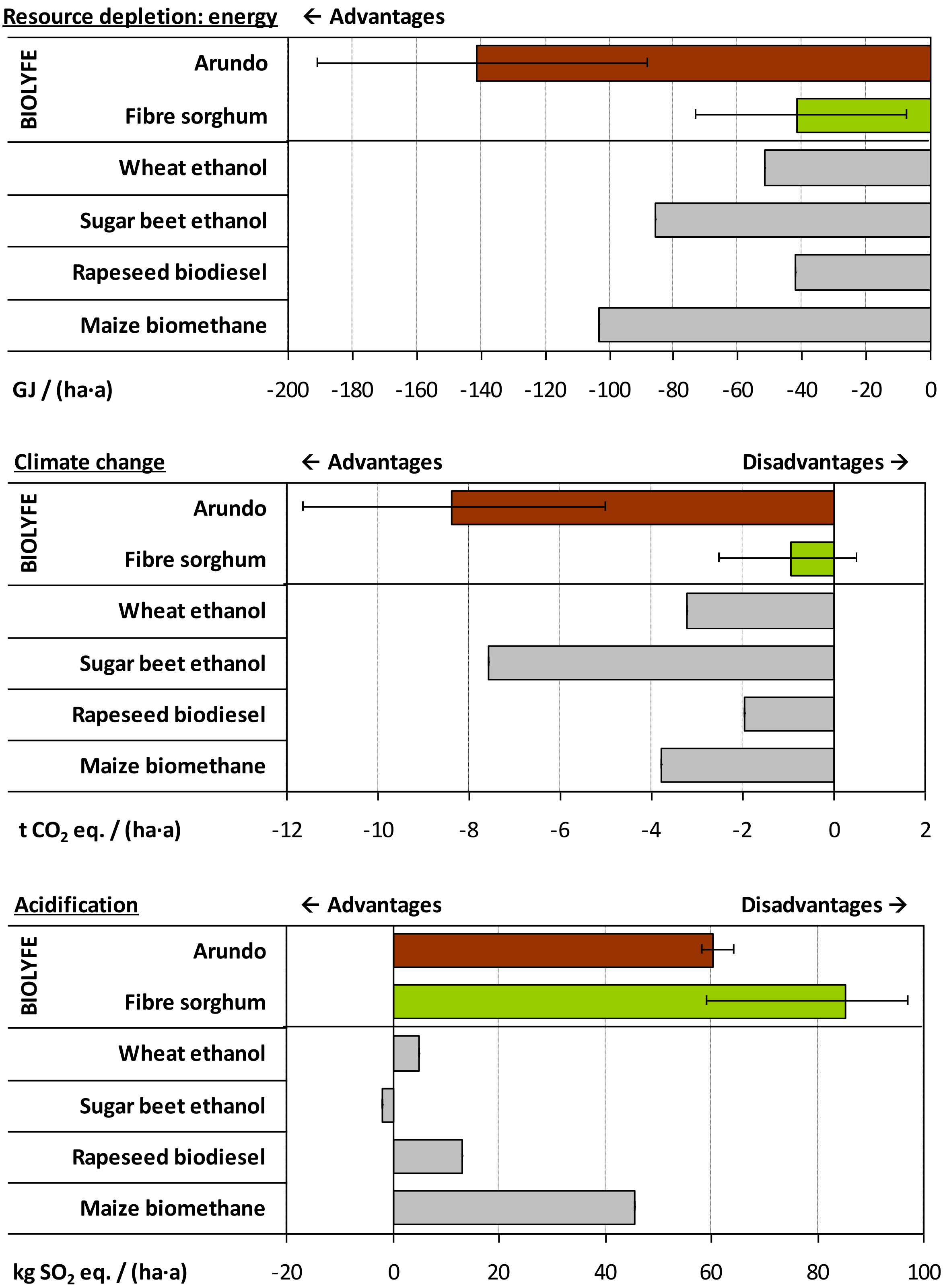
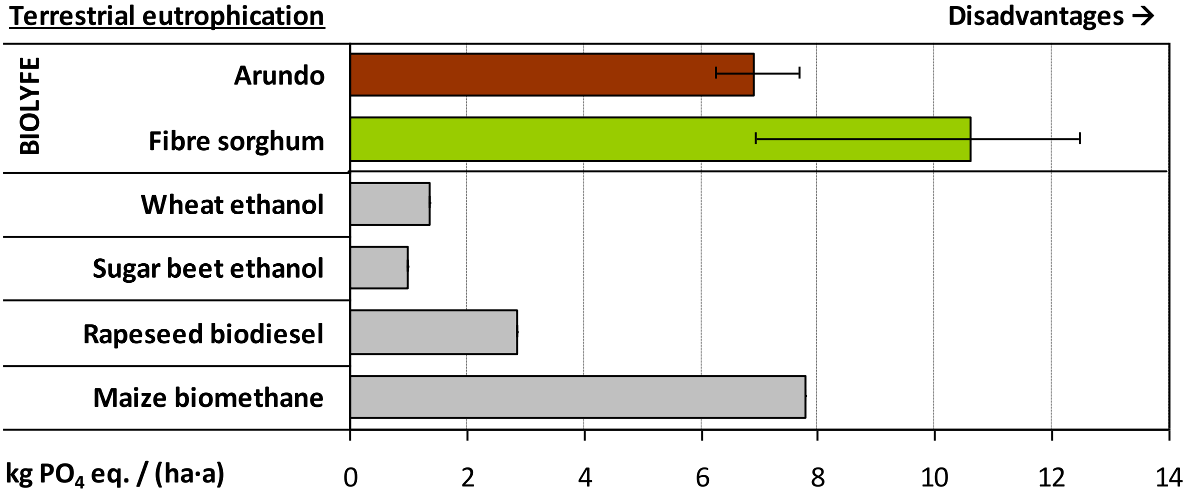


Fig. 8-5 Overview of screening LCA results for other European biofuels compared to BIOLYFE bioethanol. Results are shown per hectare and year of agricultural land use. Impact categories for which a comparison of biofuels to each other is associated with high uncertainty are not shown.



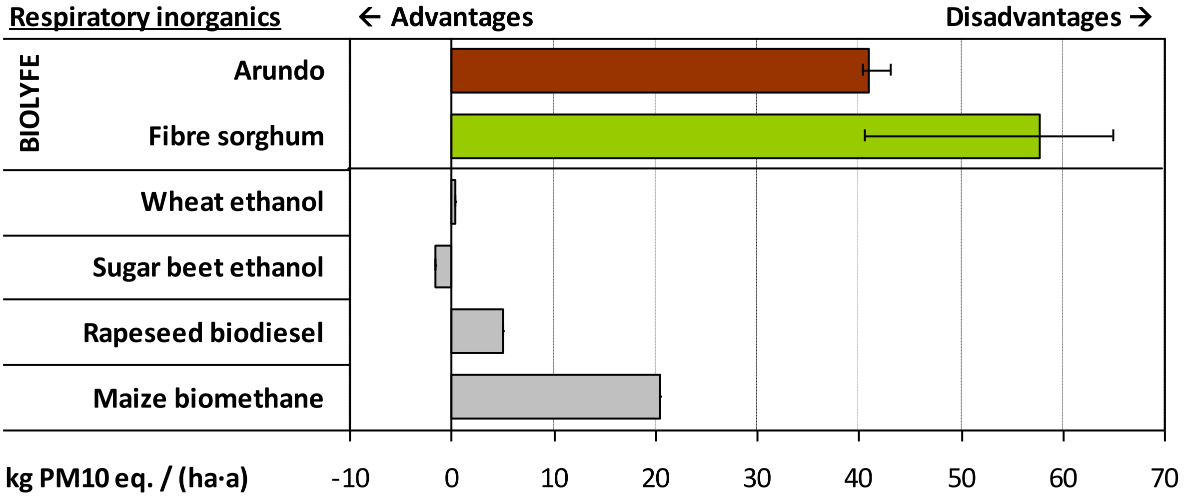


Fig. 8-5 (continued) (Further impact categories)

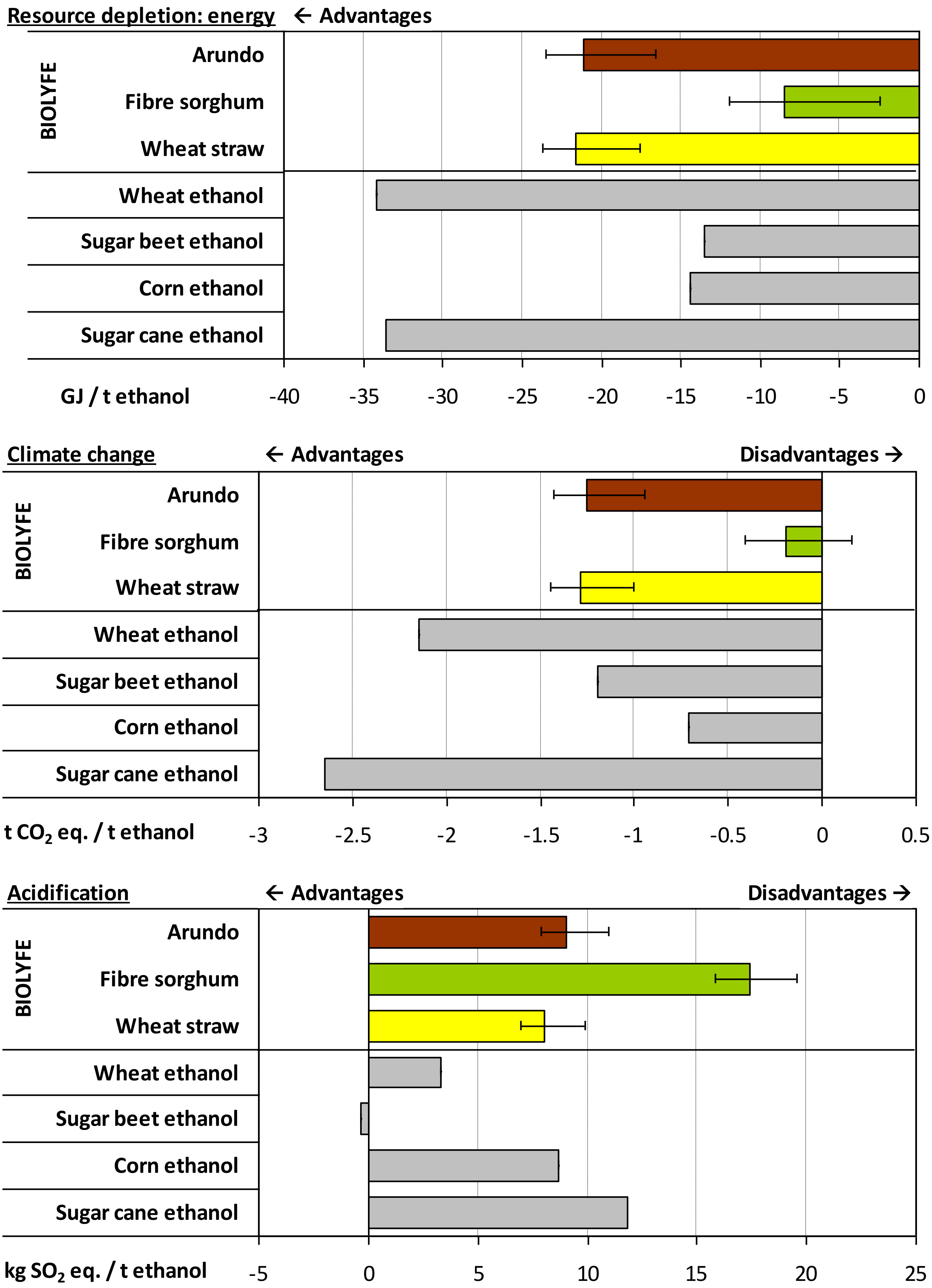


Fig. 8-6 Overview of screening LCA results for 1st generation bioethanols compared to BIOLYFE bioethanol. Results are shown per hectare and year of agricultural land use. Impact categories for which a comparison of biofuels to each other is associated with high uncertainty are not shown.

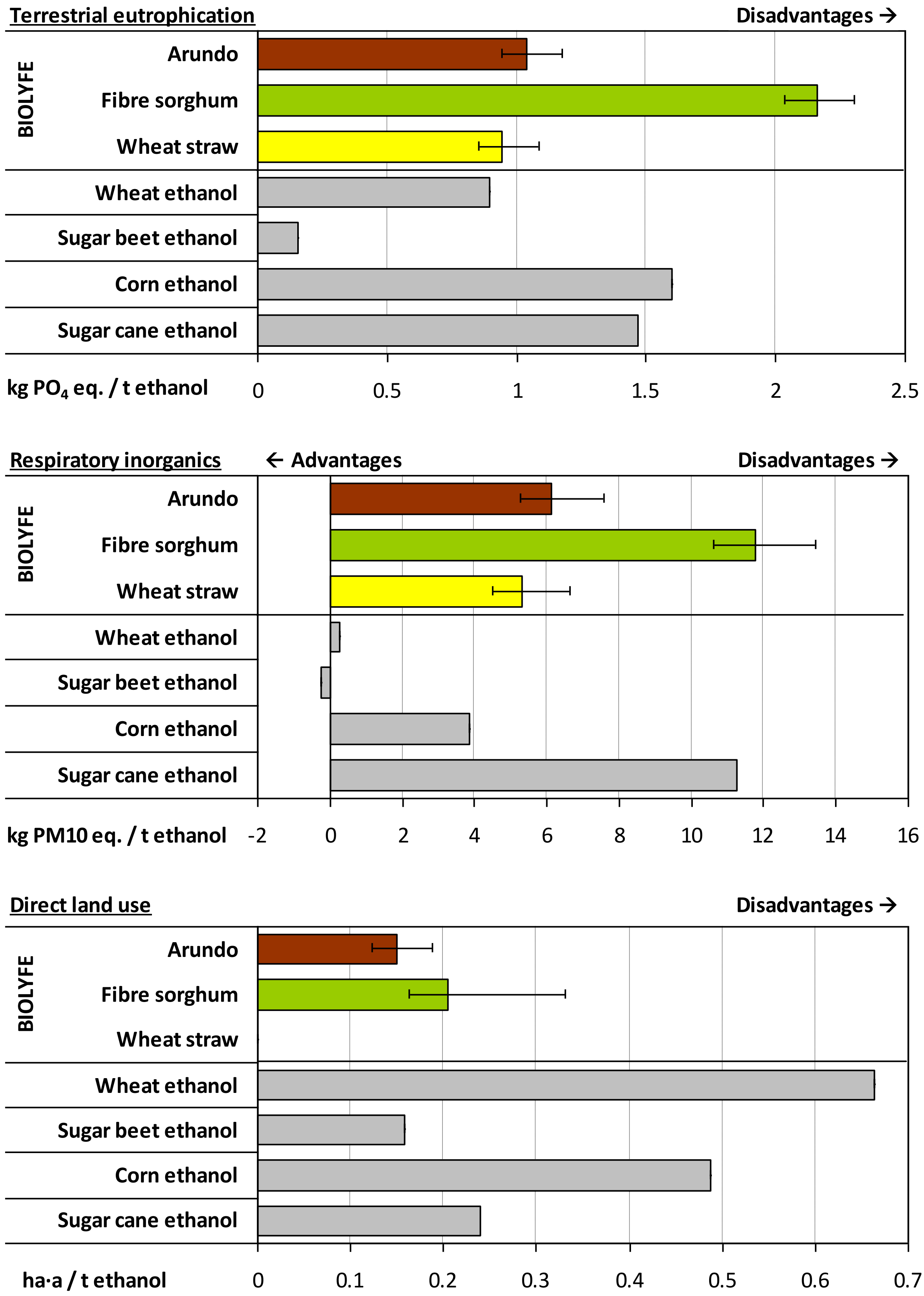


Fig. 8-6 (continued) (Further impact categories)

8.4 Further results on site-specific environmental impacts of feedstocks

This chapter contains further detailed LC-EIA results on site-specific environmental impacts of feedstocks, which cannot be shown in chapter 4.2 due to space constraints.

There are further results on:

- Perennial crops (chapter 8.4.1)
- Annual crops (chapter 8.4.2)

8.4.1 Perennial crops

8.4.1.1 Sugar cane

Plantations of sugar cane are restricted to warmer regions (South America, Africa, the Caribbean) as the plants cannot withstand temperatures below zero degrees Celsius. Optimum growth temperature is around 25 °C. The plants prefer heavy soils with high water storage capacity. As sugar cane is highly water consuming the plantations are primarily located in areas with high availability or water (e.g. riparian zones) or in areas, which afford intensive irrigation. Adverse impacts occur in depletion of ground water and often in salinisation of soils as a consequence of intensive pumping.

Plantations of sugar cane afford intensive soil management including application of fertiliser and pesticides. The danger of compaction and erosion is very high. Due to monocultures high impacts on plants, animals and biodiversity is expected.

Tab. 8-4 summarises the risks associated with cultivation of sugar beet on the environmental factors.

Tab. 8-4 Risks associated with the cultivation of sugar cane compared to the reference system of savannah (cerrado)

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 soil organic matter	neutral/ negative[1]			neutral/ negative[1]	neutral/ negative[1]				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				negative
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 in case of cultivation on the expense of natural habitats (e.g. rain forest, cerrado)

8.4.2 Annual crops

8.4.2.1 Wheat / barley (whole plant)

Wheat and barley do not differ in the requirements for soil quality. Both crops are grown on deep, heavy and nutrient-rich high quality soils. Whereas wheat needs good drainage, barley is sensible against waterlogged soils. The impacts on the environment are comparable.

Intensive agricultural use primarily leads to negative impacts on soil. Prevention from diseases, 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 as well as the recharge rate of groundwater. Erosion effects due to lacking soil coverage can be minimised after harvesting with succeeding crops (e.g. sorghum). Especially the young plants require a dressing of nitrogen fertiliser (app. 150 kg / ha) which increases the risk of nutrient leaching and eutrophication. The need for lignocellulosic material might lead to the cultivation of high stem varieties, as they offer a higher yield of feedstock. This could lower the use of herbicides as long stem varieties are competitive against the arable flora. Depending on the type of landscape used for the cultivation, the impacts are variable. Barley plantations in potato regions would slightly increase habitat variety mitigating the adverse effects on animals, plants and biodiversity.

Depending on the reference system, there are two essential scenarios: rotational set-aside land as reference to agriculture and restricted to the exploitation of straw the reference system of not using resp. extensive using of straw. Tab. 8-5 summarises the risks associated with cultivation of wheat / barley on the environmental factors with rotational set-aside land as reference system.

Tab. 8-5 Risks associated with the cultivation of wheat / barley and the use of straw compared to the reference system rotational set-aside land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants/ Biotopes	Animals	Cli-mate/ 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 soil organic matter	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)

8.4.2.2 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 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 dressings 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 ground-water and superficial water, especially by runoff during heavy precipitations. Ploughing of leaves after harvesting in fall does 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 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. Tab. 8-6 summarises the risks associated with cultivation of sugar beet on the environmental factors.

Tab. 8-6 Risks associated with the cultivation of sugar beet compared to the reference system of non-cropping (rotational set-aside land)

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants/ Biotopes	Animals	Climate/ Air	Land-scape	Human health and recre-ation	Bio-diversity
Soil erosion	negative[1]		negative						
Soil compac-tion	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

8.4.2.3 Rapeseed

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 need 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 the intensive rooting of the soil 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 Tab. 8-7 summarises the risks associated with cultivation of rapeseed on the environmental factors.

Tab. 8-7 Risks associated with the cultivation of rapeseed compared to the reference system of rotational set-aside 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 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	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, e.g. by use as a starter crop

2: Negative because of low biodiversity due to monoculture but increased number of blossom visiting insects during flowering period

8.5 Further results on site-specific environmental impacts of industrial plants

This chapter contains further detailed LC-EIA results on site-specific environmental impacts due to the implementation of industrial plants in general extended by certain aspects specific to biorefineries, which cannot be shown in chapter 4.2 due to space constraints.

Compared to the non-action alternative significant impacts of an industrial plant are expected on the following environmental factors:

- water
- soil
- plants
- animals
- landscape

For the environmental factors of climate / air quality, human health and biodiversity potential impacts are not expected to be significant. Precondition is that the plant will not be located in or in the vicinity of ecological sensitive areas.

Significant impacts are not expected to occur during the construction phase. If state of the art technology is used these impacts are temporary and restricted to the time of construction. Significant impacts are expected to occur from project related buildings, infrastructure and installations as well as during operation of the plant. The following technology related factors were identified as the main drivers for significant impacts:

- drain of land resources due to sealing and compaction and
- risk of explosions and fire in the plant or the storage areas.

Depending on the location of the plant and the local surrounding additional significant impacts might affect the environmental factor of water by

- drain of water resources for production
- waste water production and treatment.

Regions with water shortage in warmer season as well as ecological sensitive areas could be affected. A careful site-specific investigation has to be done in advance to exclude significant adverse impacts. In case of mitigation should not be possible other locations have to be taken into account.

The impacts are described according to the environmental factors tackled and distinguish between impacts related to the

- Construction phase
- Project related phase: buildings, infrastructure and installations
- Operation phase

Tab. 8-8 Technology related impacts expected from the implementation of an industrial plant in general

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 roadkills 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				A3.1		L3.1	H3.1	B3.1 (→ A3.1)
3.2 emission of gases and fine dust		S3.2	P3.2	A3.2	C3.2		H3.2	B3.2 (→ A3.2)
3.3 emission of light				A3.3		L3.3	H3.3	B3.3 (→ A3.3)
3.4 drain of water resources for production	W3.4		P3.4	A3.4			H3.4	
3.5 waste water production and treatment	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 (yellow)

Likely significant impacts (orange)

Potentially significant impacts dependent on the local surroundings of the plant (hatched yellow)

→ **Indirect impacts due to the interaction of environmental factors**

8.5.1 Water

Although water is an inorganic component of the environment, it is an indispensable precondition for life itself. It is a decisive element for other environmental factors, e.g. animals, plants and biodiversity regarding the habitat quality, landscape and climate in case of local environment and even human health and well-being. In the no-action alternative, the following factors have an - potentially differing - impact on available water quantity and quality:

- demographic changes, which lead to an increase of water demand in the future
- technologic developments, which lead to an increase in water demand for industrial purposes on one hand, but on the other hand could lead to a technologic improvement of waste water treatment und thus an increased availability of water resources
- improvements in the standard of living, with an increasing demand for clean water
- implementation of the water framework directive in Europe will lead to a more sustainable use of water resources and to the improvement of the ecological status of surface waters.

In addition to the probable impacts on groundwater and surface water by general development in the no-action alternative, the following impacts can possibly arise from building and operating an industrial plant:

Construction phase

No significant impacts will result from the construction of the plant. Temporary land use and emissions from construction traffic are secondary (W1, W5).

Buildings and infrastructure

Significant impacts result from the buildings and infrastructure due to a deduced recharge of groundwater caused by sealing and compaction of soil (W2.1). The impact can be minimised by using water permeable surfaces for smaller roads or parking sites.

Operation phase

Further impacts are expected during the operation phase by both the drain of water resources for the production (W3.4) and the wastewater production (W3.5). The drain of water resources could result in water shortage during dry seasons. This depends of course on the surroundings of the industrial plant. Regions with ground water scarcity and high quality water bodies might bear higher burdens than agricultural areas along rivers. Possible mitigation measures would be efficient water recycling in the facility to minimise the consumption of fresh water.

The release of treated sewage water (W3.5) could affect the water quality of superficial water bodies, even if it should meet national and international regulations e.g. the water framework directive with its main objective of a desirable good ecological status of water bodies. Mitigation measures are possible depending on the quality of the sewage water. The efficiency of the treatment plants must meet highest standards. In case of high nutrient contents the treated water could be used e.g. for fertilising the feedstock.

Tab. 8-9 Potential impacts on the environmental factor of “water” arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
W1.1	additional temporary land use for construction sites	- during construction of the refinery and associated infrastructure surface waters can be affected (e.g. by construction of dams or crossings for construction roads) - Water-containment can be necessary when building the fundaments of the refinery	- temporary - usually avoidance or mitigation of impacts is possible - often impacts can be reverted
W1.5	temporary emission of substances and odour	potentially eco-toxic substances, e.g. lubricants or fuel, can be emitted in the ground or in surface waters during the construction phase by accident	- temporary -usually avoidance or mitigation of impacts is possible, but smaller accidents (spilling of lubricants or fuels) occur regularly
Project related: buildings, infrastructure and installations			
W2.1	drain of land resources for project related buildings and installations	due to the sealing and compaction of natural soils the formation of groundwater is reduced	- permanent - in parts avoidance or mitigation is possible, e.g. by use of water permeable surfaces on smaller roads and parking lots
Operation phase			
W3.4	drain of water resources for production	industrial plants need water during the operational phase	- permanent - amount of water depending on technologies and size of the industrial plant
W3.5	waste water production and treatment	qualitative and quantitative influence on superficial water bodies	- permanent - avoidance or mitigation of impacts possible - potential in decrease of water quality in the receiving water
W3.6	traffic (collision risks, emissions)	- movements of vehicles / lorries due to transportations (e.g. ethanol, feedstock, maintenance) could cause emissions of eco-toxic substance; accidents possible; - storage of feedstock on the field (occasionally but recurrent)	- permanent - no significant impact expected in the industrial plant due to sealing - avoidance or mitigation of impacts in the field is possible, but smaller accidents (spilling of lubricants or fuels) occur regularly
W3.8	risk of accidents, explosion, fire in the plant or storage areas, GMO release	potentially contamination of ground water and superficial water bodies	temporary but high potential of damage

Emissions from transportation traffic (W3.6) can affect the quality of superficial water bodies, especially in ecological sensitive areas. Due to heavy and significant impacts on other environmental factors, ecological sensitive areas should be excluded as locations for an industrial plant anyway. Compared to emissions caused by other regional traffic the impact of additional traffic due to the industrial plant might be relatively low and not significant. The risk of water endangering substance due to accidents is covered within legal regulations on accident avoidance providing appropriate measures on potential incidents with eco-toxic substances. Storage of feedstock on the fields might be necessary if the storage capacity in the plant is fully exploited. Depending on the type of storage facility, this could lead to a reduced infiltration rate into the ground water during rainfalls. Because of the small-area affected, the impact will be of minor importance.

Significant impacts might occur in case of hazardous accidents within the facilities e.g. fire or explosions (W3.8), although the risk is relatively low if all relevant legal provisions have been observed. Both direct (e.g. fire extinguishing agents) and indirect impacts (emissions of gases and potentially eco-toxic or poisonous substances) could affect groundwater and superficial water bodies in the vicinity of the plant with potentially heavy impacts on water quality. High state of the art safety standards in combination with emergency plans including special trainings for the staff have to be provided to minimise the risk of hazardous incidents respectively to control and to compensate the consequences of such an accident. The risk due to release of GMO is considered as low or negligible /Hoppenheidt et al. 2004/.

8.5.2 Soil

Soil is one of the three major natural resources, alongside air and water. It functions are important for various agricultural, environmental, nature protection, landscape architecture and urban applications. According to /Blum 1993/ the six key soil functions are:

- Food and other biomass production
- Environmental Interaction: storage, filtering, and transformation
- Biological habitat and gene pool
- Source of raw materials
- Physical and cultural heritage
- Platform for man-made structures: buildings, highways

They can be influenced in many different ways. Regarding the no-action alternative, the soil functions might be influenced by following factors:

- change in land use concepts due to changes in population density
  - increase of the urban population
  - decrease of rural population
- request for change of land use based on a change of political priorities (e.g. form infrastructure to housing areas, fallow land to agriculture or industrial infrastructure)

In addition to probable impacts on soil by general development in the no-action alternative, the following impacts can possibly arise from the construction and operation of an industrial plant:

Tab. 8-10 Potential impacts on the environmental factor of “soil” arising from the implementation of an industrial plant

Envi-ron-mental impact	Source of environ-mental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
S1.1	additional temporary land use for construction sites	during construction of the refinery and associated infrastructure soil can be affected (e.g. by construction of dams or crossings for construction roads, temporary site facilities, temporary bedding of excavated soil)	- temporary - usually avoidance or mitigation of impacts is possible (e.g. bedding of excavated soil on-site) - often impacts can be reverted
S1.5	temporary emission of substances and odour	potentially eco-toxic substances, e.g. lubricants or fuel, can be emitted in the ground during the construction phase by accident	- temporary - usually avoidance or mitigation of impacts is possible, but smaller accidents (spilling of lubricants or fuels) occur regularly
Project related: buildings, infrastructure and installations			
S2.1	drain of land resources for project related buildings and installations	due to the sealing and compaction the natural functions of the soil are affected	- permanent - in parts avoidance or mitigation is possible, e.g. by use of water permeable surfaces on smaller roads and parking lots
Operation phase			
S3.2	emissions of gases and dust	- industrial plants will emit gases / substances during operation - fine durst emissions onsite due to handling / transportation of dry feedstock	- permanent - avoidance or mitigation of impacts possible (use of filter systems due to national / international laws) - no significant impact expected due to sealing in the industrial plant
S3.6	traffic (collision risks, emissions)	- movements of vehicles / lorries due to transportations (e.g. ethanol, feedstock, maintenance) could cause emissions of eco-toxic substance - storage of feedstock on the field (occasionally but recurrent)	- permanent - no significant impact expected in the industrial plant due to sealing - avoidance or mitigation of impacts in the field is possible, but smaller accidents (spilling of lubricants or fuels) occur regularly
S3.8	risk of accidents, explosion, fire in the plant or storage areas, GMO release	potentially contamination of soil by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

Construction phase

No significant impacts are expected during construction phase. Temporary land use (S1.1) and emissions from construction traffic (S1.5) are secondary. Due to legal regulations on accident avoidance potential incidents with eco-toxic substances, e.g. lubricants or fuel provide appropriate measures.

Buildings and infrastructure

Significant impacts will occur through buildings and other facilities of the refinery due to sealing effects (S2.1). This is a permanent impact and goes along with a total loss of the natural soil functions, especially with a reduced rate of groundwater recharge. Mitigation is possible by re-using abandoned industrial sites with already sealed soils and thus reducing the amount of unsealed soil for the construction of the industrial plant (Brownfield scenario). Depending on the former type of use potential contaminations have to be taken into account. In case of soil remediation, this could lead to an up valuation of contaminated soils.

Operation phase

Significant impacts might occur in case of hazardous accidents (S3.8) within the facilities e.g. fire or explosions, although the risk is relatively low if all the relevant legal provisions have been observed. Direct impacts (e.g. heat, fire extinguishing agents, etc.) could be restricted to the plant site whereas indirect infects (emissions of gases and potentially eco-toxic or poisonous substances) could affect the soil in the wider surroundings of the plant. High state of the art safety standards in combination with emergency plans including special trainings for the staff have to be provided to minimise the risk of hazardous incidents respectively to control and to compensate the consequences of such an accident.

Impacts on the soil due to local emissions from the industrial plant (S3.2) during the operational phase as well as from vehicle movements (S3.6) will be secondary. Filter systems have to meet national / international threshold standards (state of the art). The impacts of emissions from the plant on the soil are of minor importance.

Recurring storage of feedstock on the field might have minor temporary impacts on soil by reducing the infiltration rate of rainfall into the soil.

8.5.3 Flora

The environmental factor “flora” summarises different plant species as well as the whole plant community (vegetation) with its typical habitats and biotopes. Its major functions are

- provision of food, feed and biomass
- regulation of noise, local climate (temperature, water content)
- filter for pollutants and
- experience, visibility and aesthetics of landscape.

Regarding the no-action alternative, the flora might be influenced by following factors:

- decline of natural habitats due to
  - increasing industrialisation and pollution
  - growth of urban areas (on the expense of rural areas)
- change of the species community due to climatic factors (global warming, local increase / decrease of rainfall)

- spreading of invasive species
- request for change of land use concepts based on a change of political priorities (e.g. form infrastructure to housing areas, fallow land to agricultural areas)

In addition to probable impacts on the environmental factor “plants” by general development in the no-action alternative, the following impacts can possibly arise from the construction and operation of an industrial plant:

Tab. 8-11 Potential impacts on the environmental factor of “flora” arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
P1.1	additional temporary land use for construction sites	during construction of the refinery and associated infrastructure plants can be affected (e.g. temporary site facilities, temporary bedding of excavated soil)	- temporary - usually avoidance or mitigation of impacts is possible (e.g. storage facilities on plant site) - often impacts can be reverted
Project related: buildings, infrastructure and installations			
P2.1	drain of land resources for project related buildings and installations	due to the sealing and compaction the habitats are destroyed or deteriorated	- permanent - in parts avoidance or mitigation is possible, e.g. by use of water permeable surfaces on smaller roads and parking lots
Operation phase			
P3.2	emissions of gases and dust	- industrial plants will emit gases / substances during operation - fine durst emissions onsite due to handling / transportation of dry feedstock	- permanent - avoidance or mitigation of impacts possible (use of filter systems due to national / international laws) - no significant impact expected
P3.4	drain of water resources for production	- shortage of water during dry seasons - long-term changes in vegetation possible	- seasonal but permanent - significant impact possible in wetlands
P3.5	waste water production and treatment	eutrophication of ecological sensitive superficial water bodies	- permanent - significant impact possible in ecological sensitive areas
P3.8	risk of accidents, explosion, fire in the plant or storage areas	potentially contamination of habitats by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

A precondition for the construction of a industrial plant is the avoidance of impacts on conservation areas protected either by national laws (national conservation acts) or international regulations (habitat directive, birds directive). Compatibility studies to prove the ecological performance are compulsory. We may assume that the construction of a biorefinery in particular will avoid sustainable significant impacts on protected areas / species either by mitigating / compensating potentially negative impacts or by choosing alternative locations for the plant.

Construction phase

No significant impacts are expected during construction phase on the plant community. Temporary used land (P1.1) will be recolonised quickly and could even increase habitat diversity.

Buildings and infrastructure

Significant impacts arise from the sealing of the refinery site and the loss of habitats (P2.1) Depending on the habitat quality (e.g. open land, wooded areas) and its conservation significance as well as number and significance of affected species mitigation measures have to be provided. Secondary green areas or parks e.g. in the vicinity of the administration buildings provide new habitats and could help to mitigate impacts but cannot be a sufficient compensation.

Operation phase

Significant impacts might occur in case of hazardous accidents within the facilities e.g. fire or explosions (P3.8), although the risk is relatively low if all the relevant legal provisions have been observed. Direct impacts (e.g. heat, fire extinguishing agents, etc.) could be restricted to the plant site whereas indirect infects (emissions of gases and potentially eco-toxic or poisonous substances) could affect the wider surroundings of the plant with potentially heavy damages on habitat quality and species. High state of the art safety standards in combination with emergency plans including special trainings for the staff have to be provided to minimise the risk of hazardous incidents respectively to control and to compensate the consequences of such an accident.

Depending on the location of the plant, the drain of water resources (P3.4) during the operation phase will affect the availability of ground water. This could cause significant impacts especially in areas with low groundwater levels and during dry seasons, which could lead to long-term changes in vegetation and species community. Mitigation measures (e.g. water recycling) are necessary to avoid negative impacts on the availability of water and the vegetation. Otherwise different locations have to be taken into account.

The release of treated waste water can affect natural and oligotrophic water bodies (P3.5) especially in ecological sensitive areas downstream of the plant. As ecological sensitive areas are excluded as potential locations for a plant, the risk of deteriorating the environment is low. The waste water treatment plant has to meet ecological standards in order to avoid significant impacts on species community.

Quality and quantity of emissions from the regularly operating plant might have impacts on vegetation as well. State of the art standards of technology and filter systems help to provide extensively harmful emissions for the environment. No significant impacts are expected.

8.5.4 Fauna

The implementation of an industrial plant can have impacts on the availability and the quality of habitats, both threatening the living conditions and local individuals respectively populations. Regarding the no-action alternative, the habitat quality for animals might be influenced by following factors:

- decline of natural habitats due to
  - increasing industrialisation and pollution
  - growth of urban areas (on the expense of rural areas)
- change of the species community due to climatic factors (global warming, local increase / decrease of rainfall)
- spreading of invasive species
- request for change of land use concepts based on a change of political priorities (e.g. from agriculture to housing areas, fallow land to agricultural areas or land for industrial use)

In addition to probable impacts on the environmental factor “animals” by general development in the no-action alternative, the following impacts can possibly arise from construction and operation of an industrial plant:

A precondition for the construction of an industrial plant is the avoidance of impacts on conservation areas protected either by national laws (national conservation acts) or by international regulations (habitat directive, birds directive). Compatibility studies are compulsory to prove the ecological performance. We may assume that the construction of a biorefinery in particular will avoid sustainable significant impacts on protected areas / species either by mitigating / compensating potentially negative impacts or by choosing alternative locations for the plant.

Construction phase

Disturbance of animals during construction phase is usually more intense than during operation of the industrial plant. Movements of vehicles can disturb animals (A1.4). E.g. many birds are sensitive to movements and to noise emissions. In case of traffic they maintain relatively large “effect distances” from 150 m to 500 m /Garniel & Mierwald 2010/. People on the construction site will increase the chase effect.

Losses of animals due to road kills (A1.2) specially meet species not capable of quick flights e.g. snails and many insects. It is not possible to avoid losses totally. In the unlikely case of affecting whole populations, the impact would be significant. Normally single individuals or parts of subpopulations might be killed which would not affect the whole population of a species. As birds are able to flee, they usually are not killed.

Temporary emissions from construction traffic (A1.3) might be secondary in industrialised areas being the preferred location for an industrial plant. Nevertheless, industrial set-aside-land might provide special habitats for pioneer species of national and / or international interest. Sustainable significant impacts on protected species have to be avoided or compensated.

Temporary bedding sites for excavated soil could provide additional habitats for pioneer species (A1.1).

Tab. 8-12 Potential impacts on the environmental factor of "fauna" arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
A1.1	additional temporary land use for construction sites	- during construction of the refinery and associated infrastructure plants can be affected (e.g. temporary site facilities) - temporary bedding of excavated soil could provide additional habitats for pioneer species	- temporary - usually avoidance or mitigation of impacts is possible (e.g. storage facilities on plant site) - often impacts can be reverted
A1.2	risk of collisions and roadkills during construction	construction traffic could kill slow moving animals like snails or wild bees	- temporary - usually avoidance or mitigation of impacts is possible
A1.3	emission of noise	noise of construction vehicles could affect sensitive animals, e.g. many birds	- temporary - usually avoidance or mitigation of impacts is possible, e.g. regulation of construction times
A1.4	visual disturbance during construction	moving vehicles and light effects can disturb sensitive species, e.g. birds, lizards	temporary
Project related: buildings, infrastructure and installations			
A2.1	drain of land resources for project related buildings and installations	due to the sealing and compaction habitats are destroyed or deteriorated	- permanent - compensation possible
Operation phase			
A3.1	emission of noise	industrial plant will emit noise during operation, which could affect sensitive animals, e.g. many birds	- permanent - mitigation of impacts possible (use of low-noise machines, sound insulation)
A3.2	emissions of gases and dust	- industrial plants will emit gases / substances during operation - fine durst emissions onsite due to handling / transportation of dry feedstock	- permanent - avoidance or mitigation of impacts possible (use of filter systems due to national / international laws) - no significant impact expected due to sealing in the industrial plant
A3.3	emission of light	industrial plant will emit light during operation, which can disturb sensitive species, e.g. birds, lizards	- permanent - mitigation of impacts possible (use of special lamps)
A3.4	drain of water resources for production	- shortage of water during dry seasons - long-term changes in vegetation possible	- seasonal but permanent - significant impact possible in wetlands
A3.5	waste water production and treatment	eutrophication of ecological sensitive superficial water bodies	- permanent - significant impact possible in ecological sensitive areas

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
A3.6	traffic (collision risk, emissions)	- traffic could kill slow moving animals like snails or wild bees - additional roads might cause fragmentation of biotopes and / or populations	- permanent - mitigation measures possible
A3.7	electromagnetic emissions from high voltage transmission lines	wires for electricity supply, transformer or station	- permanent, low risk of impact - mitigation of impacts possible
A3.8	risk of accidents, explosion, fire in the plant or storage areas, GMO release	potentially contamination of habitats by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

Buildings and infrastructure

The construction of a plant goes along with a loss of habitats for animals (A2.1) causing significant impacts. Especially breeding sites for birds (bushes, trees, grassland), insects (soil) get lost. In addition, feeding habitats for different kinds of animals (birds, insects, bats and other kind of mammals, etc.) are affected. Depending on number and significance of affected species mitigation measures have to be provided. E.g. with minimal extra efforts in design the new buildings could be prepared to offer breeding sites for certain birds (e.g. house sparrow, house martin, black redstart, kestrel) or habitats for bats (e.g. whiskered bat, long-eared bats).

Operation phase

During the operation of the plant animals can be affected by emissions like noise (A3.1) and light (A3.3) of the plant. The effects are less significant than during the construction phase and of minor importance. They will not affect whole populations. Impacts of on-site traffic (noise, light, emissions, A3.6) on animals are secondary as well, but "effect distances" for birds /Garniel & Mierwald 2010/ have to be taken into account. E.g., the effect distance for the great spotted woodpecker is 300 m whereas the flight distance of a goshawk is 50-200 m. This indicates that the plant might cause impacts during operation in the nearer vicinity. If so, mitigation measures have to be provided.

Quality and quantity of emissions (A3.2) from the regularly operating plant might have impacts on animal communities. State of the art standards of technology and filter systems help to provide extensively harmless emissions for the environment. Proper operation and maintenance helps to avoid significant impacts.

Significant impacts are possible to occur in case of hazardous accidents (A3.8), although the risk is relatively low if all the relevant legal regulations are observed. Explosions, fire and heat in combination with extinguishing agents could directly cause severe damage, which could be restricted to the plant site itself. Indirect effects (emissions of gases and potentially eco-toxic or poisonous substances) could affect the wider surroundings of the plant with potentially heavy damages on habitat quality and species. High state of the art safety standards in combination with emergency plans including special trainings for the staff have to be provided to minimise the risk of hazardous incidents respectively to control and to compensate consequences of such an accident. The risk due to release of GMO in case of a biorefinery is considered as low or negligible /Hoppenheidt et al. 2004/.

Depending on the location of the plant, the drain of water resources (A3.4) during the operation phase will affect the availability of ground water. This could cause significant impacts especially in areas with low groundwater levels and during dry seasons, which could lead to long-term changes in vegetation and species community. Mitigation measures (e.g. water recycling) are necessary to avoid negative impacts on the availability of water and the vegetation. Otherwise, different locations have to be taken into account.

The release of treated waste water can affect natural oligotrophic water bodies (A3.5) especially in ecological sensitive areas downstream of the plant. As ecological sensitive areas are excluded as potential locations for a plant, the risk of deteriorating the ecology is low. The waste water treatment plant has to meet ecological standards in order to avoid significant impacts on species community.

The impacts of electromagnetic emissions (A3.7) from high frequency current on animals are very low but can become effective on short distances. The effects can basically result in a rise of temperature. Although a lot of research has been done, significant impacts could not be detected /Wölfle 2009/.

Potentially there is a slight increase in the risk of birds colliding with wires. In isolated incidents, this might cause damage to special species in the same way as power poles might lead to electricity shocks for birds sitting on the wires. Mitigation measures can help to minimise these risks. As the impact probability is very low, these effects are of minor significance.

8.5.5 Climate / air quality

An industrial plant can have impacts on the local climate and the air quality. Buildings, sealing, compaction, backfilling and embanking might alter the local conditions. Regarding the no-action alternative habitats, the local climate and air quality might be influenced by following factors:

- large scale climate dominate local conditions
- global climate changes (global warming) could superimpose local conditions

In addition to probable impacts on the environmental factor “climate/air quality” by general development in the no-action alternative, the following impacts can possibly arise from the construction and operation of an industrial plant:

Construction phase

Temporary modifications in landscape relief (C1.1) e.g. digging of ditches, construction of dams, bedding of soil might cause changes in local temperature balances and the flow of air. As these effects are temporary and small-scale operative the impacts are of minor importance and not significant.

Potential impacts from emissions of construction traffic (C1.5) are temporary as well. They are restricted to a small area and temporary and therefore of secondary interest.

Tab. 8-13 Potential impacts on the environmental factor of “climate / air quality” arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
C1.1	additional temporary land use for construction sites	local landscape modifications can alter temperature balance and flow of air	- temporary - often impacts can be reverted
C1.5	emissions of substances and odours	potentially eco-toxic substances, e.g. exhaust fumes can be emitted during the construction phase	- temporary - small-scale affective - of minor importance
Project related: buildings, infrastructure and installations			
C2.1	drain of land resources for project related buildings and installations	due to sealing and compaction soil will lose the local climatically balancing function	- permanent - in parts avoidance or mitigation is possible
Operation phase			
C3.2	emissions of gases and dust	- industrial plants will emit gases / substances during operation - fine durst emissions onsite due to handling / transportation of dry feedstock	- permanent - avoidance or mitigation of impacts possible (use of filter systems due to national / international laws) - no significant impact expected
C3.8	risk of accidents, explosion, fire in the plant or storage areas	potentially contamination of habitats by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

Buildings and infrastructure

Buildings and infrastructure can alter local climatic conditions permanently due to sealing and compaction (C2.1). The loss of vegetation might deteriorate particular climatic conditions e.g. by decreasing the area’s local climatic balancing function. This could lead to higher temperature amplitudes. However, it is expected to be a secondary impact because of the small-scale effect.

Operation phase

Quality and quantity of emissions from a regularly operating plant might have impacts on air quality (C3.2). State of the art standards of technology and filter systems help to provide extensively harmless emissions for the environment. Proper operation and maintenance help to avoid significant impacts.

Heavy impacts are possible to occur in case of hazardous accidents like explosions and fires (C3.8), although the risk is relatively low if all relevant legal regulations are observed. In case it should happen, eco-toxic or even poisonous substances / gases could generate during fires affecting the local air quality. As this impact is temporary and restricted to the local vicinity of the plant, it is considered a secondary effect.

8.5.6 Landscape

The perception of landscape includes different senses like seeing, hearing, smelling and even touching. Therefore, emissions of light and noise can affect the landscape especially the recreational use. The sensitivity of landscapes to visual impacts depends on the visual transparency due to relief, landscape elements and vegetation structures. E.g., wide and open plains are in general particularly sensitive to visual impacts.

An industrial plant can affect the local landscape. Regarding the no-action alternative, the local landscape might be influenced by following factors:

- Land-use changes as a consequence of the decreasing population (negative population growth in Europe till 2050) but increasing individual ambitions regarding to the quality of living (growing number of one-person-households in Germany);
- Request for change of land use concepts based on a change of political priorities (e.g. form infrastructure to housing areas, fallow land to agriculture or industrial infrastructure).

In addition to probable impacts on the environmental factor "landscape" due to general development in the no-action alternative the following impacts can possibly arise from the construction and operation of an industrial plant:

Tab. 8-14 Potential impacts on the environmental factor of "landscape" arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
L1.1	additional temporary land use for construction sites	local landscape modifications can alter visual connections	- temporary - often impacts can be reverted
L1.4	visual disturbance during construction	affection of recreational use	- temporary - small-scale affective - of minor importance
Project related: buildings, infrastructure and installations			
L2.1	drain of land resources for project related buildings and installations	- interruption of visual connections due to the construction of buildings and infrastructure - affection of recreational use	- permanent - mitigation is possible
Operation phase			
L3.1	emissions of noise	industrial plant will emit noise during operation, which could affect recreational use of the surrounding	- permanent - mitigation of impacts possible (use of low-noise machines, sound insulation)
L3.3	emissions of light	industrial plant will emit lights during operation, which could affect recreational use of the surrounding	- permanent - mitigation of impacts possible (use of special lights)
L3.6	traffic (movements, emissions)	traffic could affect recreational use of the surrounding	- permanent - mitigation measures possible

Buildings and sealing instead of vegetation can affect the perception of the local scenery by creating visual barriers. New roads might deteriorate spatial and functional relations of the landscape. Even emissions of lights, noise and odours can affect local recreational use as an additional character of this environmental factor. The impact quality and intensity is to be assessed against the background of existing affections of the local landscape.

Construction phase

Temporary modifications in landscape relief (L1.1, L1.4) e.g. digging of ditches, construction of dams, bedding of soil and visual disturbance from construction traffic might cause changes in important landscape features (e.g. loss of trees, hedges) as well as visual axes, which might result in a decreased suitability for recreational use. As these impacts are temporary, they are not considered significant.

Buildings and infrastructure

Implementing an industrial plant results in a modification of the landscape (L2.1), on the one side by modifying the relief e.g. by digging of ditches, construction of dams or roads. On the other hand, potential visual axes might be interrupted by constructing technical buildings and infrastructure. Depending on the pre-disposition of the landscape (natural, urban, industrial) this could affect the recreational potential of the area. As a biorefinery in particular contains huge technical buildings in combination with sometimes sophisticated industrial infrastructure the impacts on landscape are expected to be significant. Mitigation measures like the planting of hedges and alleys or the greenery of roof and facades can help to minimise the impacts.

Operation phase

Besides of the potential emission of gases and fine dust an operating industrial plant usually emits both noise (L3.1) and lights (L3.3). Transportation traffic (delivery of feedstock and products, maintenance, individual car transportation, L3.6) goes along with noise, emissions of gases and odours as well as more or less rapid movements, which might affect the suitability for recreation. Normally refineries are built in industrial areas with low suitability for recreation. The operational impact on landscape therefore is expected to be non-significant.

8.5.7 Human health

The environmental factor of “human health” basically aims at the conservation of natural resources for the local population taking into account different aspects of human life:

- health and well-being as the crucial factor of potential impacts
- the residential environment, tackling the quality of every-day activities e.g. home, working place, etc.
- recreation and leisure time, which in addition to the residential environment can have significant influence on life quality and well-being

An industrial plant can affect the different aspects of the environmental factor “human health”. Regarding the no-action alternative human health might be influenced by following factors:

- land use changes as a consequence of population development (negative population growth in Europe till 2050) and increasing individual ambitions regarding the quality of living (growing number of one-person-households in Germany);
- request for change of land use concepts based on a change of political priorities (e.g. agriculture to housing areas, fallow land to agriculture or industrial infrastructure).

In addition to probable impacts on the environmental factor “human health” due to general development in the no-action alternative, the following impacts can possibly arise from the construction and operation of an industrial plant:

Construction phase

The significance of the potential impacts basically depends on the environment of the prospective refinery (H1.2, H1.3, H1.4, H1.5). The closer the construction site is to urban areas the higher the impact might be. Anyhow, the European countries developed legal regulations regarding immission control and regulation of working hours. As long as the limit values of legal regulations are not exceeded, the potential impacts are non-significant. In addition, low noise and emission vehicles can help to minimise potential impacts on human health.

Buildings and infrastructure

No impacts of buildings and infrastructure are expected on human health.

Operation phase

An operating industrial plant goes along with different kinds of emissions e.g. noise (H3.1), light (H3.3) and gases / odours (e.g. waste water treatment, H3.2). State of the art technology and filter systems in combination with legal regulations regarding emission control can help to keep these impacts below the significance level. Human health must not be affected at all. Depending on the vicinity of the plant, additional efforts might be necessary to minimise the impacts on the residential environment and the recreational and leisure use (e.g. additional sound insulation, plantation of hedges, redesigning of schoolyards or playgrounds in the local vicinity, etc.). Mitigation measures in combination with the compliance of emission targets can minimise the potential impacts.

The effects of additional traffic (delivery of feedstock, transportation of products, maintenance and individual car transportation, H3.6) go along with additional emissions of noise and exhaust fumes as well as additional vehicle movements. 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 wide-scale-emissions and high traffic loads of industrial areas will be below detection limits. In rural areas, mitigation measures might be necessary (e.g. speed control for transportation traffic).

Tab. 8-15 Potential impacts on the environmental factor of "human health" arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
H1.2	risk of collisions and road kills during construction	risk of accidents caused by construction traffic	- temporary - usually avoidance or mitigation of impacts is possible
H1.3	emission of noise	noise of construction vehicles could affect human well-being	- temporary - usually avoidance or mitigation of impacts is possible
H1.4	visual disturbance during construction	moving vehicles and light effects might affect human well-being	- temporary - usually avoidance or mitigation of impacts is possible
H1.5	emissions of substances and odours	potentially eco-toxic substances, e.g. exhaust fumes can be emitted during the construction phase and might affect human well-being	- temporary - small-scale affective - usually avoidance or mitigation of impacts is possible
Operation phase			
H3.1	emission of noise	industrial plant will emit noise during operation, which could affect might affect human health	- permanent - mitigation of impacts possible (use of low-noise machines, sound insulation)
H3.2	emissions of gases and dust	- industrial plants will emit gases / substances during operation; potential effects on human health possible - fine durst emissions onsite due to handling / transportation of dry feedstock; potential effects on human health possible	- permanent - avoidance or mitigation of impacts possible
H3.3	emission of light	industrial plant will emit light during operation, which can disturb human sleeping	- permanent - mitigation of impacts possible (use of special lamps)
H3.4	drain of water resources for the production	industrial plants need water during the operational phase; water shortages might be possible	- permanent - mitigation of impacts possible
H3.6	traffic (collision risk, emissions)	road traffic increased; moving vehicles and exhaust fumes might affect human well-being	- permanent - mitigation measures possible
H3.7	electromagnetic emissions from high voltage transmission lines	wires for electricity supply, transformer station	- permanent, low risk of impact - mitigation of impacts possible
H3.8	risk of accidents, explosion, fire in the plant or storage areas, GMO release	potentially contamination of habitats by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

Electric wires and high voltage transmission lines cause electromagnetic emissions (H3.7) which might affect human beings if certain thresholds should be exceeded. Adherence of safety rules and environmental compliance wild help to minimise impacts on human health. No significant impacts are expected.

Heavy impacts are possible to occur in case of hazardous accidents like explosions and fires (H3.8), although the risk is relatively low if all relevant legal regulations are observed (safety regulations, employment protection provisions). In case it should happen, eco-toxic or even poisonous substances / gases could generate during fires affecting the local vicinity. The industrial plant should operate within all appropriate national laws and regulations covering security and health and safety. The risk due to release of GMO in case of a biorefinery is considered as low or negligible /Hoppenheidt et al. 2004/.

8.5.8 Biodiversity

"The Convention of Biodiversity defines biodiversity as the variation among living organisms from all sources including inter alia terrestrial, maritime and other aquatic ecosystems and the ecological complex of which they are part; this includes diversity within species and of ecosystems. It is the variety of life on earth at all levels from genes to worldwide populations of the same specie; from communities of species sharing the same small area of habitat to worldwide ecosystems" /IAIA 2005/.

An industrial plant can affect the biodiversity on different levels. Regarding the no-action alternative the local climate and air quality might be influenced by following factors:

- decline of natural habitats due to
  - increasing industrialisation and pollution
  - growth of urban areas (on the expense of rural areas)
- change of the species community due to climatic factors (global warming, local increase / decrease of rainfall)
- spreading of invasive species
- request for change of land use concepts based on a change of political priorities (e.g. from agriculture to housing areas, fallow land to agricultural areas or land for industrial use)

In addition to probable impacts on biodiversity due to the general likely development in the no-action alternative, the following impacts can possibly arise from the construction and operation of an industrial plant:

Tab. 8-16 Potential impacts on the environmental factor of “biodiversity” arising from the implementation of an industrial plant

Environmental impact	Source of environmental pressure	Nature of environmental impact	Assessment of impact, durability and importance
Construction phase			
B1.1	additional temporary land use for construction sites	- during construction of the refinery and associated infrastructure species can be affected (e.g. temporary site facilities) - temporary bedding of excavated soil could provide additional habitats for pioneer species	- temporary - usually avoidance or mitigation of impacts is possible (e.g. storage facilities on plant site) - often impacts can be reverted
B1.2	risk of collisions and roadkills during construction	construction traffic could affect slow moving animals like snails or wild bees	- temporary - usually avoidance or mitigation of impacts is possible
B1.3	emission of noise	noise of construction vehicles could affect sensitive animals, e.g. many birds	- temporary - usually avoidance or mitigation of impacts is possible,
B1.4	visual disturbance during construction	moving vehicles and light effects can disturb sensitive species, e.g. birds, lizards	temporary
B1.5	emissions of substances and odours	potentially eco-toxic substances, e.g. exhaust fumes emitted during the construction phase might affect species and / or habitats	- temporary - small-scale affective - usually avoidance or mitigation of impacts is possible
Project related: buildings, infrastructure and installations			
B2.1	drain of land resources for project related buildings and installations	due to the sealing and compaction habitats are destroyed or deteriorated	permanent compensation possible
Operation phase			
B3.1	emission of noise	industrial plant will emit noise during operation, which could affect sensitive species	- permanent - mitigation of impacts possible (use of low-noise machines, sound insulation)
B3.2	emissions of gases and fine dust	industrial plant will emit gases and fine dust during operation, which could affect sensitive species	- permanent - mitigation of impacts possible (use of efficient filter systems)
B3.3	emission of light	industrial plant will emit light during operation, which can disturb sensitive species, e.g. birds, lizards	- permanent - mitigation of impacts possible (use of special lamps)
B.3.6	traffic (collision risk, emissions)	- traffic could kill slow moving animals like snails or wild bees - additional roads might cause fragmentation of biotopes or / and populations	- permanent - mitigation measures possible
B3.8	risk of accidents, explosion, fire in the plant or storage areas, GMO release	potentially contamination of habitats and populations by potentially eco-toxic or poisonous emissions	temporary but high potential of damage

As precondition for conservation of biodiversity an industrial plant should not be implemented in areas of special interest for nature conservation, protected either by national laws (national conservation acts) or international regulations (habitat directive, birds directive). Compatibility studies are compulsory to prove the ecological performance. We may assume that the construction of a biorefinery in particular will avoid sustainable significant impacts on protected areas / species either by mitigating / compensating potentially negative impacts or by choosing alternative locations for the plant.

Construction phase

Potential impacts during the construction phase are temporary (B1.1, B1.2, B1.3, B1.4, B1.5). Emissions of noise, light, exhaust fumes or other substances due to construction works are not expected to have significant impacts on biodiversity.

Buildings and infrastructure

Sealing and compaction of soil will definitely have significant impacts on the environment (B2.1). As a location of the plant in ecological sensitive areas or biological hot spots is excluded, the impacts on biodiversity are not expected to be significant.

Operation phase

The industrial plant should operate within all appropriate national laws and regulations covering security and health and safety. Taking into account that a potential location would not touch ecological sensitive areas significant impacts on biodiversity (B3.1, B3.3) are not to be expected during the operation phase.

A hazardous event like explosions and / or fire in the plant might have severe impacts on the environment (B3.8). A threat of a total loss of whole populations or specific habitat types as well as the loss of specific varieties (specific genomes) is rather unlikely. Significant impacts on biodiversity are not to be expected. The risk due to release of GMO is considered as low or negligible /Hoppenheidt et al. 2004/.

8.6 Extended methodology of the economic assessment

This chapter contains further detailed information on the methodology applied in the economic assessment, which cannot be shown in chapter 2.3 due to space constraints.

Process calculation and economical evaluation of the different process options developed for the BIOLYFE industrial demo plant have been performed trough a development of a mathematical model able to perform a sensitivity analysis useful for future 2nd generation business plans.

The main goal of sensitivity analysis is to gain insight into which assumptions are critical, i.e., which assumptions affect choice. The process involves various ways of changing input values of the model to see the effect on the output value. Sensitivity analysis can be useful for a range of purposes including:

- testing the robustness of the results of a model or system in the presence of uncertainty;
- increased understanding of the relationships between input and output variables in a system or model;
- uncertainty reduction: identifying model inputs that cause significant uncertainty in the output and should therefore be the focus of attention if the robustness is to be increased (perhaps by further research);
- model simplification – fixing model inputs that have no effect on the output, or identifying and removing redundant parts of the model structure;
- enhancing communication from modellers to decision makers (e.g. by making recommendations more credible, understandable, compelling or persuasive);
- finding regions in the space of input factors for which the model output is either maximum or minimum or meets some optimum criterion.

For the purposes of proper sensitivity analysis should be developed, in addition to the baseline scenario, at least a couple of case studies and a few improvements worse.

Doing one or more sensitivity analyses allows identifying a range of values instead of having a single number available on which to base their decisions. The sensitivity analysis allows then to analyse the negative scenarios so it can however estimate what are the safety margins in the event of a downturn in the market. Finally, through this method, it can be found out, which are the most important drivers of value that will be necessary to focus attention on when the investment will be made.

The model proposed has been created following a descriptive approach with the aim to foresee the behaviour of the system. In other terms, experimental data are fundamental to calculate the parameters (such as conversion or yield) of every step because all the input variables are not related to the operative conditions. The main model feature that has to be considered is his high flexibility, in order to permit as much as possible the complete change of the input data.

Another important point, it is the utilisation of a user-friendly interface with the aim to facilitate the application of the model. For this reason, the tool has a dedicated section in which are summarised all the input and the most important output key parameters for each step of the process. All the auxiliary calculations for each step were formulated in dedicated worksheets in order to reduce the information on the interface.

Following this standard, the model includes a series of worksheet that could be classified in five main areas:

- database properties (biomass composition, chemical-physical properties of involved substances, stoichiometry of all relevant reactions, enzyme data);
- mass balance;
- energy balance;
- input-output parameters;
- sizing of equipment.

A wide number of assumptions have been adopted to carry out the techno-economical study of the process and they are described in the following chapters.

Database properties and mass balance:

Second generation biomasses contain a wide range of compounds that can have an impact on the performance of the feedstock in the process. In order to guarantee the usability of the tool, it has been necessary to minimise the number of species considered in the mass balance calculations.

During the development of the tool, it has been decided to consider only four main classes of compounds:

- water;
- sugars (as insoluble polymers, soluble oligomers and simple sugars);
- inhibitors;
- lignin.

For the calculation purposes, C5 and C6 sugars are respectively assimilated to xylans and glucans (as model compounds). It means that all the sugars with the same molecular weight (e.g. glucose, galactose, and mannose) are grouped and considered as a single compound.

In the inhibitors class are included Acetic acid, Formic acid, furfural, 5-HMF, Levulinic acid and phenolic compounds. It is possible to neglect, if not necessary, one or more of them.

Lignin is considered with the main aim to evaluate its potential as high value added by-product source of energy for the energy recovery into the process.

Energy balance:

The lignin co-produced in the sugars production process represents a relevant energy source for the overall process. Total equivalent thermal energy consumption of the process is compared to the energy content of the available lignin, in order to verify whether a surplus energy import is necessary.

Utilities consumption data for the part of the process afferent to the conversion of the biomass to fermentable sugars are derived from a specific model that calculates the consumption of water, steam and electricity for the process section of interest, along with the production of lignin from the remaining solid fraction of the treated biomass. Utilities consumption for the production of 2G-ethanol from the obtained lignocellulosic sugars is based on data provided by Biochemtex.

Input-output parameters:

By a process point of view, the intermediate yields and utilities consumptions have been assumed as entries data. It is possible to vary the default values in order to meet the process requirements and improvements. The parameters are divided into two main sections: “Process Input-Output” and “Economics Input-Output”. Each factor is described in the following subchapters.

Sizing of equipments and capital investments evaluation:

The estimation of equipment cost sizing has been conducted with the help of an economic modelling tool included in a process simulation software on the basis of equipment cost data from existing plants. The analysis does not deep to an equipment list detail level but considers available capital investment cost data divided by section, which is then converted to the selected plant size through power law. Biochemtex data relative to its pilot plant in Rivalta and to the bioethanol demo plant in Crescentino are used as reference.

Battery limits:

The battery limits considered for the economic evaluation of ethanol production include raw material handling, the hydrolysis and fermentation sections and ethanol purification. The battery limits do not consider any costs related to the auxiliary equipments (e.g. cogeneration packages and cooling towers) and the disposal of waste products outgoing the auxiliary sections of the plant (e.g. ash from burner).

Both operative costs (e.g. raw material, utilities, …) and capital investment have been estimated for the sections included in the battery limits.

Economical evaluation:

The economic evaluation of second generation bioethanol production takes into account many factors that can affect production costs, such as variable costs (OPEX) and fixed costs (CAPEX).

Operational expenditure or OPEX (from the English OPerating EXpenditure, or OPerational EXpenditure) is the cost required to manage a product, a business and has been calculated by an accountant from raw materials, utilities and labour demands.

CAPEX (from CAPital EXpenditure or CAPital EXpenditures) is the fixed capital investment that a company pay if the processing plant has been bought.

8.6.1 Input of the assessment

By a process point of view, the intermediate yields and utilities consumptions have been assumed as entries data. Each parameter is set to the optimal value in accord with current Biochemtex knowledge. The entries are divided into two main sections: “Process Input” and “Economics Input”. Each entry is described below.

Process input:

Feedstock type: the model considers different types of feedstock and users can set these parameters through a dedicated drop-down menu. Up to now, data are set for Arundo donax, wheat straw and fibre sorghum. The composition utilised in tool is referred to standard feedstock type in agreement with Biochemtex’s analytical results. Biochemtex has the possibility of updating the feedstock database with new types of raw materials or specific compositions when it is needed. The feedstock behaviour in the process (consequence of the biomass structure and recalcitrance to pre-treatment) is included in the model according to Biochemtex experience.

Production capacity: the user can set the production throughput in terms of tonnes per year. In this case the production capacity of the plant is fixed at 100,000 t / a. The frontend requirement for the feedstock is calculated on the basis of specified production needs.

Sugars conversions and selectivity of sugar reaction: these parameters are always the same for all types of biomass as the sensitivity analysis is made only on the initial composition of feedstock.

Enzyme dosage: during enzymatic hydrolysis step, the model considers different enzyme input in order to meet the process requirements. Data are set according to Biochemtex's experiences with the commercial enzyme supplier. The enzyme input parameters are normalised based on a standard value (set as consequence of Biochemtex experience) which is expressed as "1X". The other ones are calculated on the basis of predictions about enzyme formulation performances and improvements. Indeed, several enzymes suppliers foresee the development of new generation cocktails with very specific side activities and able to reduce dosages and cost and to improve performances.

- Fermentation yields: for this section, the main entries are split for two different classes, C5 and C6 sugars. The main data entries of the stage are :
  - sugar conversion (fraction of monomers reacting during the process)
  - selectivity (reacting sugars can be converted to ethanol or dedicated to yeast growth and maintenance)

Economics input:

The model allows setting the economic inputs that are divided into variable, fixed costs and capital investment.

The variable production costs are classified in three main areas:

- Raw material: the economic impact of the biomass is related to biomass type and to plant location. Price can be adjusted in agreement with the considered scenario.
- Consumables: this area includes chemicals, yeast and enzyme costs. The enzyme cost is set according to the information provided by the supplier, while the chemicals cost depend on dosage and on the yield of the process.
- Utilities: total equivalent energy consumption is compared to the overall energy production coming from the lignin and the concentrated stillage resulting from the process. If an energy import is necessary, an external load of electricity and natural gas is foreseen. The impact of the utilities cost is estimated for an energetic scenario in which an OSBL CHP plant produces the steam and the electricity necessary for the 2nd gen bioethanol plant. Only the lignin surplus amount coming from lignin and stillage in excess for the energy requirement of the plant is sold.

The fixed production costs considered by the assessment are related to labour and maintenance costs of the plant. The estimation requires the setting of specific parameters for the calculation of these items:

- Labour: the economic impact of the section is strictly related to plant type and location. The user can adjust the different voices in agreement with his needs. In determining costs for labour, account must be taken of the type of worker required, geographic location of the plant, prevailing wages rates, and worker productivity.

  For general chemicals processing, operating labour usually amounts to about 10 to 20 percent of the total product cost. In preliminary cost analysis, the quantity of operating labour can often be estimated either from company experience with similar processes or from published information on similar processing. The method of estimating labour requirements considered in the model is a function of plant capacity that adds the various principal processing steps on the flow sheet. In this method, a process step is defined as any unit operation, unit process, or combination thereof that takes place in one or more units of distillation, evaporation, filtration, etc.

- Maintenance: constitute an important and necessary budget item in any healthy manufacturing operation. These expenses are proportional to an operation's size, scale, and complexity. Generally, in the process industry, the maintenance and repair cost is estimated as a percentage of the capital investment and ranges from 2 to 10 percent of the fixed capital investment.

Regarding the capital investments costs, they have been considered as divided by plant section; the cost of each section has been adjusted to the selected plant size through power law, with the proper exponent set according to the section type. Key equipment costs have been evaluated based on existing offers, Biochemtex worldwide experience and finally validated through process simulation software and available databases.

Capital investment have been estimated only for the sections included in the battery limits that include raw material handling, the hydrolysis and fermentation sections and ethanol purification. They do not consider any costs related to the auxiliary equipments and the disposal of waste products outgoing the auxiliary sections of the plant.

8.6.2 Output of the assessment

The output of the assessment is divided in process and economics data.

Process output:

- Ethanol yield: expressed as the amount of dry biomass needed to produce 1 ton of bioethanol (biomass consumption)
- Consumables consumption
- Lignin total production: lignin cake is separated from sugars during the saccharification process and it represents a relevant energy source for the overall process. The total amount could be affected by biomass type and process parameters.

- Concentrated stillage production
- Overall plant duty: the output, expressed as energy unit per year, represent the net plant duty as difference between energy plant requirements and energy content recovered from the available lignin and concentrated stillage.

Economics output:

- Second generation ethanol operating costs: the cash cost of 2G-ethanol is the sum of variable and fixed production costs.
- Plant capital investment

8.7 Further results of the economic assessment

This chapter contains further detailed economic assessment results, which cannot be shown in chapter 4.3 due to space constraints.

For every scenario analysed, all the key process and economics parameters considered have been summarised in the following tables. They report the estimation of total production costs and the detail of variable and fixed production costs estimates for a standard case, that is a system in which the expected performances for a mature technology facility have been estimated, and two different cases in which the system performs better (favourable case) or worse (less favourable case) than the standard.

8.7.1 Main scenario

The analysis focuses on the reference case for an ethanol facility in Central Europe of 100 kt per year dry ethanol plant, in the hypothesis that Arundo donax is used as feedstock for a continuous production system (8,000 hours per year).

Tab. 8-17 Production cost results for a 100 kt / a 2nd generation ethanol from Arundo donax

			Arundo		
			Favourable	Standard	Less Favourable
OUTPUT	Variable	UoM	Value	Value	Value
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.3	4.5	4.7
	Enzyme solution consumption	X	2/3	1	1 2/3
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 215	€ 225	€ 235
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 72	€ 98	€ 150
	Fuel	€/ton EtOH	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ -	€ -	€ -
	Surplus lignin cake sold	€/ton EtOH	-€ 11	-€ 10	-€ 6
	EtOH variable production cost	**€/ton EtOH**	**€ 276**	**€ 313**	**€ 379**
	Fixed production costs	€/ton EtOH	€ 66	€ 68	€ 70
	EtOH cash cost	**€/ton EtOH**	**€ 342**	**€ 381**	**€ 449**
	Fixed Capital Investment	MM €	€ 82	€ 89	€ 112
	Capital charge	€/ton EtOH	€ 96	€ 104	€ 131
	EtOH production cost	**€/ton EtOH**	**€ 438**	**€ 485**	**€ 580**

8.7.2 Additional scenarios: feedstock

The analysis has been driven by the same process and economic assumptions that have been made for the main scenario, but it shows the main differences between the main scenario and alternative scenario with the use of different feedstocks, such as wheat straw and fibre sorghum.

Tab. 8-18 Production cost results for a 100 kt / a 2nd generation ethanol from wheat straw

			Wheat straw		
			Favourable	Standard	Less Favourable
OUTPUT	Variable	UoM	Value	Value	Value
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.0	4.2	4.4
	Enzyme solution consumption	X	2/3	1	1 2/3
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 200	€ 210	€ 220
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 72	€ 98	€ 150
	Fuel	€/ton EtOH	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ -	€ -	€ -
	Surplus lignin cake sold	€/ton EtOH	-€ 3	-€ 3	€ -
	EtOH variable production cost	**€/ton EtOH**	**€ 269**	**€ 305**	**€ 370**
	Fixed production costs	€/ton EtOH	€ 64	€ 66	€ 67
	EtOH cash cost	**€/ton EtOH**	**€ 333**	**€ 371**	**€ 437**
	Fixed Capital Investment	MM €	€ 80	€ 88	€ 109
	Capital charge	€/ton EtOH	€ 93	€ 103	€ 127
	EtOH production cost	**€/ton EtOH**	**€ 426**	**€ 474**	**€ 564**

Tab. 8-19 Production cost results for a 100 kt / a 2nd generation ethanol from fibre sorghum

			Fiber Sorghum		
			Favourable	Standard	Less Favourable
OUTPUT	Variable	UoM	Value	Value	Value
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.9	5.1	5.3
	Enzyme solution consumption	X	2/3	1	1 2/3
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 245	€ 255	€ 265
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 77	€ 103	€ 155
	Fuel	€/ton EtOH	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ 49	€ 58	€ 72
	Surplus lignin cake sold	€/ton EtOH	€ -	€ -	€ -
	EtOH variable production cost	**€/ton EtOH**	**€ 371**	**€ 416**	**€ 492**
	Fixed production costs	€/ton EtOH	€ 64	€ 66	€ 67
	EtOH cash cost	**€/ton EtOH**	**€ 435**	**€ 482**	**€ 559**
	Fixed Capital Investment	MM €	€ 94	€ 103	€ 128
	Capital charge	€/ton EtOH	€ 110	€ 120	€ 150
	EtOH production cost	**€/ton EtOH**	**€ 545**	**€ 602**	**€ 709**

8.7.3 Sensitivity: biomass costs

From an economical point of view, the study for the determination of the sustainability of the system has considered five different total biomass production costs in the hypothesis that Arundo donax is used as feedstock for the reference case.

Tab. 8-20 Production cost results for a 100 kt / a 2nd generation ethanol from Arundo donax in the sensitivity analysis on biomass cost

			Arundo			
			Standard	Standard	Standard	Standard
OUTPUT	Variable	UoM	Value	Value	Value	Value
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.5	4.5	4.5	4.5
	Enzyme solution consumption	X	1	1	1	1
ECONOMIC INPUT	**Biomass Cost**	€/ton dry biomass	€ 40	€ 50	€ 70	€ 100
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 180	€ 225	€ 315	€ 450
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 98	€ 98	€ 98	€ 98
	Fuel	€/ton EtOH	€ -	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ -	€ -	€ -	€ -
	Surplus lignin cake sold	€/ton EtOH	-€ 10	-€ 10	-€ 10	-€ 10
	EtOH variable production cost	**€/ton EtOH**	**€ 268**	**€ 313**	**€ 403**	**€ 538**
	Fixed production costs	€/ton EtOH	€ 68	€ 68	€ 68	€ 68
	EtOH cash cost	**€/ton EtOH**	**€ 336**	**€ 381**	**€ 471**	**€ 606**
	Fixed Capital Investment	MM €	€ 89	€ 89	€ 89	€ 89
	Capital charge	€/ton EtOH	€ 104	€ 104	€ 104	€ 104
	EtOH production cost	**€/ton EtOH**	**€ 440**	**€ 485**	**€ 575**	**€ 710**

8.7.4 Sensitivity: enzymes

The enzyme cost impact on the final production cost of one tonne of ethanol has been normalised on the basis of a standard value (set according to Biochemtex experience) which is expressed as “1X”. It basically depends on the enzyme dosage, performance and price.

Five scenarios have been considered for the sensitivity analysis, centred on the reference case (1X). In order to not introduce an additional uncertainty factor, the simulation does not assume any variation of the specific price of the enzyme between the different scenarios.

Tab. 8-21 Production cost results for a 100 kt / a 2nd generation ethanol from Arundo donax in the sensitivity analysis on enzyme impact cost

			Arundo				
			Standard	Standard	Standard	Standard	Standard
OUTPUT	Variable	UoM	Value	Value	Value	Value	Value
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.5	4.5	4.5	4.5	4.5
	Enzyme solution consumption	X	1/3	2/3	1	1 1/3	1 2/3
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 225	€ 225	€ 225	€ 225	€ 225
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 46	€ 72	€ 98	€ 124	€ 150
	Fuel	€/ton EtOH	€ -	€ -	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ -	€ -	€ -	€ -	€ -
	Surplus lignin cake sold	€/ton EtOH	-€ 10	-€ 10	-€ 10	-€ 10	-€ 10
	EtOH variable production cost	**€/ton EtOH**	**€ 261**	**€ 287**	**€ 313**	**€ 339**	**€ 365**
	Fixed production costs	€/ton EtOH	€ 68	€ 68	€ 68	€ 68	€ 68
	EtOH cash cost	**€/ton EtOH**	**€ 329**	**€ 355**	**€ 381**	**€ 407**	**€ 433**
	Fixed Capital Investment	MM €	€ 89	€ 89	€ 89	€ 89	€ 89
	Capital charge	€/ton EtOH	€ 104	€ 104	€ 104	€ 104	€ 104
	EtOH production cost	**€/ton EtOH**	**€ 433**	**€ 459**	**€ 485**	**€ 511**	**€ 537**

8.7.5 Other sensitivity analyses

The regional variability influence on the economics of the standard case of main scenario (100 kt per year dry ethanol plant from Arundo donax) has been studied in terms of costs of labour and maintenance of the plant for three different European locations.

Tab. 8-22 Production cost results for a 100 kt / a 2nd generation ethanol from Arundo donax in the sensitivity analysis on European locations

			Arundo		
			Standard	Standard	Standard
OUTPUT	Variable	UoM	CENTRAL	NORTHERN	EASTERN
PROCESS OUTPUT	Biomass consumption	dry ton/ton EtOH	4.5	4.5	4.5
	Enzyme solution consumption	X	1	1	1
ECONOMIC OUTPUT	Biomass	€/ton EtOH	€ 225	€ 225	€ 225
	Consumables (Chemicals and enzyme)	€/ton EtOH	€ 98	€ 98	€ 98
	Fuel	€/ton EtOH	€ -	€ -	€ -
	EE exported (-) / purchased (+) to/from grid	€/ton EtOH	€ -	€ -	€ -
	Surplus lignin cake sold	€/ton EtOH	-€ 10	-€ 10	-€ 10
	EtOH variable production cost	**€/ton EtOH**	**€ 313**	**€ 313**	**€ 313**
	Fixed production costs	€/ton EtOH	€ 68	€ 83	€ 18
	EtOH cash cost	**€/ton EtOH**	**€ 381**	**€ 396**	**€ 331**
	Fixed Capital Investment	MM €	€ 89	€ 89	€ 89
	Capital charge	€/ton EtOH	€ 104	€ 104	€ 104
	EtOH production cost	**€/ton EtOH**	**€ 485**	**€ 500**	**€ 435**

8.8 Further SWOT results

The following SWOT matrices supplement the results presented in chapter 4.4.1.

8.8.1 Fibre sorghum

Fibre sorghum is a second feedstock for BIOLYFE. The strengths, weaknesses, opportunities and threats for fibre sorghum cultivation are defined in comparison to other agricultural crops that are common in Europe and can be used for energy purposes (wheat, sugar beet, rapeseed, perennial grasses like Arundo, etc.). The aim of the analysis is to identify success and failure factors and help farmers and biorefining companies to decide on suitable feedstocks.

Tab. 8-23 SWOT analysis for fibre sorghum as energy crop

Strengths	Weaknesses

• S1: **Annual crop** → can be integrated easily into a crop rotation. Does not bind the farmer to sorghum production for a longer time. Same yields from 1st year on.
• S2: **Robust crop** with regard to the following aspects. This makes sorghum suitable for the cultivation on some types of low fertility soil.
  ◦ S2a: Survives temporary waterlogging.
  ◦ S2b: Can grow in a broad environmental range and under a broad range of soil conditions.
  ◦ S2c: High nutrient use efficiency compared to other annual crops like e.g. maize.
  ◦ S2d: High drought tolerance compared to other crops as e.g. maize.
  ◦ S2e: High salinity tolerance (but: careful establishment in saline soils required).
• S3: **Suitable biomass properties:**
  ◦ S3a: High sugar content in stem → can be easily fermented to ethanol.
  ◦ S3b: Sorghum cellulose is of low crystalinity, which increases efficiency of enzymatic hydrolysis.
• S4: **High yielding** (15-30 t dry matter per year).
• S5: **Long-time experience** in sorghum cultivation available from outside Europe. High acceptance amongst farmers because of successful cultivation experience in other regions of the world.
	• W1: **Annual crop**
	  ◦ Has to be re-established each year. → **higher expenditures compared to perennial crops**.
	• W2: Higher erosion risk compared to perennials.
	• W3: **Sensitive crop** with regard to the following aspects:
	  ◦ W3a: Does not like stagnant moisture.
	  ◦ W3b: Needs high temperature for germination (ca. 12°C). Not frost tolerant.
	  ◦ W3c: High salinity can inhibit germination.
	• W4: Susceptibility to diseases and pests; low competitiveness against weeds in early development stages → demand for remarkable amounts of pesticides / fungicides.
	• W5: Many cultivars are susceptible to lodging, in particular in locations with strong winds.
	• W6: Weaknesses in **biomass properties**
	  ◦ W6a: Can contain relevant amounts of prussic acid → toxicity if used as feed, effects on fermentation not clear.
	  ◦ W6b: High moisture content at harvest (above 40 %): Need for drying
	  ◦ W6c: Sugars in sorghum degrade fast → difficult to store, has to be processed quickly.
	• W7: **New cultivar as bioenergy crop in Europe**
	• W8: Sorghum is not a traditional crop in Europe → **lack of experience** and possibly lack of acceptance amongst European farmers.

Tab. 8-23 SWOT analysis for fibre sorghum as energy crop (continued)

Strengths	**Weaknesses**
• S6: **Cultivation methods available**: Methods used for other row crops such as maize can be easily adapted to sorghum. Machineries used for other grain and green biomass crops can be used for sorghum cultivation. • S7: Low ability to spread naturally → **low risk of invasiveness** to natural ecosystems. • S8: **Short growing period: harvest after 90-120 days → can be cultivated as catch crop / second crop.** • S9: **Crop establishment can be done cheap and easily by seeding.** • S10: **Flexible use**: Suitable also for food and feed production. • S11: Could be cultivated as a ratoon crop (but with lower yields!). • S12: High amount of organic residues after harvest contribute to soil enhancement. • S13: Currently no GMO varieties on the market: beneficial for European markets because of low acceptance of GMOs in Europe.	• W9: High genetic variety → inhomogeneity → suitable varieties and traits have to be identified, further breeding needed. Lack of knowledge on sorghum genetic, interactions between genetics and environment. • W10: Commercial seed availability very limited in Europe • W11: **Mechanical harvesting technologies for separate harvest** of seed, stalk and leaf are not yet mature. • W12: Sweet Sorghum has **short harvesting season**, usually 20-40 days. • W13: High feedstock demand for large scale processing units may be an **incentive for too narrow crop rotations** and a too high percentage of arable land used for sorghum cultivation. • W14: Intellectual Property (IP) issues hinder free sharing of germplasm among sorghum researchers. • W15: Sorghum is traditionally used for feed and food production → **direct competition for food and feed.**
Opportunities	**Threats**

• O1: **High genetic variability provides good breeding opportunities** to create new improved varieties. New hybrid seeds for European conditions under development → could facilitate availability of high performance seeds.
• O2: Came into the focus of research only in recent years → improvements likely if **more efforts are made in sorghum research.**
• O3: CGIAR proved that enhanced cultivars originating from research in one specific region are in many cases highly transferable across different environments. Thereby, farmers in many regions of the world could profit from increased investment in sorghum breeding in some regions.
	• T1: **New pests** can occur in case of an increased and intensified production in Europe.
	• T2: **May turn out to be not economically feasible**:
	  ◦ T2a: Other crops and renewable energy carriers could turn out to be cheaper, making sorghum cultivation for bioenergy uneconomic.
	  ◦ T2b: Increased prices for agricultural means of production may also affect the economy of sorghum cultivation.
	  ◦ T2c: Changes in ethanol-promoting policies as well as trade policies may negatively affect the prospects of sorghum ethanol (sorghum is also food crop!).
	• T3: Because of good response to fertiliser input → **incentive for high input cultivation on fertile land** → increased competition to food and feed is likely.
	• T4: **Stable crop of the most food insecure people in Africa → fuel / food competition.** Care has to be taken that those people are not affected by competition for land and biomass nor affected by intellectual property rights issues.

8.8.2 Comparison of different cultivation systems

The SWOT analysis in BIOLYFE also considers different cultivation systems for Arundo donax and fibre sorghum. The results are described in the following three tables.

Tab. 8-24 SWOT analysis on high input cultivation of herbaceous crops on fertile land

Strengths	**Weaknesses**
General • S1: High yields per hectare → high use efficiency of the limited resource “arable land”. • S2: High biomass production within a certain distance from the processing unit technically achievable → lower transport costs. Sorghum • S3: Good response to additional N fertiliser. Arundo • -	General • W1: High competition with other uses for the available traditional cultivated land. • W2: Displacement of food and feed production. Sorghum • - Arundo • W3: Poor response to N fertilisation. • W4: High fertilisation lowers energy return per energy input.
Opportunities	**Threats**
General • O1: High income opportunities for farmers in case of comparatively low prices of means for agricultural production. • O2: Additional income opportunity for farmers who could not economically use their land because of a lack in market opportunities (fallow land). Sorghum • - Arundo • -	General • T1: Negative social impacts: Displacement of food production (land use change) can lower global food availability and lead to rising food prices. In the worst case, rising food prices can increase mortality by hunger in developing countries because people cannot afford the daily food anymore. Sorghum • - Arundo • -

Tab. 8-25 SWOT analysis on low input cultivation of herbaceous crops on fertile land

Strengths	**Weaknesses**
General • S1: Efficient use of scarce nutrient and water resources. • S2: High energy return per energy input. Sorghum • - Arundo • S3: Only little less yields compared to high input systems.	General • W1: Competition with other uses for the available traditional cultivated land is higher compared to high input cultivation. • W2: Displacement of food and feed production even higher because more land is needed to produce the same amount of biomass. Sorghum • W3: Pesticides cannot be omitted without severe threats for yields. Arundo • -
Opportunities	**Threats**
General • O1: Additional income opportunity for farmers who could not economically use their land because of a lack in market opportunities. Sorghum • O2: Sorghum as annual crop can be rotated with legumes as an organic nitrogen source. Arundo: • O3: Intercropping systems with Arundo and legumes could be developed to reduce mineral nitrogen demand.	General T1: Negative social impacts might be even worse than in high input cultivation systems because of higher land demand for the same biomass yield. Displacement of food production can lower global food availability and lead to rising food prices. In the worst case, rising food prices can increase mortality by hunger in developing countries because people cannot afford the daily food anymore.

Tab. 8-26 SWOT analysis on low input cultivation of herbaceous crops on marginal land, which is idle (abandoned) for economic reasons, e.g. because of low fertility soils

Strengths	Weaknesses

General
• S1: Additional income opportunity in rural areas.
• S2: No or little competition to food and feed production.
• S3: Large marginal land areas available.
Sorghum
• S4: Suitable for cultivation on marginal lands because of high drought tolerance.
Arundo
• S5: Suitable for cultivation on marginal lands because of saline tolerance, metal tolerance (contaminated land!) and tolerance to stagnant moisture.
• S6: Low demand for fertilisers and pesticides → suitable for low input systems.
	General
	• W1: No clear definition available for "marginal land".
	• W2: Marginal land might have other functions that are no longer fulfilled if the land is used for cultivation of lignocellulose crops. These functions could be e.g.
	  • W2a: Being a habitat for endangered wildlife.
	  • W2b: Being used by local population for recreation, collection of plants, mushrooms, wood etc.
	  • W2c: Being used for pasturing.
	• W3: Infrastructure in many cases not existing or weak.
	Sorghum
	• W4: Pesticides cannot be omitted without threats for yields → not very suitable for low input systems.
	Arundo
	• W5: Lower yields if soil is too poor.

Opportunities	**Threats**
General: • O1: Increased adaptability of crops to marginal land by progress in breeding. Sorghum - Arundo -	General: • T1: Negative environmental impacts in case the marginal land has high ecological value or high biodiversity. • T2: Negative social and economic impacts if the marginal land is used by local populations, e.g. for pasturing, collection of wood etc. Sorghum - Arundo -

8.8.3 Use of straw as feedstock for bioethanol production

Straw and corn stover is another option to feed second generation bioethanol plants. The strengths, weaknesses, opportunities and threats are defined mainly in comparison to cultivated lignocellulosic biomass.

Tab. 8-27 SWOT analysis for the use of straw as feedstock for bioethanol production

Strengths	**Weaknesses**

• S1: Additional **income opportunity for farmers** without change in production patterns (but: for livestock farmers as straw buyer the income could decrease!)
• S2: Agricultural by-product → **no additional land use.**
	• W1: **Risk for environmental sustainability**:
	  ◦ W1a: Regular high extraction rates reduce soil fertility (soil biodiversity and soil carbon content) and increases erosion risk.
	  ◦ W1b: Increases extraction of nutrients → need for higher mineral fertiliser inputs.
	  ◦ W1c: Sustainable extraction rate depends on pedoclimatic conditions and cultivation systems → efforts needed to define the extraction rates
	• W2: **Low biomass yield per hectare** (wheat: up to 8 t per hectare if 100 % of the straw is extracted, but this is not recommendable). Reduction of straw length on high yield cultivars.
	• W3: **Production depends from cereal production, not from demand for bioethanol**.
	  ◦ W3a: Farmers are not willing to sign long term contracts
	  ◦ W3b: High variability in straw availability between years is a risk for constant feedstock supply to the biorefinery
	• W4: **Harvest only once a year.** Storage facilities needed for year round storage (high volume because of low density of balls, rain protection needed).
	• W5: **Harvest is in time with high agricultural work load**: Seasonal workers and new machineries needed
	• W6: **Competition** with other uses (livestock production, combustion, thermochemical conversion, biorefineries for production of high value chemicals)
	• W7: **Many farmers** have to be involved, this is a risk for successfully establishing the supply chain.

Opportunities	**Threats**
• O1: On some sides, straw extraction can have **positive effects on agricultural productivity**: Straw residues can be hosts of pests and harm following crops • O2: **Long-stem-varieties** could be bred to increase straw yields • O3: **High straw potential in some regions** • O4: **Nutrient efficiency** can be increased by returning stillage or ashes	• T1: **Withdrawal of straw from conventional uses** → negative economic and social effects for those who used straw for conventional purposes, e.g. for animal bedding. • T2: **Decrease of soil fertility** if no mandatory environmental sustainability criteria applied. • T3: Increased frequency of droughts because of **climate change** could decrease straw availability • T4: **High competition** with other users can lead to insufficient straw availability •

8.8.4 Feedstock mixes

In the following, the advantages and disadvantages of using a feedstock mix are described in comparison to single feedstock plants.

Tab. 8-28 SWOT analysis for the use of feedstock mixes in 2nd generation bioethanol plants

Strengths	Weaknesses

• S1: **Higher biomass availability**, because supply relies on different crops.
• S2: **Higher flexibility** if plant can run on different feedstocks:
  • Lower risk of a lack of feedstocks
  • Low Arundo availability in the first year can be compensated by a higher share of sorghum or straw
  • Different harvest times for straw, sorghum and Arundo: Shorter storage, biomass does not have to be stored for an entire year.
	• W1: **Difficult to adopt sensitive biochemical process to changing biomass properties →** conversion in batch mode instead of continuous mode.

Opportunities	**Threats**
• O1: Process adaptation to different feedstocks may become easy by **technological development**.	• T1: **Efficiency losses** because of adaptation to different feedstocks → lower bioethanol yields per kg of dm, may decrease economic performance.

8.8.5 Discussion of key issues of SWOT analysis

During the international workshop held in Madrid, some key issues for the success of BIOLYFE systems were discussed. The results of the discussion are summarised in the following.

8.8.5.1 Avoidance of negative impacts of too high straw extraction rates

The challenge

Straw is a main feedstock for lignocellulosic ethanol. As a residue, it has a potentially high sustainability combined with low prices and low competition. Selling of straw is an additional income opportunity for farmers and contributes to rural development. But too high straw extraction rates can have a negative impact on soil fertility and thereby reduce straw availability in the future and the sustainability of the entire value chain. The total straw availability is considered high (about 50 Mio t in Europe) but on a regional scale sufficient straw availability for an industrial bioethanol plant can be critical. Competition with traditional uses (animal bedding) and other innovative uses (use for direct combustion in CHP plants) limits straw availability for lignocellulosic ethanol plants. A high demand for straw combined with limited regional straw availability might increase the "temptation" of unsustainably high extraction rates.

What has to be considered?

The sustainable straw extraction rate differs remarkably between regions because it depends on pedoclimatic conditions. Furthermore, the sustainable extraction rates also depend on tillage systems. Further research is needed to come up with side specific values. There is still a knowledge gap on “real” surplus of using straw as feedstock under consideration of long-term soil fertility effects.

The regional availability of straw has to be considered by planning bioethanol plants to avoid incentives for unsustainable farming practices. There are regions with high straw potential, e.g. in Eastern Europe, but also regions with very limited biomass potential. Leaving straw on the field can also have negative impacts on the agricultural production: In some regions in Eastern Europe, burning of straw was a common practice until some years ago, and nowadays the straw residues are sometimes a problem for establishment of following crops. Furthermore, straw left on the fields can be a source of pests and fungi, and hence higher extraction rates lower the negative implications. Such technical and agricultural aspects can increase the willingness of farmers to harvest the straw, but do not necessarily go in line with scientifically sound sustainability parameters. The nutrient availability in the soils could be increased by returning the stillage or ashes to the soil.

Straw availability varies between years, putting the sustainable biomass supply at risk in low yielding years. There are some models available for harvest predictions that could be applied to estimate straw harvest some month in ahead but not more.

The availability of straw could be increased by breeding new long-stem-varieties. But farmers prefer short stem varieties because they are less sensible to breakdown by wind and heavy rainfalls. The willingness to crow long-stem-varieties might grow if economic opportunities for straw selling increase.

8.8.5.2 Cooperation between farmers and industries

Introduction

A good cooperation between farmers and industries is unavoidable to achieve sustainable biomass supply chains. The cooperation between farmers and 2nd generation biofuel industries is not yet fully established, in particular with regard to the cultivation of bioenergy crops like Arundo, which are currently cultivated only on a small scale. Farmers are motivated to grow bioenergy crops or to sell straw to the biofuel industry because of additional income opportunities. On the other hand, agronomical, technical or social difficulties may hinder them to shift to bioenergy crop cultivation. E.g., a lack of knowledge with regard to perennial grass cultivation may hinder farmers to plant Arundo.

What has to be considered?

Different options to increase cooperation between farmers and industries are available. The key points are economic incentives and knowledge. It is considered crucial to involve farmers unions and regional institutions to facilitate the communication between industries and the large numbers of farmers. The economic incentives could be increased by making farmers shareholders of the processing plants, by grounding farmer cooperations that can deliver the biomass more efficiently by sharing infrastructure, logistics and knowledge. Industries and policy makers could support trainings for farmers and exchange of experience amongst farmers in different regions.

8.8.5.3 Logistics and storage

Introduction

Mature 2nd generation bioethanol plants require very large amounts of feedstocks (some hundred t DM per plant and year). This requires efficient logistics. Some types of biomass (e.g. straw) have only one harvest period per year and have to be stored year round. Others (e.g. Arundo) are more flexible in harvest time but require drying. If bioenergy crops are grown on idle (abandoned) land in remote areas, the infrastructure is often not sufficiently developed.

What has to be considered?

Transportation of feedstock to plant should be centralised: use of bigger trucks is more appropriate than small farm vehicles. However, centralised transport requires organisation between farmers' organisations and the biomass company. In some regions, governmental support might be needed because of too high transportation costs. Farmers should be encouraged to organise themselves but likely support of farmers by policy and industries is needed.

Besides transportation, storage is a big issue. The large amounts of biomass needed to run a 2nd generation bioethanol plant should be stored decentralised if possible to avoid very large storage sites at the plant. But it has to be considered that decentralised storage at the farm causes costs for the farmers. Suboptimal storage at farms could lower biomass quality and biomass availability. Two main issues are moisture content and pests. If the biomass is too wet, technical drying is needed which is costly. Solar drying on the field is cheaper but not always possible. The moisture content depends very much on weather conditions and is very variable; hence, costs for drying are volatile. Facilities for technical drying are expensive and uneconomic at small scale (farm level). Storage on unpaved soil increases the risk of pests (mice) and moisture damage. The same applies to holes in the covering foil that can occur e.g. through storms. Paving the storage ground is expensive for the farmers.

8.8.5.3.1 Acceptance and public support

Introduction

A successful establishment of 2nd generation bioethanol on European markets can only be achieved with public support and public acceptance. Up to now, the EC strongly supported the research and development of the technologies. But the public acceptance of biofuels is low because of feared negative impacts on engines and sustainability issues, in particular the food vs. fuel debate and environmental concerns, even though the acceptance of 2nd generation biofuels is higher compared to first generation biofuels.

What has to be considered?

Acceptance is a very important issue because, if bioethanol plants are not accepted by the public, there will be a low market potential for bioethanol and a low willingness of farmers to deliver biomass. Eventually the plants will not even get a building permit. Public acceptance is influenceable via media by public and private actors. There are some actors that have an economic interest to lower acceptance for biofuels (e.g. some car companies). Other actors fear environmental or social harms and therefore campaign against biofuels. The acceptance can only be increased in a sustainable way by delivering true, profound and transparent information. This requires efforts by companies as well as by policy makers who want to establish the new technologies. An indispensable part of the efforts will be the development of credible strategies to avoid the negative impacts of biorefining. In particular, sustainability criteria and strategies to achieve compliance have to be set up. The communication efforts should highlight on the other hand the advantages of biorefining in comparison to realistic alternatives (e.g., carbon fuels). Creating jobs and income in rural areas is considered a good basis for high acceptance amongst the local population.

8.8.5.4 Economic performance of 2nd generation bioethanol plant

Introduction

If 2nd generation bioethanol plants are not economically competitive with other fuel plants, they cannot succeed on the market. Even though remarkable cost reductions could be achieved by R&D during the last years (e.g.: reduction of enzyme costs), the production costs are still high, leading to high prices of 2nd generation biofuels, which are not yet competitive without subsidies.

What has to be considered?

It has been stated repeatedly by companies that they are economic competitive with conventional fuels. Nevertheless, other companies still see large economic risks that hinder construction of biorefinery plants: Notably long-term stable policy is a precondition for large investments. EC should guarantee long-term stable policies, at least by grandfathering already established plants in the case of future policy changes. Another main difficulty for starting 2nd generation biorefining are high investment costs. Policy makers could lower the burden by financially supporting the companies to fasten the establishment of the new technology. Companies on the other hand should not rely the production on one feedstock only, because a shortage in this particular feedstock would be a severe risk for the plants economy.

8.9 Further results of the integrated assessment

The following chart provides an overview of the complete dataset for the integrated assessment, which cannot be shown in chapter 4.5 due to space constraints.

			Standard conditions							Less favourable conditions				Favourable conditions				Standard conditions							
			BIOLYFE scenarios							BIOLYFE scenarios				BIOLYFE scenarios				Alternatives to BIOLYFE							
	Indicator	Unit	Arundo	Fibre sorghum	Wheat straw	Biopoly-mers (Arundo)	High enzyme demand (Arundo)	Low enzyme demand (Arundo)	Low fertility soil (Arundo)	Arundo	Fibre sorghum	Wheat straw	Biopoly-mers (Arundo)	Arundo	Fibre sorghum	Wheat straw	Biopoly-mers (Arundo)	BTL 1 (Arundo)	BTL 2 (Arundo)	Wheat ethanol	Beet ethanol	Corn ethanol (US)	Cane ethanol (Brazil)	Rape seed biodiesel	Maize bio-methane
Technology	Maturity	-	- -	-	-	- -	- -	- -	- -	- -	-	-	- -	- -	-	-	- -	- -	- -	0	0	0	0	0	0
	Availability of infrastructure	-	- -	- -	-	- -	- -	- -	- -	- -	- -	-	- -	- -	- -	-	- -	- -	- -	0	0	0	0	0	0
	Use of GMOs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Toxicity risks	-	+	0	+	+	+	+	+	+	0	+	+	+	0	+	+	0	0	0	0	0	+	0	0
	Risk of explosions and fires	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+
Environment	Resource depletion: energy	GJ / t ethanol (eq.)	-21	-8	-22	-28	-18	-23	-21	-17	-2	-18	-22	-23	-12	-24	-32	-25	-9	-34	-14	-14	-34	-39	-34
	Climate change	t CO_2 eq. / t ethanol (eq.)	-1.3	-0.2	-1.3	-1.6	-1.1	-1.3	-1.2	-0.9	0.2	-1.0	-1.2	-1.4	-0.4	-1.4	-1.8	-1.6	-0.4	-2.1	-1.2	-0.7	-2.7	-1.9	-1.2
	Acidification	kg SO_2 eq. / t ethanol (eq.)	9	17	8	9	10	8	9	11	20	10	11	8	16	7	7	5	5	3	0	9	12	12	15
	Terrestrial eutrophication	kg PO_4 eq. / t ethanol (eq.)	1.0	2.2	0.9	1.0	1.1	1.0	1.0	1.2	2.3	1.1	1.1	0.9	2.0	0.9	0.9	0.9	0.8	0.9	0.2	1.6	1.5	2.7	2.6
	Aquatic eutrophication	kg PO_4 eq. / t ethanol (eq.)	2.1	7.6	3.2	2.0	2.2	2.1	2.0	2.3	7.9	3.4	2.2	1.9	7.3	2.9	1.9	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	Photochem. ozone formation	kg ethene eq. / t ethanol (eq.)	-1.1	-1.0	-1.2	-1.0	-1.1	-1.1	-1.1	-1.0	-0.9	-1.1	-0.8	-1.2	-1.1	-1.3	-1.1	-0.9	-0.8	-1.6	-1.2	-1.3	-0.3	-0.2	-0.7
	Ozone depletion	g CFC-11 eq. / t ethanol (eq.)	28	52	28	29	29	28	28	31	54	30	31	26	50	25	26	13	10	12	-7	33	16	52	37
	Respiratory inorganics	kg PM10 eq. / t ethanol (eq.)	6	12	5	6	7	6	6	8	13	7	7	5	11	5	5	2	3	0	0	4	11	5	7
	Direct agricultural land use	ha·a / t ethanol (eq.)	0.15	0.20	0.00	0.15	0.15	0.15	0.23	0.19	0.33	0.00	0.19	0.12	0.16	0.00	0.12	0.20	0.15	0.66	0.16	0.49	0.24	0.94	0.33
	Water	-	- -	-	0	- -	- -	- -	-	- -	-	0	- -	- -	-	0	- -	- -	- -	0	-	-	-	-	-
	Soil	-	0	-	0	0	0	0	- -	0	-	0	0	0	-	0	0	0	0	-	- -	- -	0	- -	- -
	Fauna	-	0	-	0	0	0	0	- -	0	-	0	0	0	-	0	0	0	0	-	-	-	-	-	-
	Flora	-	-	-	0	-	-	-	- -	-	-	0	-	-	-	0	-	-	-	-	- -	- -	-	-	- -
	Landscape	-	0	0	0	-	-	-	0	-	-	0	-	0	0	0	-	0	0	0	0	0	-	0	0
Economy	Production costs	€ / t ethanol (eq.)	485	602	474	485	537	459	485	580	709	564	580	438	545	426	438	900	900	850	670	690	470	860	940
	Cost difference to gasoline*	€ / t ethanol (eq.)	-115	-232	-104	N/A	-167	-89	-115	-210	-339	-194	N/A	-68	-175	-56	N/A	-530	-530	-480	-300	-320	-100	-490	-570
	Fixed capital investment	Million €	89	103	88	89	89	89	89	112	128	109	112	82	94	80	82	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	CO_2 avoidance costs	€ / t CO_2 eq.	91	N/A	81	N/A	151	67	93	222	N/A	193	N/A	47	423	39	N/A	323	323	224	250	450	38	263	456
	Energy resource savings costs	€ / GJ	5	27	5	N/A	9	4	6	13	N/A	11	N/A	3	15	2	N/A	21	21	14	22	22	3	12	17
Society	Local community and farmers																								
	Access to land	-	- -	- -	0	- -	- -	- -	-	- -	- -	0	- -	- -	- -	0	- -	- -	- -	- -	- -	- -	- -	- -	- -
	Access to jobs & income	-	+	+	++	+	+	+	++	+	+	++	+	+	+	++	+	+	+	+	+	+	0	+	+
	Acceptance	-	- -	+	++	- -	- -	- -	++	- -	+	++	- -	- -	+	++	- -	- -	- -	+	+	+	+	+	+
	General society																								
	Acceptance	-	-	- -	-	-	-	-	-	-	- -	-	-	-	- -	-	-	-	-	- -	- -	- -	- -	- -	- -
	Contribution to innovation	-	++	+	+	++	++	++	++	++	+	+	++	++	+	+	++	++	++	0	0	0	0	0	0

Fig. 8-7 Complete dataset selected for the integrated assessment including additional indicators on avoidance costs. All relative quantities are expressed on a product basis (per tonne of ethanol). For details please refer to chapter 4.5.1 and 4.5.2.

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