BIOCORE

BIOCOmmodity REfinery

Grant agreement no. : FP7-241566

Collaborative project

Seventh framework programme

BIOREFINERY

Integrated sustainability assessment of the BIOCORE biorefinery concept (D 7.6)

Due date: February 28th, 2014

Actual submission date: February 28th, 2014 (Update March 31st 2014)

Project start date: March1st, 2010 **Duration**: 48 months

Work package concerned: 7

Concerned work package leader: IFEU

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Dissemination level: PU

BIOCORE:

WP 7: Integrated assessment of overall sustainability

Integrated sustainability assessment of the BIOCORE biorefinery concept (D 7.6)

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Suggested citation:

Rettenmaier, N. *et al.*, Integrated sustainability assessment of the BIOCORE biorefinery concept, Report prepared for the BIOCORE project www.biocore-europe.org, Heidelberg, 2014

Acknowledgements

The authors would like to thank all BIOCORE partners for the provision of the data, which forms the basis of the sustainability assessment and especially the colleagues from NTUA for their invaluable contributions regarding data collection and aggregation into comprehensive technical models. We are very grateful to Stephan Piotrowski, Fabrizio Sibilla and Michael Carus from the nova-Institut; Rocio Diaz-Chavez from Imperial College London; Shilpi Kapur, Souvik Bhattacharjya and Ipsita Kumar from TERI as well as Hanna Pihkola and Klaus Niemelä from VTT for the close and successful collaboration within work package 7 and their input for this report. We thank all partners involved in work package 1 for the fruitful collaboration and for invitations to their internal meetings. Furthermore, we acknowledge Michael O' Donohue for his exceptional achievements in coordinating the whole consortium.

This work was supported by the European Commission through the FP7 project "Biocommodity refinery" ("BIOCORE", GA no. 241566).

SEVENTH FRAMEWORK PROGRAMME

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1 Executive summary

The BIOCORE project

The aim of the BIOCORE project is to generate an advanced lignocellulosic biorefinery concept that sustainably processes non-food biomass feedstocks such as agro-residues (wheat and rice straw), woody and herbaceous perennial energy crops (poplar short rotation coppice (SRC) or Miscanthus) and hardwood. Using an innovative, patented Organosolv technology, the objective of BIOCORE is to overcome current hurdles linked to lignocellulosic biomass fractionation and to be able to transform the obtained biomass components into value-added products. The Organosolv fractionation technology provides the three major biomass components (cellulose, lignin and hemicellulose) from the different biomass feedstocks. Obtained in forms optimal for further processing, these fractions are used as major building blocks for the synthesis of viable product portfolios. Several products were produced on pilot scale during the project period and dozens of further products were developed on lab scale.

Objective and approach of the sustainability assessment

In the last couple of years, a controversial discussion on the net benefit of bioenergy and bio-based materials has been ongoing, showing that simply because biomass is renewable, the replacement of fossil resources by biomass is not sustainable *per se*. Therefore, BIOCORE applies a multi-criteria sustainability assessment of the overall concept, which analyses the impacts of BIOCORE on the environment and on society as well as its economic viability. This sustainability assessment applies a generic, life cycle-oriented comparison of bio-based product portfolios from a potential BIOCORE biorefinery and conventional (mostly petroleum-based) product portfolios. Furthermore, BIOCORE is compared to other biomass-based systems which are competing in terms of biomass or land use. The assessment is based on scenarios reflecting potential implementations of the BIOCORE biorefinery concept in 2025 using mature technology[1]. In order to cope with the uncertainties of future technical implementations, sub-scenarios for standard, favourable and less favourable conditions were defined.

In the absence of an internationally standardised methodological framework for integrated sustainability assessments, a comprehensive and streamlined approach has been developed in BIOCORE. Based on exactly the same system boundaries, potential impacts of BIOCORE biorefineries on all major aspects of sustainability (environment, society and economy) were investigated individually, using a set of existing state-of-the-art methodologies. The latter were harmonised with the sister biorefinery projects SUPRABIO and EUROBIOREF. This

[1] No prognoses or predictions can be made to which extent the BIOCORE scenarios can be realised in practise. A corridor of parameters according to expectations of experts in the respective fields (e.g. regarding yields and energy consumption) is reflected in bandwidths for each scenario. Furthermore, critical sources of uncertainty / variability are investigated in sensitivity analyses.

was supplemented by separate analyses of biomass competition and various sustainability aspects, which were not covered by the other assessments.

Finally, all sustainability aspects were integrated into an overall sustainability assessment using multi-dimensional comparison metrics and a structured transparent discussion.

Results and conclusions: BIOCORE vs. conventional systems

The BIOCORE concept facilitates the production of a wide range of potential products from the three major biomass components (cellulose, lignin and hemicellulose). These products can be combined into hundreds of different product portfolios. Unsurprisingly, the overall sustainability impacts can be either positive or negative depending on the product portfolio, technical implementation, capacity and biomass feedstock type. Hence, **no general conclusion can be drawn for the BIOCORE concept as a whole**, but only for its individual implementations.

Product portfolio and technical implementation of the biorefinery – both related to the biomass conversion step – are very relevant in terms of global/regional environmental impacts and economics, whereas the biomass production step (location of biomass sourcing area and biorefinery unit) is dominating the local environmental impacts as well as the social impacts. Thus, it is very **important to consider the entire value chain**.

From a sustainability point of view, the **choice of product portfolios is very important**: some product portfolios are promising (e.g. xylitol, itaconic acid-based polymers, and lignin-based polymers), others are less recommendable (e.g. SHF ethanol) – at least under standard conditions. In order to achieve environmental advantages and economic viability, all three biomass fractions (cellulose, lignin and hemicellulose) need to be turned into value-added products, i.e. none of them can be omitted. It is of special importance to exploit the potentials of the C5 and lignin fraction, respectively, since these lead to substantial credits arising from the substituted conventional products. Regarding the lignin fraction, our analysis shows that the high-quality CIMV Organosolv lignin (Biolignin™) should definitely not be used for energy. In addition, we could show that the size of smallest intermediate molecule often has an important influence on the results: molecules with only 1 - 2 carbon atoms should be avoided if alternatives exist. This means that drop-in molecules such as ethanol or ethylene are less favourable than novel bio-optimised platform molecules from a sustainability point of view.

In addition to the choice of product portfolio, a close-to-optimum technical implementation is paramount: under favourable conditions, environmental advantages and economic viability increase substantially. Both biomass fractionation (i.e. the Organosolv process) as well as separation and purification are rather energy-intensive processes, so all efforts should be taken to minimise energy use, e.g. via effective process integration. Moreover, process integration is crucial since the used Organosolv process yields considerable amounts of residual heat, which is available to downstream processes. This means that biomass fractionation and downstream processes should take place at the same location.

Apart from product portfolio and technical implementation, biomass feedstock type and the biorefinery's capacity are decisive, among others, in terms of economics. Under standard conditions, a straw-fed 150 kt biorefinery in Europe is unlikely to be profitable. A switch from straw to hardwood or SRC poplar increases profitability. However, even in this case an IRR threshold of 25 % was not surpassed. A larger biorefinery capacity (> 250 kt dry biomass per year) improves the situation, as could be shown for a rice straw-fed 500 kt biorefinery in India, which would be profitable. Moreover, biomass feedstock type is also influencing the local environmental and social impacts. Depending on soil conditions, a certain amount of agricultural residues such as straw can be used without major local impacts on the environment or even benefits in case in-field rice straw burning is avoided.

However, the success of biorefineries is not just a question of resolving technological challenges. A main bottleneck for establishing biorefineries in general is the **supply of sustainable biomass**. Potential locations for BIOCORE biorefineries in Europe and India have been identified by BIOCORE partners, which support sufficient biomass supply. However, residues, forestry biomass and agricultural land are needed for bioenergy, biofuels, bio-based materials and chemicals, feed and food as well as nature conservation. Not only increasing competition about land use and use of forestry biomass but also competition about residues is to be expected in Europe if only part of the expansion plans in biofuels and bioenergy sectors are realised. If increasing imports of cultivated biomass are used to meet this demand then conflicts with food security and indirect land use changes including logging of rainforests are plausible consequences. In this respect, a big advantage of BIOCORE is the possibility to use rice straw (e.g. in India) and also wheat straw because these residues do not cause indirect conflicts. Furthermore, direct competition especially about rice straw is expected to be less intense than for cultivated crops or forestry biomass. Another strength of BIOCORE is its feedstock flexibility, which can help to buffer shortages in certain feedstocks.

Apart from feedstock potentials, its actual availability will also be influenced by many involved stakeholders (e.g. farmers / forest owners). Their willingness to sell biomass will be affected by their perception if their share of benefits along value chain is fair. Furthermore, depending on the region, infrastructure is partly not in place, polices are unfavourable and the legal framework may not be stable enough.

Results and conclusions: BIOCORE vs. other biomass-based systems

Due to expected **competition**, it is not only important if sustainability advantages exist compared to conventional products but also compared to competing biofuels and bioenergy. Some of the assessed exemplary products have the potential to create bigger environmental benefits from the limited resources biomass and agricultural land than competing use options. Depending on how well technical processes can be transferred to industrial scale and how production efficiency of competing conventional products develops until 2025, BIOCORE biorefineries can be more environmentally friendly than any first generation biofuel and even have the potential to outperform combustion of biomass in CHP plants. Depending on technological performance, oil price and other market developments, BIOCORE biorefineries may also be attractive to investors at lower support levels than European first generation biofuels. In this respect, it is of crucial importance that policy makers create a level playing field for material use of biomass including biorefineries compared to competing highly supported biofuels and partially also bioenergy. Otherwise, potentials for a more sustainable development through bio-based chemicals and materials have little chances to be realised. Besides this first step, competition about land and biomass needs to be actively managed by politics in the long run to ensure a stable investment climate and social sustainability while maximising environmental benefits. One option to achieve this could be sustainability-oriented European biomass and land use allocation plans and regional planning based on these.

Under the conditions outlined in this integrated sustainability assessment, biorefineries according to the BIOCORE concept have the potential to become environmentally, socially and economically sustainable building blocks for a future bio-based economy. It should be born in mind that the results cannot be generalised for all kinds of biorefinery concepts and / or product portfolios. Our scenario-based, generic analysis provides guidance to different stakeholders, but a case-specific assessment is needed (already at the concept or design stage) if a concrete biorefinery was to be built. Likewise, a case-specific environmental / social impact assessment and an in-depth feasibility study would be required.

Recommendations for policy makers

Actively manage increasing biomass and land use competition to which biorefineries will contribute: One options is the establishment of biomass and land use allocation plans at national and European level. Based on these, regional plans, which include regulations for project planning, should be developed to e.g. foster the cultivation of crops adapted to local conditions.

Mandatory area- and cultivation-specific sustainability criteria should be uniformly defined for all biomass applications, i.e. for bio-based materials, chemicals, fuels and energy, and ideally also for food and feed.

Create a level-playing field between all uses of biomass, especially between bioenergy and bio-based products: The current policy framework (10% renewable energy target in the transport sector and multiple counting in the EU Renewable Energy Directive 2009/28EC) leads to a misallocation of biomass and undesired effects (iRUC, indirect residue use change).

Ensure a stable investment climate as biorefineries will most likely require investments beyond 100 million € each: One-time investment subsidies are more attractive to investors than various mechanisms of product price support, which may be subject to frequent changes. Furthermore, consider the Equator principles of the World Bank for large investments.

2 Introduction

The BIOCORE project

The scope of the BIOCORE project is to generate an advanced lignocellulosic biorefinery concept that aims to provide a sustainable solution for the processing of non-food biomass feedstocks such as agro-residues (wheat and rice straw), short rotation coppice (SRC) wood, grass-like biomass from perennial energy crops and hardwood. Using an innovative, patented Organosolv technology, the objective of BIOCORE is to overcome current hurdles linked to lignocellulosic biomass fractionation and to be able to transform biomass components into value-added products. The Organosolv fractionation technology is streamlined and integrated with tailored refinement processes, to provide the three major biomass fractions (cellulose, lignin and hemicellulose) from the different biomass feedstocks. Obtained in forms optimal for further processing, these fractions are used as major building blocks for the synthesis of viable product portfolios.

Objective of the sustainability assessment

In the last couple of years a controversial discussion on the net benefit of bioenergy and bio-based products has been ongoing, showing that the replacement of fossil resources by biomass is not sustainable *per se*, simply because biomass is renewable. It is widely held that biorefining can positively affect environmental and social aspects /van Dam et al. 2008/, e.g. by replacing non-renewable resources and by promoting rural development. However, biorefineries can also have negative effects on environmental, social or economic sustainability. Potentially higher risks for biodiversity loss or possible higher acidification and eutrophication of natural ecosystems have to be taken into account. The controversy surrounding the supposed benefits especially of bioenergy has gained momentum as undesirable competition between food and non-food uses of biomass and land has been added to the list of adverse side effects. Indeed, this particular aspect of biorefining is likely to be accentuated in the decades to come, with greater demands for both food and energy being expected. Most likely, agricultural land will be expanded at the cost of (semi-)natural ecosystems, which will be converted into cropland. Several studies have pointed out the negative effects of such direct and indirect land-use changes, among others in terms of biodiversity loss and greenhouse gas emissions.

Taking all of the above considerations into account, it is obvious that in order to validate the benefits of any given biorefinery concept and, ultimately, to provide a basis for the development of incentive policies, it is essential to apply a strict and sufficiently overarching sustainability assessment.

This sustainability assessment is designed to answer the following key questions selected beforehand[2]:

- How does BIOCORE perform compared to the conventional production of the same products?
  - Which BIOCORE biorefinery variant (feedstock + product portfolio) is best from a sustainability point of view?
  - How does a straw-based biorefinery perform compared to a biorefinery based on hardwood or a biorefinery based on a mixed feedstock?
  - Which downstream processes should follow the Organosolv fractionation, i.e. which product portfolio is most sustainable?
  - What is the influence of different product / co-product uses?
  - Which unit processes determine the results significantly and what are the optimisation potentials?
  - Are there differences depending on plant capacity?
  - Do the results differ within Europe and between Europe and India?
- How does the BIOCORE biorefinery concept perform compared to alternative uses of the same feedstock (biomass) or cultivation area?

Approach of the sustainability assessment

BIOCORE implements and applies a multi-criteria sustainability assessment of the overall concept, which demonstrates the impacts of BIOCORE with respect to the environment and society as well as its economic viability. This sustainability assessment is based on the life cycle approach comparing the impacts of the whole life cycle of a potential BIOCORE biorefinery and its products to the impacts of conventional means of providing equivalent products (Fig. 2-1). The organisational subdivision of the sustainability assessment is shown in Fig. 2-2. Each of the three pillars of sustainability (environment, society and economy) is assessed within one work task. An additional work task covers various sustainability aspects, which are not covered by the other work tasks, using a SWOT analysis (strengths, weaknesses, opportunities and threats) and analyses biomass competition in more detail. Finally, all sustainability aspects are integrated into an overall sustainability assessment. To facilitate the integrated sustainability assessment, all work tasks assessing individual pillars of sustainability use the same settings that were specified beforehand where possible and appropriate /Rettenmaier et al. 2011/.

This report concerns the integrated sustainability assessment.

2 Further interesting dependencies were revealed during the study and not all of the questions selected beforehand turned out to be crucial for the sustainability of the biorefinery. Therefore, the conclusions section does not answer the questions one by one but presents the most important findings.

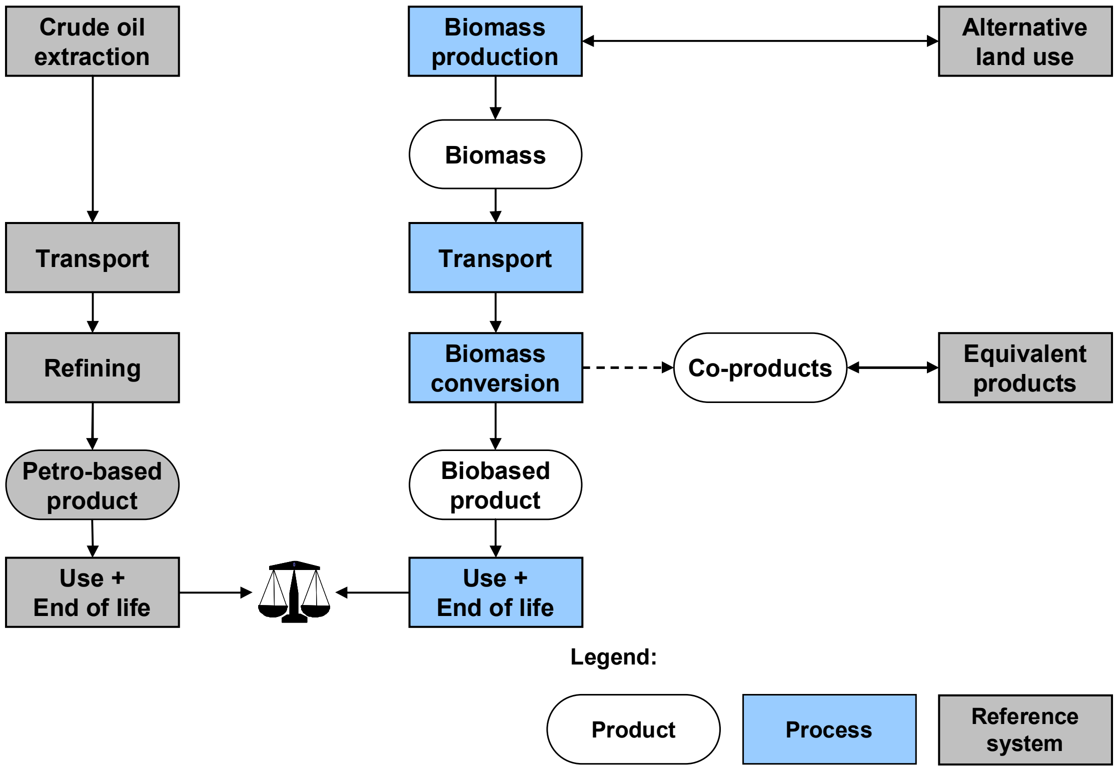

Fig. 2-1 General approach of the sustainability assessment in BIOCORE: life cycle-oriented, comparative assessment

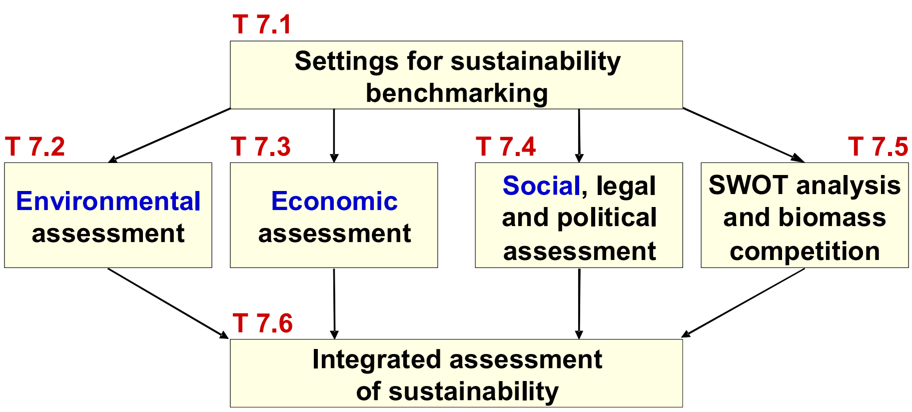

Fig. 2-2 Structure of the sustainability assessment (work package 7) in BIOCORE

3 Methodology for the integrated assessment

This chapter describes the methodology of the integrated sustainability assessment, which builds on results from previous assessments of individual sustainability aspects. For the methodologies used in these individual assessments, please refer to the respective reports /Piotrowski et al. 2013/ (economic assessment and social / legal / political assessment), /Rettenmaier et al. 2013/ (environmental assessment) and /Kretschmer et al. 2013/ (SWOT analysis and biomass competition).

3.1 General approach

There are several options of how to implement biorefineries according to the BIOCORE concept or not to do so and instead adopt existing alternatives to this technology. These options are represented in this assessment in the form of scenarios. On each scenario, various indicators from economic assessment, environmental assessment via screening LCA and LC-EIA, social assessment and from the assessment of other sustainability aspects via SWOT analysis such as technological aspects are made available in this study. All these aspects are integrated into an overall picture to facilitate decisions between the options.

There are two general ways of integrating this information:

Weighting and mathematical integration

All indicators could be mathematically combined into one score using weighting factors or ranked otherwise according to a weighting algorithm. These approaches cannot be entirely based on scientific facts but depend on personal value-based choices defined beforehand. 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.

3.2 Collection of indicators and results

Indicators and results for all scenarios are provided by the individual assessments /Piotrowski et al. 2013/, /Rettenmaier et al. 2013/, /Kretschmer et al. 2013/. They are collected in overview tables. In some cases, indicators are selected or aggregated by the authors of the respective individual assessment to focus on the most relevant aspects for decision support. No further adjustments are made except for rescaling quantitative data to a common basis if necessary. Thus, all specific settings, methodological choices including underlying estimates, and data sources apply unchanged as documented in the respective reports.

3.3 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 additional efficiency indicators can be defined for other quantitative sustainability indicators. In this case, such indicators are available from the screening LCA like for example acidification (basis for SO_2 avoidance costs) or resource depletion (basis for 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 reference, which is e.g. for biofuels the use of fossil fuels.
- 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:

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

CO_2 avoidance costs are expressed in Euro per tonne of CO_2 equivalents. Costs refer to the support in € maximally required to make an investment attractive (i.e. to reach an expected rate of return of 25 % without green premium product prices unless specified otherwise) and greenhouse gas emissions (GHG emissions) expressed in CO_2 equivalents.

One methodological option is to discount the avoided CO_2 emissions for the calculation of the avoidance costs as well, in order to create a preference for temporally preceding measures. 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.

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

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. 3-1 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. 3-1 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. This especially applies to analyses of technologies not yet implemented for a timeframe more than a decade ahead as it is the case in this study.

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. However, avoidance costs have to be interpreted carefully because in many situations their robustness and comparability are poor.

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

3.4 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.

A variant of the benchmarking process, termed potential analysis, shows whether a certain innovative technology scenario has the potential to be more sustainable than an established scenario under certain conditions. This reflects that novel technology scenarios are probably not realised under less favourable conditions if those are identified beforehand but that instead the conditions are optimised ("self-destroying prophecy"). Nevertheless, such scenarios under less favourable conditions are important to highlight the risks. Potential analysis is thus a valuable tool to assess innovative technology scenarios as developed within the BIOCORE biorefinery concept. In contrast, existing technology scenarios do not show such pronounced less favourable variants because these options have never been realised. Technically, ratings of [+] or [(+)] are given if an innovative scenario under standard and favourable conditions is better than the established benchmark under standard conditions, respectively. A rating of [0] is given if a scenario under favourable conditions is better than or equal to the benchmark under standard or less favourable conditions. [-] indicates that the scenario under investigation has no potential to be more sustainable than the benchmark under any of the assessed conditions.

3.5 Overall comparison

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

The integrated sustainability assessment of this project is based on six qualitative technological indicators originating from the SWOT analysis, eleven quantitative and five qualitative environmental indicators, eleven quantitative and one qualitative economic indicators supplemented by two additional quantitative efficiency indicators, and nine qualitative social indicators (see Table 5-13 for an overview). These are a subset of all possible indicators, which were assessed in previous steps of the sustainability assessment and found to be relevant for the decision process. 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.

4 System description

The sustainability assessment analyses the impacts of substituting conventional, mostly petroleum-based products (reference products) by novel bio-based products using a life cycle comparison approach. All scenarios and life cycle steps that need to be assessed according to this approach are described in this chapter. As a first step, the whole life cycles of **potential BIOCORE biorefineries** and their products are assessed from cradle to grave. They are described in detail in chapter 4.1 and in Annex 1 (chapter 9.1). In the next step, they are compared to **alternative means of providing the same products**, or more general the same utility, by conventional established means. The life cycles of these alternative products are described in chapter 4.2. Finally, **alternative ways of using limited biomass or agricultural land** are assessed and compared to the use of these resources by BIOCORE. The life cycles studied in this step are outlined in chapter 4.3. Further **general specifications** regarding time, geography and technology are provided in chapter 4.4.

For further specifications and sensitivity analyses relevant to the assessments of individual aspects of sustainability (environment, economy, society, SWOT analysis and biomass competition analysis), please refer to the respective reports /Rettenmaier et al. 2013/, /Piotrowski et al. 2013/, /Kretschmer et al. 2013/.

4.1 The BIOCORE biorefinery concept

The biorefineries according to the BIOCORE concept can produce multiple products including biomaterials and biofuels from various lignocellulosic feedstocks. Fig. 4-1 gives a generic overview of its whole life cycle, which can be implemented in many different variations. This sustainability assessment is based on analysing scenarios, which depict potential implementations, and compare them with each other to determine the effects of choices to be made.

For a better orientation, the multitude of options described in chapter 9 in Annex 1 was condensed into four main scenarios with different product portfolios (see Table 4-1 for assessed products). Furthermore, 12 additional scenarios were defined, in which selected aspects of one main scenario are varied. These scenarios are summarised in Table 4-2 and flow charts of all main scenarios can be found in chapter 9.4 in Annex 1.

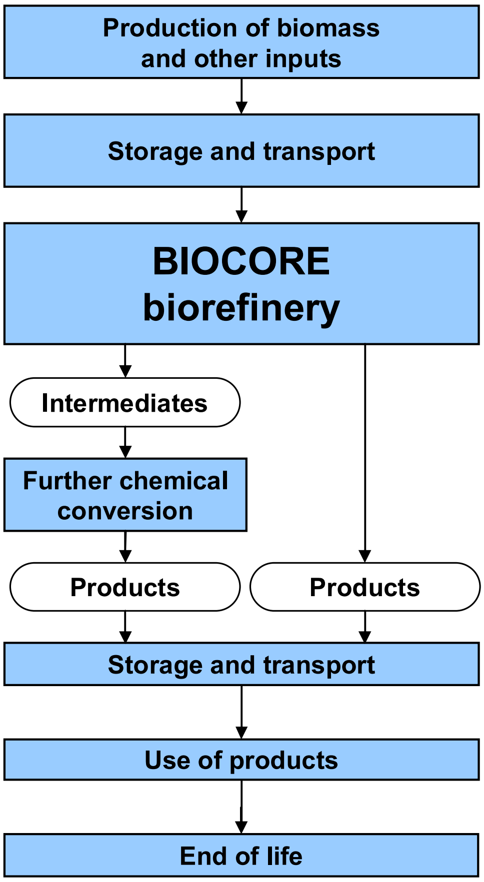

Fig. 4-1 Generic life cycle of a biorefinery according to the BIOCORE concept

Table 4-1 Assessed BIOCORE products (Products of main scenarios underlined)

Biomass fraction	Biorefinery product	Consumer product
Hemicellulose / C5*	Xylitol Ethanol Ethylene C5 syrup (fallback)	Sweetener Biofuel Products from bio-based PVC Animal feed
Cellulose / C6*	Itaconic acid Ethanol Ethylene Pulp (fallback)	Superabsorber e.g. in hygiene / sanitary products made of poly(itaconic acid); bio-based polyester resin Biofuel Products from bio-based PVC Paper
Lignin powder	Lignin powder Crude lignin (fallback)	Bio-based phenol formaldehyde (PF) resins e.g. in wood products; bio-based polyurethane resins e.g. in electrical devices No consumer product (Energy provision to biorefinery)

*: Five or six carbon sugars, respectively

Table 4-2 Summary of BIOCORE scenarios

Scenario	Description
Main scenarios (feedstock: wheat straw, scale: 150 kt biomass (dry) / year, location: EU)	
Xyl / IA	Production of xylitol (C5), itaconic acid (C6), and lignin powder (lignin)
Xyl / ethanol	Production of xylitol (C5), ethanol (C6), and lignin powder (lignin)
Ethanol / IA	Production of ethanol (C5), itaconic acid (C6), and lignin powder (lignin)
SHF ethanol	Production of ethanol from C5 and C6 in separate hydrolysis and co-fermentation, and lignin powder (lignin)
Additional scenarios on feedstocks	
Rice straw	Xyl / IA with feedstock rice straw (instead of base case wheat straw)
Hardwood	Xyl / IA with feedstock hardwood
Poplar SRC	Xyl / IA with feedstock poplar wood from short rotation coppice
Miscanthus	Xyl / IA with feedstock Miscanthus
Additional scenarios India	
Wheat straw, India	Xyl / IA for location in India
Rice straw, India	Xyl / IA with feedstock rice straw for location in India
Rice straw, India 500 kt	Xyl / IA with feedstock rice straw and input of 500 kt dry biomass per year for location in India
Additional scenario on fallback options	
Fallback options	Production of animal feed (C5), paper (C6) and process energy (lignin)
Additional scenarios on process variants	
IA material recycling	Xyl / IA with additional material recycling step in IA process
Ethanol to PVC	SHF ethanol with subsequent conversion of ethanol via ethylene to PVC
Additional scenarios on energy provision	
Straw powered	Xyl / IA with substitution of the whole natural gas input by additionally harvested wheat straw (amount of products remains constant)
Lignin to energy	Xyl / IA without production of lignin powder – crude lignin is instead burned internally for process energy provision

Additionally, many sensitivity analyses specific for each assessment of individual sustainability aspects have been carried out as described in the respective reports /Kretschmer et al. 2013/, /Piotrowski et al. 2013/, /Rettenmaier et al. 2013/.

4.2 Reference products

The sustainability assessment analyses the impacts of the substitution of conventional products (reference products) by novel bio-based products using a life cycle comparison approach (Fig. 4-2). Therefore, also the life cycles of these reference products are assessed from cradle to grave. Furthermore, it has to be specified, how much of which conventional product is replaced by the assessed bio-based product.

The conventional products that are replaced by BIOCORE products are mainly produced from fossil resources. An exception is e.g. xylitol, which replaces other bio-based xylitol produced by conventional processes. In Table 4-3, the standard reference products are listed for each use option of each biorefinery product (see chapter 9.2 for more details). The alternative land / biomass use is covered in chapter 4.3.

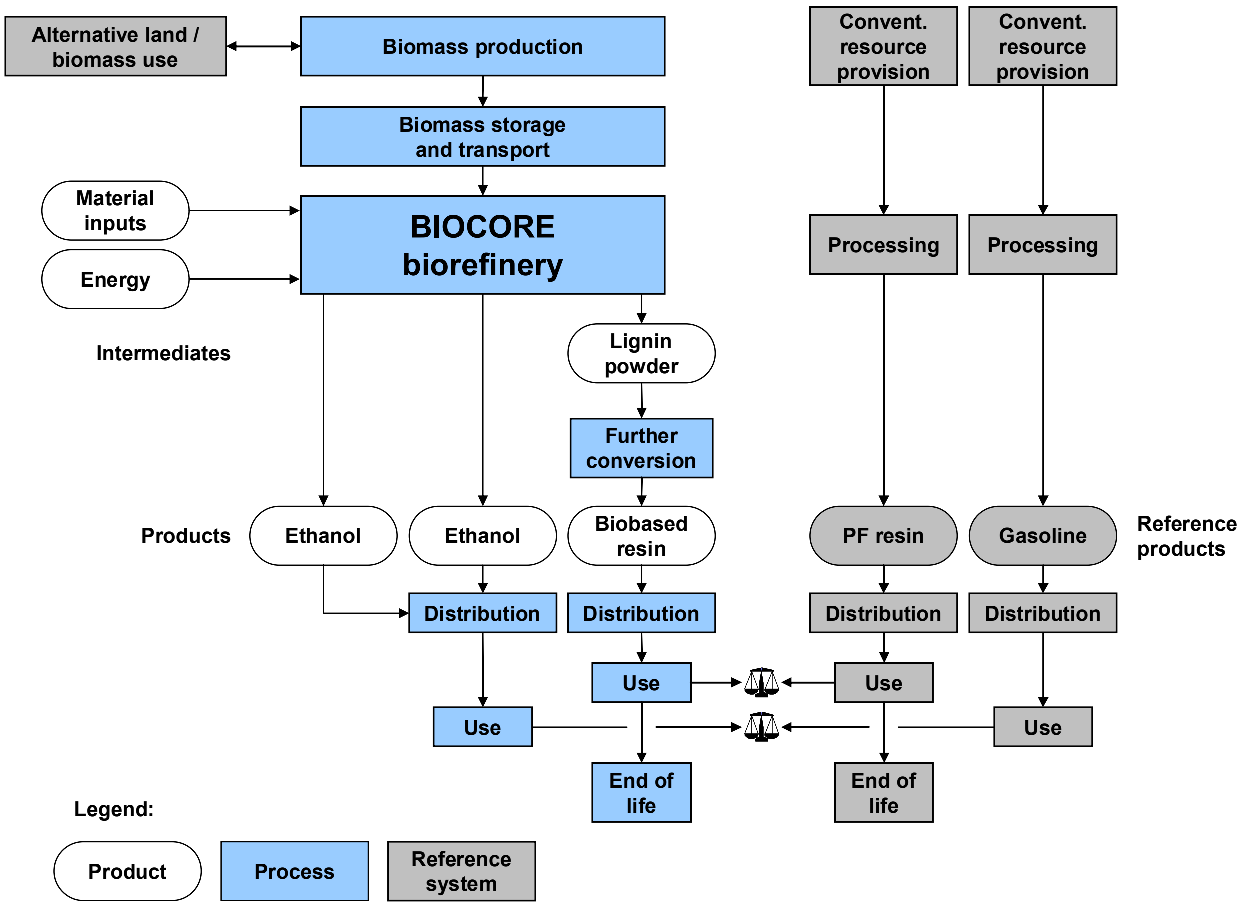

Fig. 4-2 Scheme of a life cycle comparison. This scheme exemplarily shows the products and reference products of the main scenario SHF ethanol. PF resin: phenol formaldehyde resin

Table 4-3 Overview of standard reference products for each biorefinery product

Biorefinery product (Consumer product)	Standard reference product
Xylitol (sweetener)	Xylitol from corn cobs
Ethanol (biofuel)	Gasoline
Ethylene (PVC)	Fossil resource-based PVC
Itaconic acid (superabsorber)	Superabsorber from poly(acrylic acid) (PAA)
Itaconic acid (polyester resin)	Mineral oil-based polyester resin
Lignin powder (phenol formaldehyde resins)	Mineral oil-based phenol formaldehyde (PF) resin
Lignin powder (polyurethane)	Mineral oil-based polyurethane (PU)
Pulp (paper)	Conventional paper
Animal feed from C5 sugars	Wheat grains
Bioenergy from lignin (none)	(Less consumption of natural gas in the biorefinery)
Fermentation residues (fertiliser)	Mineral fertiliser

4.3 Alternative uses of biomass or land

4.3.1 BIOCORE vs. conventional systems

The use of residual biomass like straw from agricultural land always has to be compared to a **reference system** because something will happen to the biomass or the land even if no BIOCORE biorefinery is implemented. In the initial part of the assessment focussing on the BIOCORE biorefinery concept is based on the precondition that sufficient biomass or agricultural land is available. Independent of how much unused biomass or agricultural land may be available in reality in 2025, this precondition allows to independently assess the BIOCORE biorefinery and its optimisation options before comparing it to alternative use options of the biomass or agricultural land in a second step. Thus, the implementation of the BIOCORE biorefinery concept is compared to not extracting the agricultural residues and forestry biomass or not using the agricultural land. Nevertheless, this reference system can still cause environmental benefits (e.g. remaining straw serves as fertiliser reducing the demand for mineral fertiliser) or environmental burdens (e.g. straw is burned in the field causing significant emissions). These environmental impacts of the reference system are credited to the BIOCORE biorefinery, which leads to the reduction of its environmental impacts (if burdens are avoided) or to additional impacts (if benefits are prevented). These reference systems are part of the life cycle of the BIOCORE biorefinery (see Table 4-4 for an overview).

Table 4-4 Feedstocks for the BIOCORE biorefinery concept and their reference systems (main scenario underlined)

Feedstock type	Feedstock	Reference system
<u>Agricultural residues</u>	<u>Wheat straw</u>	<u>Ploughing in, serves as fertiliser</u>
	Rice straw	Burning in field
Forestry biomass	Hardwood stems from thinnings (diameter > 5 cm)	Remain in forest
Agricultural biomass	Miscanthus, poplar short rotation coppice (SRC)	No production, land is not used (non-rotational fallow land)

4.3.2 BIOCORE vs. other biomass-based systems

In most cases, a BIOCORE biorefinery will compete with other uses of the limited resources biomass and agricultural land. In this case, another life cycle comparison is necessary to assess the impacts (Fig. 4-3). To this end, products originating from alternative biomass or land uses like bioenergy are themselves compared to alternative fossil-based products like energy from natural gas. This leads to the situation that e.g. either the demand for chemicals is satisfied by biomass and the demand for energy is satisfied by fossil resources or vice versa. The underlying question is whether the BIOCORE biorefinery concept or alternative use options of the same biogenic resources are more sustainable.

The **alternative biomass use options** for all kinds of biomass assessed in this study are (see chapter 9.3.2 in Annex 1 for more details):

- Direct combustion
- Synfuels

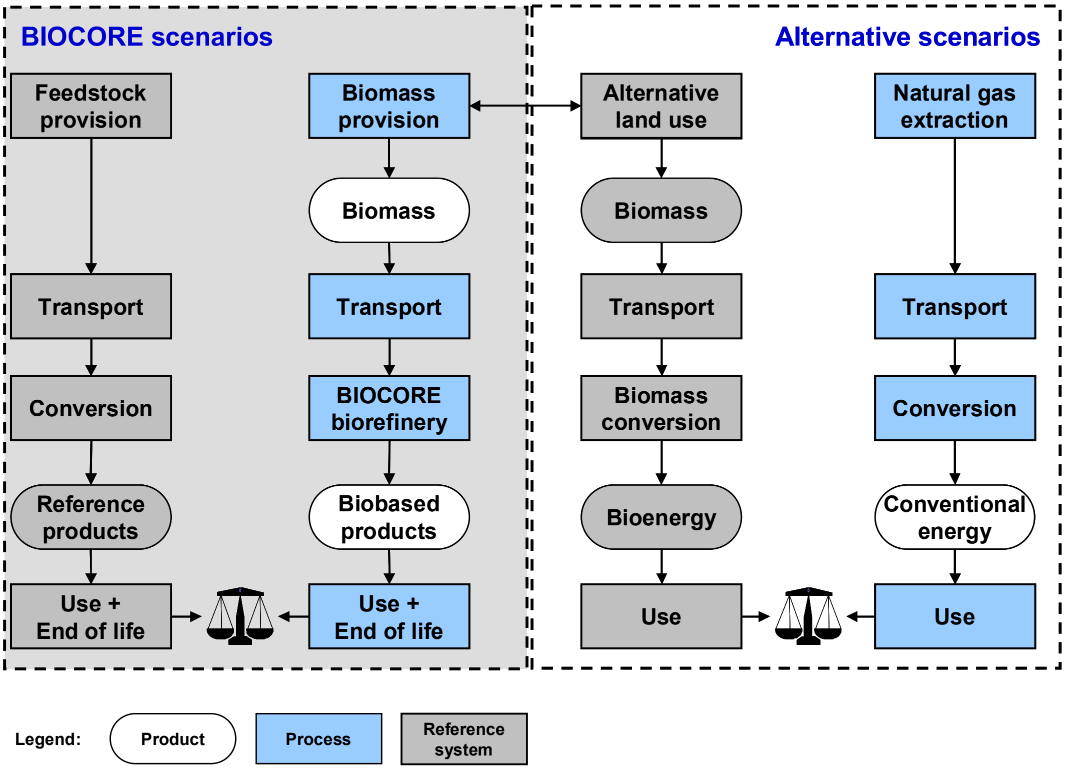

Fig. 4-3 Simplified exemplary scheme of the assessment of competing land use options. Please note that the BIOCORE biorefinery provides several products, which are each compared to a separate reference product.

The following **alternative land use options** are assessed for all biorefinery schemes, which are based on agricultural biomass (here: poplar SRC and Miscanthus) (see chapter 9.3.2 in Annex 1 for more details):

- Sugar beet, wheat grains and maize grains
- Maize (whole plant)
- Triticale (whole plant)
- Rapeseed

4.4 General specifications

Technical reference

The technical reference describes the technology to be assessed in terms of plant capacity and development status / maturity. The following plant capacities are assessed:

- 150,000 tonnes / year of dry matter input in the standard scenarios
- 500,000 tonnes / year of dry matter input in an excursus

The plant capacity of 500,000 tonnes / year is only assessed for a scenario in India with rice straw as feedstock because a sustainable supply of such an amount of biomass per year is questionable in Europe (see also /Kretschmer et al. 2013/ for an assessment of biomass potentials).

In addition to plant capacity, development status / maturity plays an important role. In order to evaluate whether the BIOCORE biorefinery concept is worth being developed / supported further, it is essential to know how future biorefineries perform as compared to established biomass use options, which are operated at industrial scale and with mature technology. Only mature technology is assessed in order to allow for a fair comparison of biorefineries to existing technologies.

Time frame

The time frame of the assessment determines e.g. the development status of biorefinery technology. 2025 is set as the reference time because a whole value-added chain of biomass provision, conversion technology and adaptation of consumer products to new bio-based intermediates and polymers as raw materials will not be established in a few years from now. Besides the development status of the biomaterials sector, also other sectors will change until 2025. The most relevant impacts are to be expected from the change in the energy sector, which is taken into account in this study.

Geographical coverage

Geography plays a crucial role, determining e.g. agricultural productivity, transport systems and electricity generation. The BIOCORE project focuses on two world regions: Europe and India. The assessment only covers domestic biomass production, i.e. imported biomass from outside Europe and India, respectively, is not considered as feedstock for the BIOCORE biorefineries. The main scenarios are based on European conditions. The scenarios dealing with rice straw, which is a promising feedstock in India, are modelled according to Indian conditions.

5 Results

As a basis for further analyses, this chapter contains summaries of the assessments of individual sustainability aspects (chapter 5.1 - 5.4). The results from these individual assessments are combined, extended and jointly assessed in the results chapter on the integrated assessment (chapter 5.5).

5.1 Summary: Environmental assessment

For detailed results and a description of the methodology please refer to the original environmental assessment report /Rettenmaier et al. 2013/.

The life cycles of the analysed BIOCORE biorefinery scenarios are associated with distinct local, regional and global environmental impacts. A combination of screening LCA and LC-EIA showed that virtually any modification of the life cycle may significantly influence all environmental indicators in complex ways. However, the consequences of decisions or changing circumstances follow a general trend. Local environmental impacts are generally more likely to be influenced by biomass supply, and are strongly dependent on site-specific circumstances. For global and regional impacts, however, the focus is rather on biomass conversion and product use. Thus, optimisation of the life cycles may entail an emphasis of different aspects, depending on an optimisation focus on local, regional or global environmental impacts. Detailed conclusions regarding environmental impacts may be summarised as follows:

For **local environmental impacts**, results of the comparison between the BIOCORE biorefinery concept and conventional petrochemical production practices vary depending on the life cycle stage. Due to the fact that the individual associated risks differ considerably between the two life cycles in both qualitative and quantitative terms, a meaningful comparison may be drawn at the level of the affected environmental factors only. With regard to raw materials supply, biomass tends to be advantageous compared to fossil reference products, as long as the biomass in question is produced sustainably.

Furthermore, in contrast to provision of conventional fossil raw materials, the consequences of biomass production are to some extent reversible. With regard to the conversion of raw materials, the differences between biorefineries and petrochemical plants are negligible in terms of construction or facility-related impacts. For any kind of plant, impacts can and should be minimised by building it on a former industrial site (“Brownfield”) instead of on previously unsealed / not compacted soil (“Greenfield”). Actual differences observed are rather associated with operational impacts. In this context, biorefineries may show both advantages (e.g. regarding waste generation) and disadvantages (e.g. high specific water consumption, potential increase in traffic in the Greenfield scenario). Thus, the outcome depends on the individual implementation of the BIOCORE biorefinery concept.

A comparison of BIOCORE with competing uses of the same biomass revealed no relevant differences regarding local environmental impacts. Compared to competing land use options, BIOCORE scenarios are often associated with smaller disadvantages. This is primarily due to the fact that lignocellulosic biomass can be provided with relatively low negative environmental impacts from underutilised agricultural residues such as wheat straw or wood from thinnings of forests in Europe, or rice straw in India (Table 5-1). In the case of rice straw, the utilisation even results in environmental benefits. Perennial crops (e.g. Miscanthus and short rotation coppice) qualify as biomass source with similarly low associated environmental impacts.

Table 5-1 Crop specific environmental impacts versus different reference scenarios. 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

Type of risk	Perennial crop / feedstock			Annual crops / feedstock						
				Crops		Residues				
				Europe (vs. no cropping)		Europe (vs. straw left on field)	India (vs. straw left on field)		India (vs. on-site burning of straw)	
	Hardwood stems	SRC	Miscanthus	Sugar beet	Wheat grains	Cereal straw	Cereal straw	Rice straw	Cereal straw	Rice straw
Soil erosion	C	C	C	E	C	C	C	C	B	B
Soil compaction	C	C	C	E	C	C	C	C	C	C
Soil organic matter	C	B	B	E	D	C	C	C	B	B
Soil chemistry / fertiliser	C	C	C	E	D	C	C	C	D	D
Nutrient leaching	C	C	C	D	D	C	C	C	D	D
Water demand	C	B	D	E	D	C	C	C	D	D
Weed control / pesticides	C	C	C	E	E	C	C	C	C	C
Loss of habitat / species diversity	C	B	D	D	D	C	C	C	A	A
Loss of landscape elements	C	B	C	C	C	C	C	C	A	A

However, for the supply of biomass, please note:

- Seek to avoid harvesting of straw and timber to an extent that reduces the long-term productivity of agricultural land and forests, respectively. Sustainability criteria and quota for biomass extraction are strongly dependent on local conditions.
- Seek to prevent major land use change such as the conversion of grasslands.
- Endeavour to cultivate crops appropriate to the local growing conditions.

Environmental risks may be associated locally with the cultivation of Miscanthus due to invasiveness and increased water demand.

Notable local environmental benefits can be promoted by

- perennial instead of annual crops, with a particular benefit if perennial crops further results in diversification of the local agricultural landscape. Thus, cultivation of perennial crops outside the food / feed production sector should be encouraged.
- abandoning the practice of burning rice straw in the field. Significant regional environmental benefits ensue if the rice straw residues are utilised instead. Biorefineries may provide the critical incentive to eliminate this environmentally hazardous practice.

The comparison of the types of lignocellulosic biomass did not result in an overall favourite, as individual site-specific circumstances such as soil conditions and water availability are of vital importance. Moreover, the local availability of unexploited residues is critical in determining the type of biomass, plant species and mode of cultivation most beneficial to the local environment.

With respect to **global and regional environmental impacts**, the main advantage of biorefineries in comparison with the petrochemical industry usually is that a conservation of non-renewable carbon sources is realised. However, the energy consumption of the CIMV Organosolv process applied in BIOCORE is relatively high compared with other available biomass pretreatment processes. Therefore, despite the obvious conservation of fossil carbon sources, the biorefinery scenarios presented here may not always provide environmental benefits. In consequence, the BIOCORE biorefinery concept, depending on the individual implementation scenario, may cover a considerable spectrum of outcomes (see Fig. 5-1). These may extend from very favourable to distinctly detrimental environmental impacts in comparison with conventional products, or alternative biomass and land use options. Depending on the following factors, either advantageous effects on individual environmental impacts may occur simultaneously with disadvantages on other environmental aspects (with no consistent pattern evident), or detrimental environmental impacts emerge across all environmental impact categories:

- Product portfolio of the biorefinery
- Technical implementation (e.g. energy efficiency)
- External factors (e.g. developments in electricity generation)

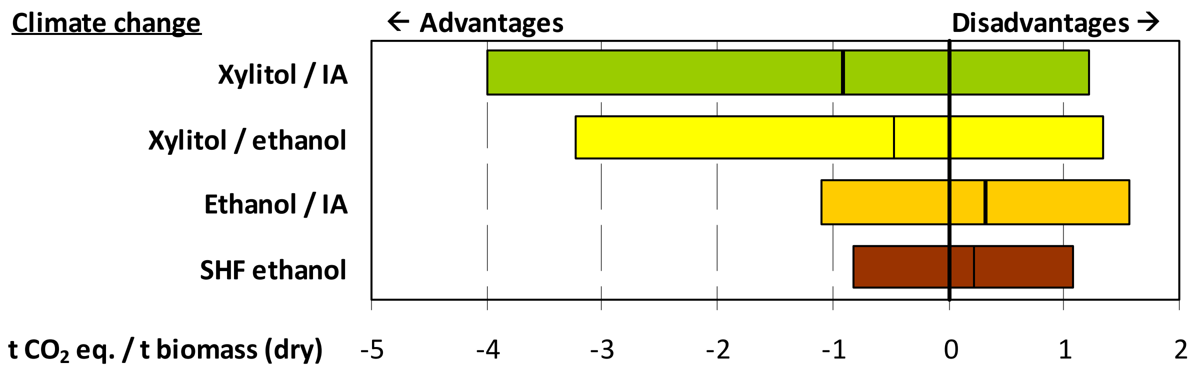

Fig. 5-1 Environmental impacts of production and use of various biorefinery products from wheat straw. Exemplary net results are shown per tonne of biomass input (dry matter) in the category climate change. The coloured bars show the bandwidths of results under favourable and less favourable conditions and the black lines show the results under standard conditions.

Due to the considerable range of the results for biorefineries, a conclusive judgement concerning the advantages and disadvantages compared to conventional products and alternative biomass and land use options is not possible whilst no specific plans for a concrete biorefinery are available. At the same time, proposed plans for a biorefinery may, and should, be optimised from an environmental point of view. In order to achieve distinct positive environmental impacts in comparison with alternative measures of production and biomass or land use, regardless of external factors, all adjustable factors (product portfolio and technical implementation) have to be considered for optimisation. Although the choice of feedstock has limited direct influence on the global and regional environmental impacts, indirect effects, which are hard to quantify, can occur through competition about land and biomass. In the worst case this can lead to clearing of valuable natural land such as rainforests. Therefore, underutilised residues such as straw should be preferred over largely already utilised forestry biomass or cultivated agricultural biomass. The possibility to use such residues is a key strength of the BIOCORE concept that should be taken advantage of.

Regarding energy and material efficiency across the entire value chain, biorefineries are initially at a disadvantage compared to the chemical industry. This is due to the fact that the established chemical industry produces with high efficiency, and has optimised all value chains to maximum productivity through the choice of certain platform chemicals that best exploit the properties of fossil raw materials. A comparable level of efficiency may be achieved for bio-based chemicals if an analogous network of processes and corresponding enterprises is established. This network needs to focus on platform chemicals that serve best to exploit the individual properties of the biomass.

The principal recommendations for optimisation include:

- For the product portfolio:
  - The potential of the energy-intensive CIMV Organosolv process in BIOCORE, which yields high-quality biomass fractions, should be fully exploited by focusing on value-added products such as xylitol or itaconic acid instead of e.g. production of biofuels.

- Selection of the product portfolio should avoid the intermediate fractionation into small molecules with 1 - 2 carbon atoms, and should include products for which energy-efficient separation and purification methods are available
- In the initial implementation stage of the BIOCORE biorefinery concept, initial facilities should provide products that currently generate considerable environmental burdens during manufacture with conventional techniques such as xylitol or phenol. Since such products can be as diverse in origin and structure as these two examples, individual screening life cycle assessments are required.

- For the technical implementation:
  - For the purpose of optimal heat integration, all the stages of the production process should be carried out in one centralised facility.
  - The heat demand of purification steps within the CIMV Organosolv process as well as for the purpose of separation and purification of the fermentation products should be minimised as feasible.
  - Optimisation of the product yield after fermentation is frequently associated with major benefits; however, an increased energy demand during purification may be the result.
  - Fresh water consumption should be minimised by increased efforts in process water recycling, in particular in regions with water scarcity. As process water recycling is no main focus of the assessed scenarios, improvements in this regard should be possible – probably even with limited additional energy consumption.
  - Additional specific optimisation measures are dependent on the individual process.

Please note that the majority of optimisation measures recommended above are expected to result in virtually universal improvements of environmental impacts, apart from a small number of conflicts such as the trade-off between efficiency and energy consumption during separation and purification.

In conclusion, the BIOCORE biorefinery concept and the resulting products show the potential to deliver considerable environmental benefits in almost all assessed environmental aspects in comparison with the utilisation of conventional products and with alternative biomass and land use options. To succeed in this purpose, an optimal product portfolio, a locally customised biomass supply and an optimised technical implementation are required.

5.2 Summary: Economic assessment and market analysis

For detailed results and a description of the methodology please refer to the original assessment report /Piotrowski 2013/, section on economic sustainability assessment (chapter 3).

5.2.1 Methodology and results for capital expenditures (CAPEX)

For the economic assessment, the same dataset has been used as for the environmental sustainability assessment, /Rettenmaier et al. 2013/. For all scenarios, comprehensive energy and material flow data was available. However, the provision of further data such as equipment sizing, which is required for standard approaches to determine investment and operating costs, proved impossible due to the innovativeness of this biorefinery concept. Hence, a different approach was needed for estimating investment and operating costs.

We have therefore made use of an innovative model which proposes a correlation between the fixed capital investment (FCI) of a chemical plant and the sum of the rated power of all equipment parts expressed in megawatts (MW). This correlation has first been proposed by Jean- Paul Lange of the Shell Research and Technology Centre in Amsterdam, Netherlands, in 2001, /Lange 2001/. The original equation proposed by Lange was:

$$FCI\ [\text{Mill. USD 1993}] = 2.9 * \text{Rated Power}\ [MW]0.55$$

The conversion of this formula into Euro in 2010 resulted in the following equation:

$$FCI\ [\text{Mill. EUR 2010}] = 3.3 * \text{Rated Power}\ [MW]0.55$$

Efforts have been made to validate this model to estimate FCI. For this purpose, data on other bio-based processes have been searched for. This proved difficult, because data on the rated power are typically not published and also not readily available from other sources. Nevertheless, a few data points could be added to the graph as shown in Fig. 5-2 (the data points shown in light blue are those originally found by Lange). First, actual business data was obtained for a starch plant. Then, respective data was found for an investment to convert an ethanol to a butanol plant /Larson et al. 2008/. Finally, data was used from the BIOCORE partner ECN for their ethanol-based Organosolv process.

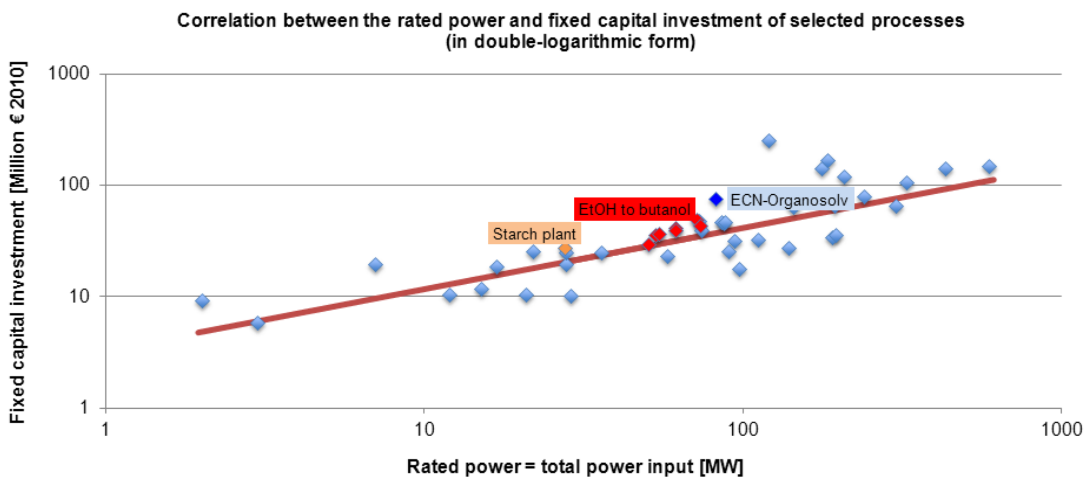

Fig. 5-2 Validation of the model for estimating capital expenditures (CAPEX)

As can be seen from these data entries, the proposed correlation appears to fit rather well. Although further analyses are not possible with such few data points, it appears that the bio-based processes tend to lie above the curve, meaning that their FCI is higher at the same rated power compared to petrochemical processes, which confirms our intuition. Note that this does not say anything about differences in production costs.

The application of this model thus led to estimates for the fixed capital investment for each of the biorefinery concepts. The total capital expenditures (CAPEX) were then obtained by adding an estimate for the working capital which was assumed to amount to 4 % of the fixed capital investment.

The estimation results for CAPEX for the standard scenarios are displayed in Fig. 5-3. The estimates lie between about 120 - 160 million Euro.

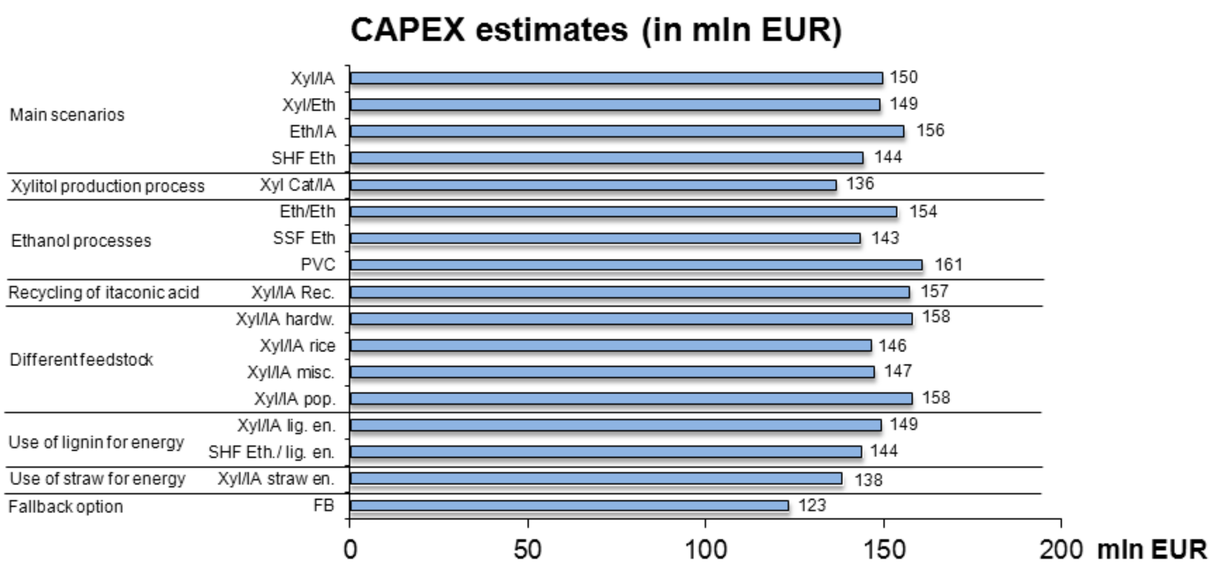

Fig. 5-3 Overall results for capital expenditures (CAPEX)

5.2.2 Methodology and results for operating expenditures (OPEX)

Also for the estimation of operating expenditures (OPEX), only limited data could be made use of. We have therefore applied a standard model which derives estimates for those cost items that cannot be calculated directly.

According to /Turton et al. 2012/, the annual OPEX can be grouped into direct or variable manufacturing costs (DMC), fixed manufacturing costs (FMC) and general expenses (GE). The following Table 5-2 shows the types of cost items as grouped into these categories following /Turton et al. 2012/.

Table 5-2 Cost items included in direct costs (DMC), fixed costs (FMC) and general expenses (GE). According to Turton et al. 2012, total OPEX can be determined when the following costs are known or can be estimated: 1. Fixed capital investment, 2. Cost of operating labour, 3. Cost of utilities, 4. Cost of raw materials. Source: /Turton et al. 2012/.

DMC	FMC	GE
Raw materials	Depreciation	Administration costs
Utilities	Local taxes and insurance	Distribution and selling costs
Operating labour	Plant overhead costs	Research and development
Direct supervisory & clerical labour		
Maintenance and repairs		
Operating supplies		
Laboratory charges		
Patents and royalties		

This result follows from the assumption, as described in /Turton et al. 2012/, that all other cost items are fixed factors of these four cost components shown above. The procedure for estimating FCI has been explained above and the costs of operating labour, utilities and raw materials (feedstock and operating materials) could be directly calculated from the BIOCORE process data. Overall, the model therefore provides a robust and transparent means of estimating both CAPEX and OPEX from limited data.

Fig. 5-4 shows the results for the operating expenditures for the standard scenarios, split between biomass, operating labour, operating materials, utilities (natural gas, electricity and tap water), other direct manufacturing costs (DMC), general expenses (GE) and fixed manufacturing costs (FMC). On average across all scenarios, both operating materials and utilities account for about 20 % of manufacturing costs each. The other direct manufacturing costs, fixed manufacturing costs and general expenses combined account for about 40 %. Biomass accounts for only about 15 % and operating labour for only 5 %.

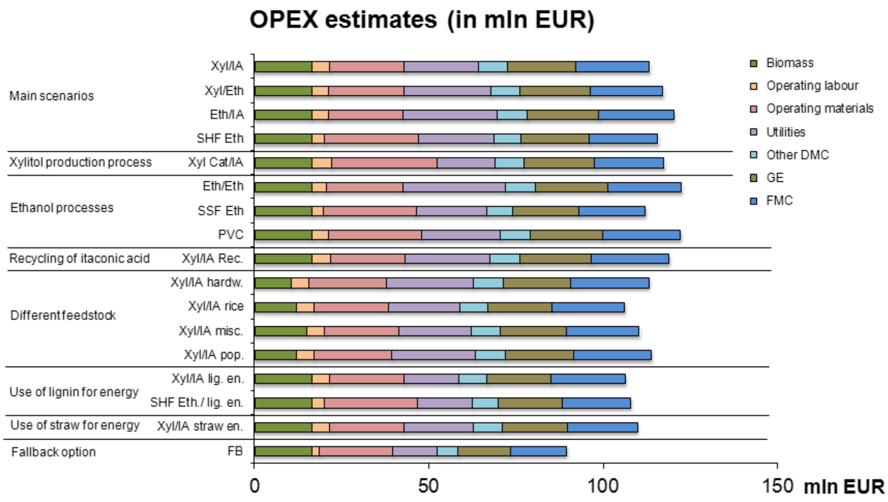

Fig. 5-4 Overall results for operating expenditures (OPEX)

5.2.3 Methodology and results on economic sustainability

In order to compare the economic performance of the different biorefinery concepts, suitable indicators are needed. As the main indicator for comparison, the Internal Rate of Return (IRR) had been chosen.

The IRR is defined as the discount rate at which the net present value of an investment is just equal to zero. The higher the IRR, the more favourable the investment project appears because it implies that future cash flows could be discounted at a higher discount rate until the NPV would become zero. The IRR is a very popular indicator for the evaluation of an investment project. According to expert information and secondary sources, an IRR of 25 % is usually considered “as the threshold for securing capital investment in new processing technology” /Brown et al. 2012, p. 82/. This threshold was therefore used as a benchmark which BIOCORE concepts would have to achieve in order to become attractive for investors.

The results show that most of the biorefinery schemes would make annual losses under standard process conditions. Only a few would make profits, but these would not be sufficient to achieve an IRR of 25 %. We conclude that they would need some kind of support mechanism in order to reach the target of 25 % IRR which would render an investment interesting without having to rely on favourable implementation conditions.

One possible support mechanism would be the direct price support on the sold production of the biorefinery. In a first instance, we assume that all sold products would be supported by a certain percentage on top of the assessed market prices without Green Premium. The results in Fig. 5-5 clearly show that the first main scenario (Xyl/IA) and all of its variations would need the lowest overall price support in order to reach the target of 25 % IRR. In the favourable sub-scenarios (indicated by green colour), the Xyl/IA scenarios based on wheat straw, hardwood, poplar, miscanthus and rice would even be able to achieve an IRR above 25 % without any support. The dotted vertical lines in Fig. 5-5 indicate actual current price support levels for biodiesel and bioethanol in Europe and Germany. These lie between about 45 % in the case of average European support levels for biodiesel and 70 % in the case of bioethanol support in Germany. This comparison shows clearly that the necessary price support for some of the selected biorefinery schemes could be quite moderate compared to the actually existing current support for biofuels.

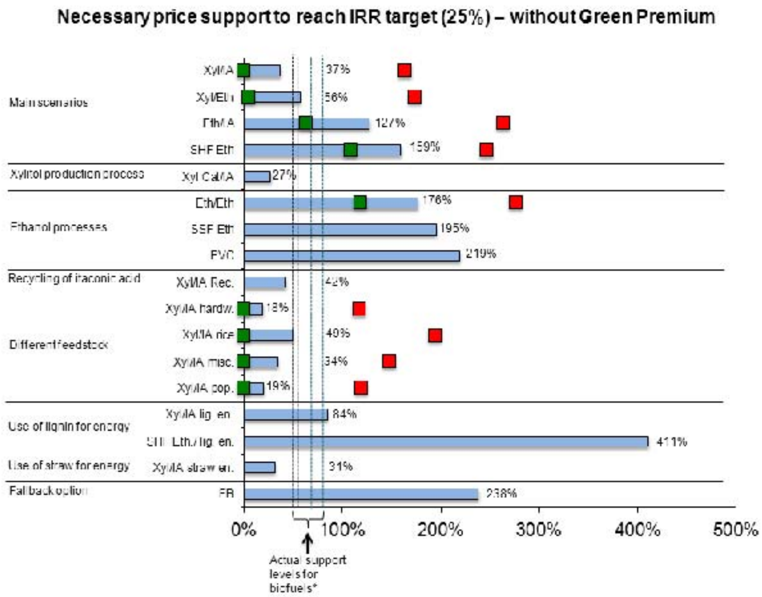

Fig. 5-5 Necessary price support to reach an Internal Rate of Return (IRR) of 25 % without Green Premium. *Price support levels for biodiesel (black dotted lines; on average about 45 % in the EU in 2010 and 50 % in Germany in 2012) and bioethanol (blue dotted lines; on average about 60 % in the EU in 2010 and 70 % in Germany in 2012).

These results significantly improve if Green Premium prices are taken into account. Green Premium is basically understood as the extra-price market actors are willing to pay for a product just for the fact that it is "green" or in our specific case "bio-based" (= derived from biomass).

The results from market research indicated that both itaconic acid and ethylene could fetch Green Premium prices. For an assessment of the impact of this price premium we assume a Green Premium of 50 % for itaconic acid and a Green Premium for ethylene of 30 %. As Fig. 5-6 shows, the Green Premium for itaconic acid could cut the remaining necessary price support down further so that even the standard sub-scenarios of Xyl/IA based on hardwood and poplar could come very close to profitability without any further support. The Green Premium for ethylene, however, could not bring the PVC scenario anywhere near profitability.

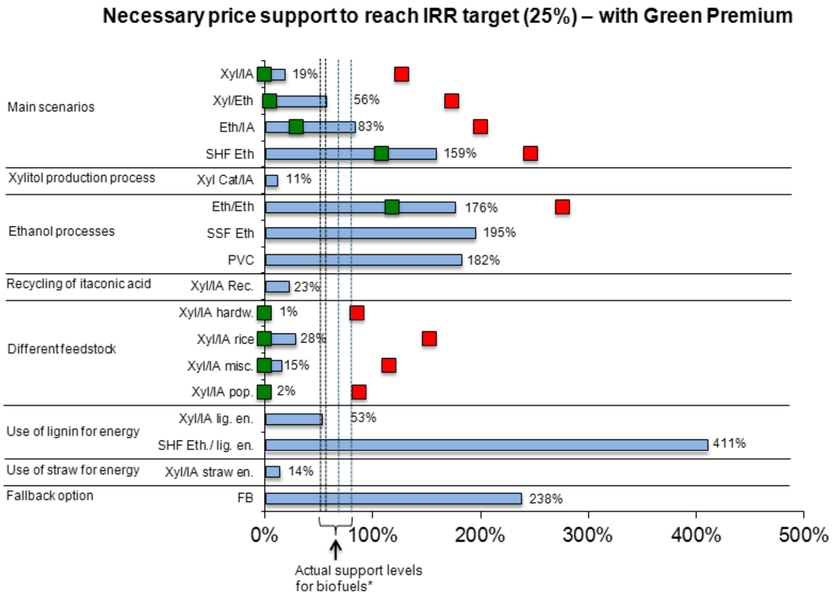

Fig. 5-6 Necessary price support to reach an Internal Rate of Return (IRR) of 25 % with Green Premium

Fig. 5-7 shows the effects of a 50 % reduction of CAPEX (as foreseen in the new framework of the European Bioeconomy by DG Research & Innovation and the Public Private Partnership Bio-based Industries Consortium) on the remaining necessary price support (with Green Premium). With such CAPEX reduction, the standard sub-scenarios of the first main scenario Xyl/IA based on hardwood, miscanthus and poplar could now reach the target of an IRR of 25 % without any further subsidies.

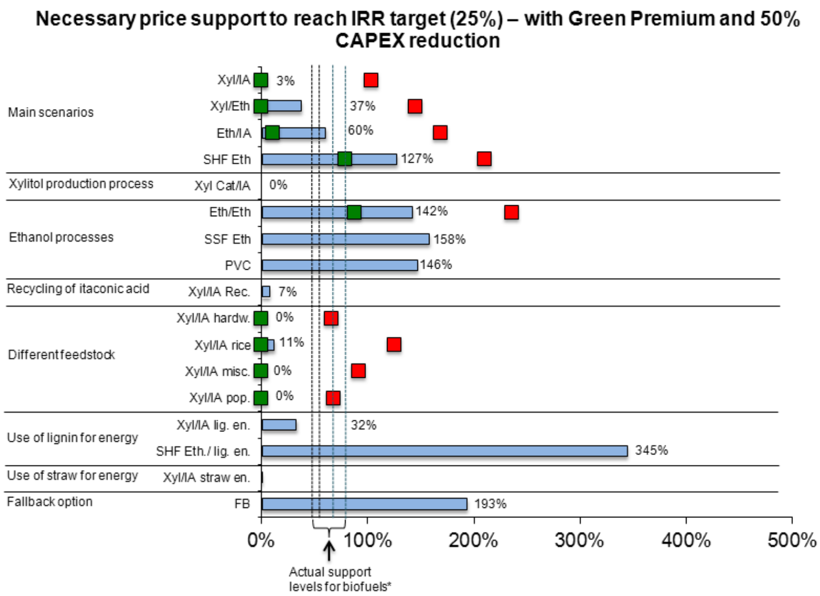

Fig. 5-7 Necessary price support to reach an Internal Rate of Return (IRR) of 25 % with Green Premium and 50 % CAPEX reduction

5.2.4 Summary and discussion

This report has first presented a newly developed model for an economic evaluation of biorefinery processes in a situation of limited data availability (for example no data for sizing of the equipment). The starting point of the analysis was the estimation of the capital expenditures (CAPEX) based on the calculated rated power of all equipment of the whole plant. Applied to the dataset that formed the basis for the sustainability assessment in the BIOCORE project, this model has proved to achieve reasonably good and coherent results. The newly developed, coarse model provides therefore, given the limited available data, satisfactory results.

In the standard scenarios, which were defined based on experts' input regarding the most plausible technological performance in 2025, only a few of the biorefinery schemes are able to generate profits and none of these are able to achieve the target of an Internal Rate of Return of 25 %, which is the standard threshold usually considered necessary to attract capital investment in the Chemical Industry.

However, a few of these biorefinery schemes could pass over this threshold either under more favourable process conditions or with moderate subsidy levels. Also if customers turn out to be willing to pay Green Premiums on selected products, the profitability target could be achieved for some of the schemes.

For those scenarios with moderate subsidy levels needed, these lie below 20 % output price support in selected cases, which is well below the current support for biofuels (e.g. for biodiesel on average about 45 % in the EU and 50 % in Germany and for bioethanol about 60 % in the EU and 70 % in Germany). Given the strong political will to develop biorefineries in Europe and the higher value-added of biorefineries compared to just producing biofuels from biomass, this result provides a strong support for biorefineries.

An alternative support instrument which results in a CAPEX cut has also been assessed. This support instrument has been developed within the new framework of the European Bioeconomy by DG Research & Innovation and the Public Private Partnership Bio-based Industries Consortium (BIC). According to this policy, it will be possible to get financial support for demonstration plants (40 % average) and for flagship plants (average 15 %). In combination with other programmes, e.g. regional development or member states support, the capital investment could be in total reduced by 50 % in some cases. With such an instrument in place, profitability for many scenarios would be significantly increased. Furthermore, the analysis has also shown that the biorefinery product portfolio determines profitability to a large extend. All of the BIOCORE processes that are focused on ethanol are expensive and provide only low revenues. Policies targeted at bioethanol production therefore apparently set wrong incentives. Rather, policies should be directed towards value-adding chemicals and polymers.

The impact of returns to scale have been assessed for one of the scenarios, which was based on rice straw in India. In this scenario, the effect from moving from 150,000 t to 500,000 t was very significant and lead to annual profits in the range of 40 mln EUR compared to losses of about 10 mln EUR. This result provides a strong case for higher biorefinery capacities.

Also the choice of the feedstock has been shown to be an important determinant for profitability. The chemical composition, especially the shares of usable components, i.e. cellulose, hemicellulose and lignin, determines products output and thus revenues. This effect can make a difference in the range of 20 mln EUR when moving from wheat straw as feedstock to hardwood (according to the assumptions, the share of usable components in hardwood was 98 % compared to 77 % for wheat straw).

The scenarios presented above all assumed one single feedstock. In reality, however, a multi-feedstock supply is much more realistic and also more sustainable in the long-run: Short supply or price spikes of one feedstock could be better buffered in a multiple feedstock scenario.

As another finding of the economic evaluation of the selected biorefinery processes, it has been shown that the Organosolv process itself is the largest contributor to utility costs (about 60 – 80 %). This is an interesting finding and it raises questions about the choice of the fractionation technology as well as the focus on lignocellulosic feedstocks that need to undergo intensive pretreatment such as Organosolv in our case.

Lessons learned:

- The economic analysis shows clearly that a biorefinery can and will be much more profitable compared to a pure biofuel plant.
- This is due to higher value added from high-value chemical building blocks and chances to receive Green Premium prices for some of the bio-based chemicals or polymers (in contrast to fuels).
- A biorefinery should produce as little as possible low-value chemicals like ethanol and try to valorise lignin-derived chemicals on the highest level.
- The existing political framework is only in favour of biofuels. A new policy in favour of biorefineries could bring new investments, value added and employment to Europe – and in addition would even show more CO_2 reduction. The recent PPP activities with support for demonstration plants and flagship investment are the first visible steps in the right direction.
- The analysis supports high capacity biorefinery concepts.

5.2.5 Economic impacts of current policy landscape

The economic viability of any business, especially within or competing with the energy sector, is highly affected by various policies. As a supplement to the economic assessment and crosslink to the social, legal and political assessment (chapter 5.3), the most important impacts of policies on the bio-based products industry are summarised in this chapter.

Analyses of nova-Institute have shown that the material use of biomass is hindered from entering the market by more than 50 small and big barriers (see /Carus et al. 2014/). This state of affairs can be summed up in a "competition triangle" (Fig. 5-8), which illustrates the following:

Right side: Bioenergy / biofuels and material use competing for biomass

Material use is competing with bioenergy for biomass that is not used for food or feed. As a result of the comprehensive support system for bioenergy and biofuels, which was ultimately created by the EU RED, the prices for biomass and land have greatly increased. This makes access to biomass for material use much harder and more expensive, but this is not compensated for by support measures. This market distortion hinders the competitiveness of producers of materials from biomass.

Left side: Petrochemical products competing with bio-based products

The bio-based chemistry and plastics industries are exposed to full competition from chemical industry products. Without any accompanying measures, new, bio-based industries must be developed that can prove their viability in the face of the well-established and long-optimised mass production of the chemical industry. Then there are high biomass prices resulting from the promotion of energy use, which are not counteracted by taxes on fossil carbon sources as a raw material for the chemical industry. All of this creates an extremely tough competitive environment.

Upper side: Fossil energy competing with bioenergy / biofuels

Due to the comprehensive support system for the energetic use of biomass, originating from the RED and its national implementations, an artificial competitive situation compared to fossil energy sources has been created over the years. Furthermore, the latter are subject to a substantial energy tax – this makes for extremely favourable, artificially created competitive conditions for bioenergy and biofuels.

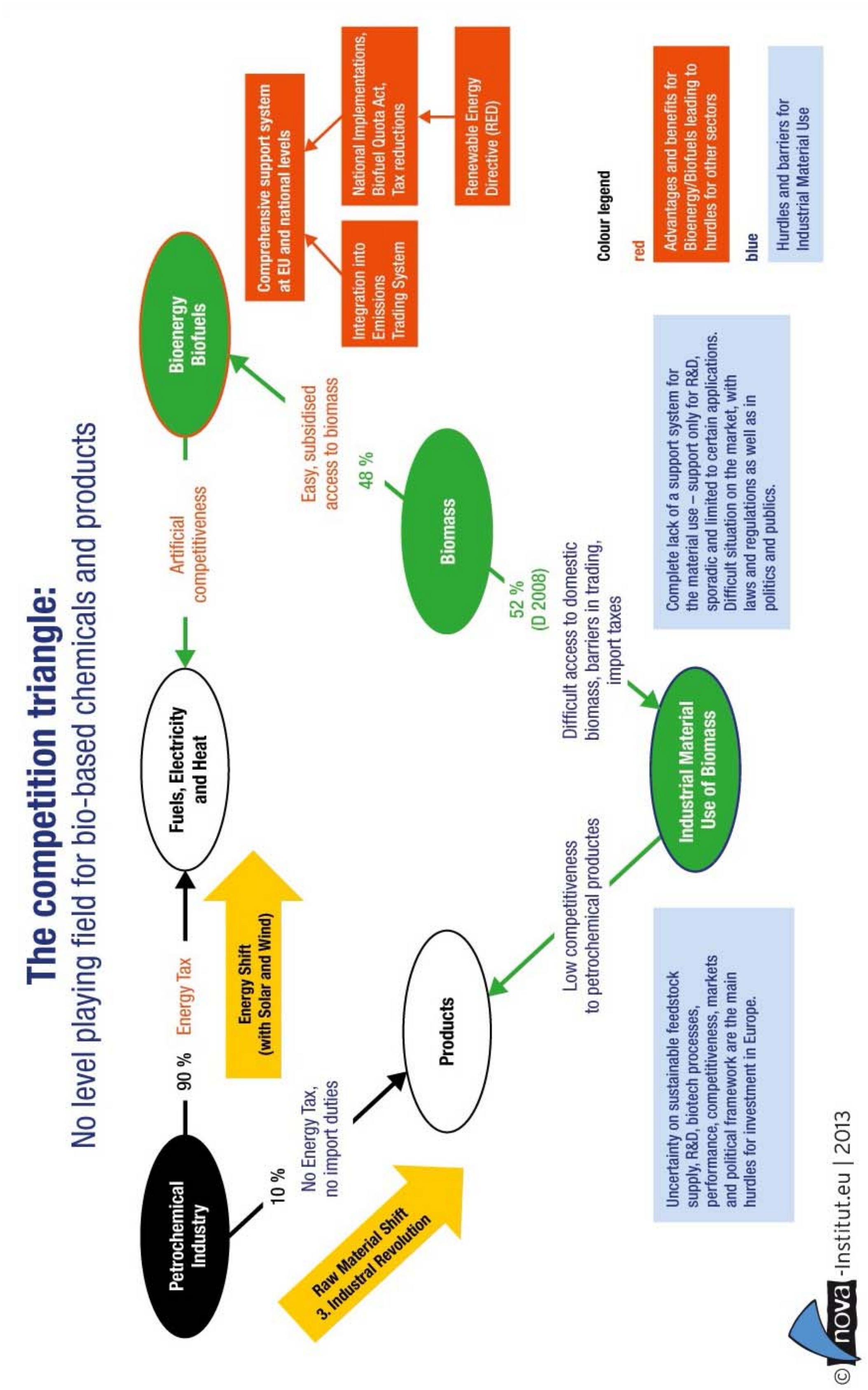

Fig. 5-8 The competition triangle on biomass, bioenergy and bio-based products: Non-level playing field for bio-based chemicals and bio-based products

5.3 Summary: Social, legal and political assessment

For detailed results and a description of the methodology please refer to the original assessment report /Piotrowski 2013/, section on social, political and legal sustainability assessment (chapter 4) and /Diaz-Chavez 2013a/, a separately available annex to that report.

5.3.1 Introduction

Social, legal and political considerations play an important role with regard to acceptability and diffusion of new technologies. Social sustainability in the context of BIOCORE implies that the systems, structures and the relationships formed by the biorefinery actively support the capacity of current and future generations to evolve within a sustainable livelihood framework. The legal and political aspects of sustainability explore efforts to address pressing sustainability concerns through policies, legislation, conventions, directives, treaties, and protocols.

5.3.1.1 Key objectives

- To assess socio-economic costs and benefits using inputs from other work packages (and in particular from WP 1)
- To understand existing social, legal and political framework at the regional, national and international level
- To evaluate and analyse potential impact of BIOCORE on social legal and political structures in the selected sites
- Suggest recommendations/provide inputs along with task 7.3 and directions for integrated assessment of overall sustainability issues

5.3.1.2 Key issues covered under social, legal and political sustainability assessment

Evaluating social sustainability of BIOCORE first needs an appropriate identification of linkages between the bio-refinery supply chain and possible social structures followed by identification of suitable indicators to make such linkages measurable and finally their measurement and assessment. Critical social structure would typically include job creation, human rights, displacement, conflict with other forms of livelihoods, possible impact on local, national and global dynamics, ability to meet end-users and consumer needs compared to reference products, etc. Measurement of these issues through suitable indicators can either be undertaken based on stakeholder discussion and learning their perception, or through detailed review of literatures. Because of the complex nature of undertaking such social assessments, a combination of both approaches is more helpful in presenting robust comprehensive results.

The legal and political aspects of sustainability explore efforts to address pressing sustainability concerns through policies, legislation, conventions, directives, treaties, and protocols. It looks into the effectiveness of international law versus national law in protecting the environment, and about the effect of current laws on future generations. They analyse the efficacy and shortcomings of present legal instruments, private and public policies, social movements, and conceptual strategies – offering readers a prelude of steps we must take to develop laws and policies that will promote sustainability.

5.3.2 Methodology for social legal and political sustainability assessment

5.3.2.1 Legal and political assessment

The legal and political assessment included critical review of different regulations and policies, currently in place at EU and India that are relevant for BIOCORE. In the Indian context, various sub-national and state level programs that are relevant for Bio-Commodity refining, was also reviewed as a part of the study.

5.3.2.2 Socio-economic impact assessment using MCA

One of the major approaches widely used for socio-economic impact assessment is the multi-criteria analysis (MCA). MCA is a decision-making tool which is primarily developed for complex multi-criteria problems that may include qualitative or quantitative aspects (or both) of the problem in the decision-making process. MCA has found growing application in recent times particularly in the decision making process associated with environmental sustainability. One of the commonly used tools under MCA is the Analytical Hierarchical Process. It is a decision support tool that can be used to solve complex decision problems taking into account tangible and intangible aspects. The tool supports policy makers to make decisions based on primary and secondary information. The AHP decomposes a decision problem (research question) into elements, according to their common characteristics, and levels, which correspond to the common characteristic of the elements.

5.3.2.3 Social impact assessment

To address social and economic impacts, the BIOCORE project used a combined methodology of social impact assessment (SIA), social life cycle assessment (sLCA) and sustainability assessment to link it with the environmental assessment. The mapping of stakeholders was included as part of the scoping and assessment and a number of indicators were assessed using the Hotspot Database /Diaz-Chavez 2013a/. Social life cycle assessment (sLCA) showed a direct link with three of the techniques used in social impact assessment: identifying stakeholders, creating a baseline (inventory) using indicators and identifying the chain of impacts. The methodology was applied to three case studies in Europe and one in India. Direct interviews were conducted and surveys were distributed among the stakeholders identified. A review of the market was also conducted to understand the need for bio-based products. The stakeholders' opinion was complemented through a workshop organised by the BIOCORE Project in Brussels in 2013 with stakeholders from the EU and India.

5.3.3 Key findings from legal and political assessment

5.3.3.1 Findings from India

Although the government of India has introduced policies to promote biofuels from time to time, it lacked an integrated approach and hence resulted in low awareness level. Further the emphasis has only been in energy related applications, while non-energy applications have been ignored. The focus of India's biofuel programmes has been on non-edible feedstock (like Jatropha, Pongamia seeds etc.) and on molasses produced as a co-product of sugarcane based processes of bioethanol production for its subsequent blending with gasoline or petrol. Some of the important policies reviewed include the bioethanol program, the national mission on biodiesel, India's integrated energy policy 2006, national biofuel policy, various programs of MNRE, state level biofuel policies, etc. (Fig. 5-9).

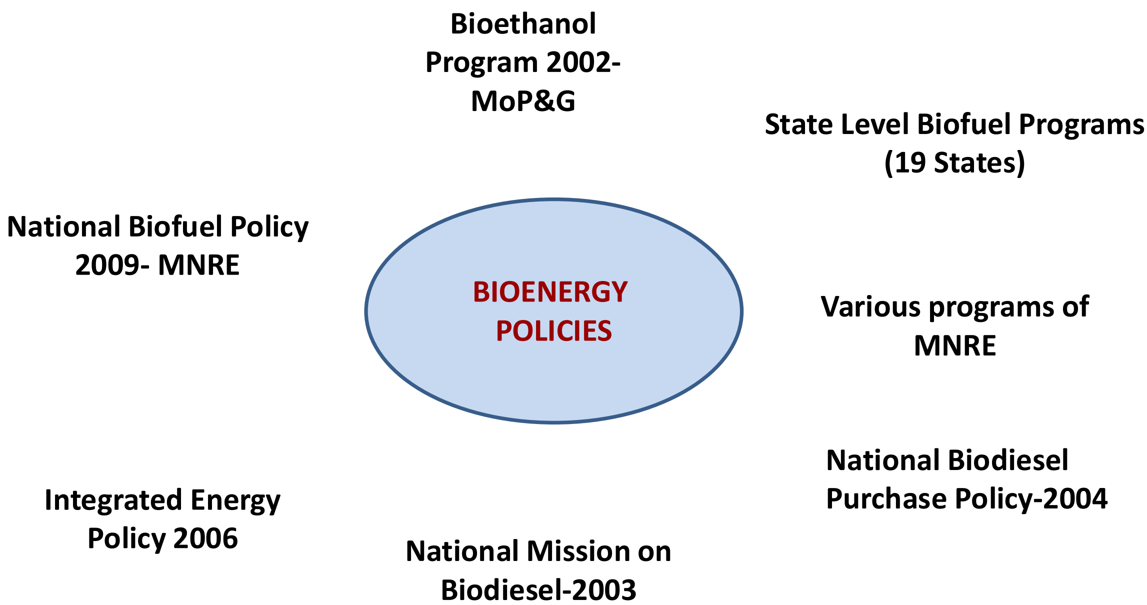

Fig. 5-9 Key policies for promotion of biofuel in India

The review reveals that the government's initiatives have not translated into results on the production and commercialisation fronts to meet the country's energy demand and calls for a re-examination of the policy from various stages of the biofuel supply chain. Moreover the policy is sugarcane centric. This calls for adjustments in the National Policy on Biofuels favouring bioethanol production from alternate feedstock that is expected to benefit all the stakeholders in the biofuels supply chain hasten the pace of biofuel production in India. There are also significant hurdles in technology development that need to be overcome before second-generation biofuels can be produced at commercial scale, even with the massive investments in R&D observed in recent years. While there are policies to promote the biofuel sector, those promoting the production of feedstock need to be highlighted in order to fully realize the benefits provided on the processing front, since production and processing are interdependent. There also has to be a higher focus by the government on carbon trading and renewable energy targets.

5.3.3.2 Findings from EU

In the context of the European Union several policies, programmes and strategies have included the elements for Research and Development in the topic of biotechnology. Different policy and regulatory policy instruments, along with the participation of stakeholders, help to develop the pathway in order to have a bio-based economy in Europe. Some of these instruments more related to biorefineries activities were analysed (Fig. 5-10).

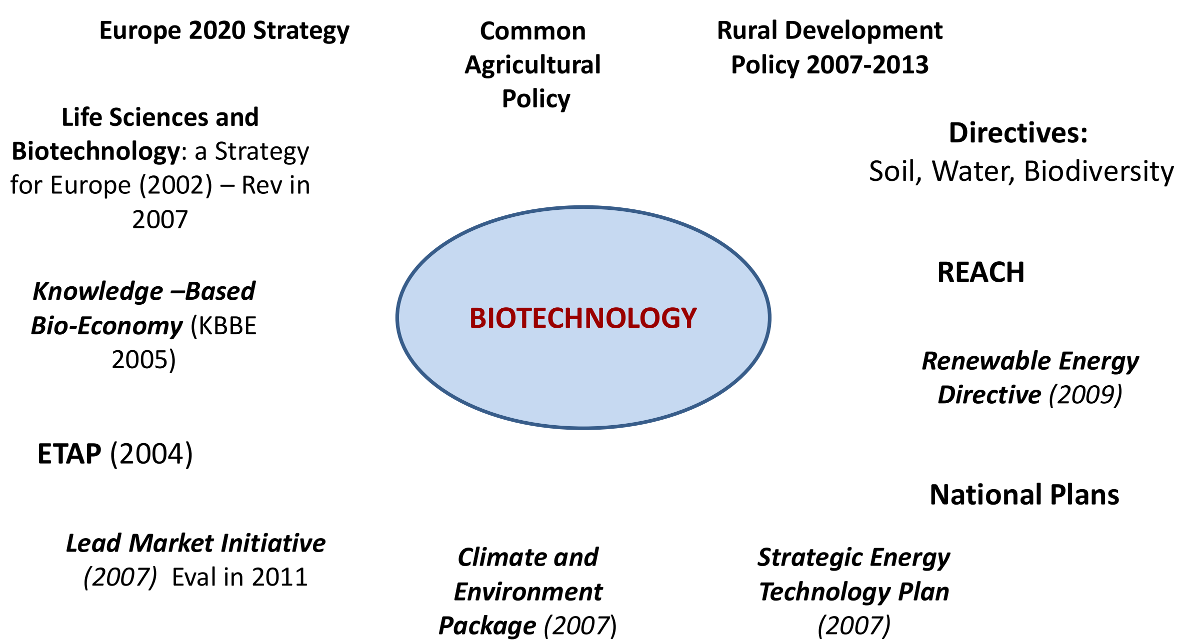

Fig. 5-10 Overview of strategic and regulatory documents related to biorefineries concept, research and implementation /Diaz-Chavez 2012/

The analysis also included the review of regulations at national level, EU Directives (e.g. on Biodiversity) international agreements and initiatives (e.g. ILO, MDGS). Several EU legislation instruments are related to the promotion of bio-based products including packaging, monitoring of environmental impacts, eco-labelling. Nevertheless it has been reported (e.g. LMI, 2009) that the different legal and regulatory instruments apply at different levels and this makes difficult to influence all levels of the supply chain (manufacture, sale and disposal of bio-based products) mainly because they are not one uniform product group, but a wide range of products with completely different characteristics, qualities and uses.

5.3.4 Socio-economic sustainability assessment using MCA

Socio-economic sustainability assessment was carried out using AHP tool for the two study sites in the State of Punjab in India. The major sustainability indicators included production and availability of feedstock, employment, health, environment and food security, rural development, research and development, other issues related to political, legal and economic barriers. Stakeholders consulted were farmers, policy makers, transporters/aggregators, panchayat members, and representatives from competing industry. Analysis reveals that production and availability of feedstock and employment will not pose any challenge for the sustainability of biorefineries. Despite increased interest in expanding second-generation biofuels and progress made in recent years, significant hurdles in technology development still need to be overcome before second-generation biofuels can be produced at commercial scale, even with the massive investments in R&D observed in recent years. Factors on "research and development" may cause barriers for a biorefinery to be set up, i.e. not much investment has been made in the research and development area in clean / bioenergy. "Rural development" is another sustainability indicator of concern, which may cause hindrance to a possible biorefinery setup, i.e. there has not been much improvement in rural development in the area even with the current levels of industrialisation.

5.3.5 Social assessment

The social assessment used the combined methodology of sLCA and SIA for each one of the cases for Europe (France, Hungary and Germany). The assessment was based on the background information for each case study. The indicators are the same for the three case studies in the EU. There are some indicators that are different for the case study in India (e.g. land tenure) /Diaz-Chavez 2013a, 2013b/. The overall assessment demonstrated that:

- Three cases in the EU France, Hungary and Germany) show the differences at national and regional level as well as with the Indian case study
- There is limited availability of feedstock in some cases and negative willingness to sell the biomass to a bio-refinery
- Skills are in place but may be limited in isolated areas where feedstock is available (e.g. Hungary)
- Job creation has more emphasis on the feedstock production, treatment and transport and less for conversion
- Rural development was considered by stakeholders a main asset of these projects
- Some gender and health issues to be considered at the production and transformation level

Table 5-3 Summary of the overall assessment for the cases in Europe, see /Diaz-Chavez 2013a/.

NO	Parameter	Characteristics/Criteria	Type	Impact	Risk	Benefit	Mitigation/Other comments
1	Production of feedstock	Incentives	B	+		H	Incentives have an advantage but fair play is necessary to reduce/avoid competition with other sector
		Barriers	B	-	L		Look for market opportunities and avoid Financing Insecurity for large investments.
2	Identification of Stakeholders along the supply chain	Producers (farmers); Regulators; Business; Traders; Research	B	+		H	
3	Policies and regulations	National	B	+		H	
		Enforcement	B	-	L		In general for the EU there is no problem with enforcement although the HSDB presented some problems in the Hungarian case.
5	Land use tenure	Land ownership rights	B	N			
6	Community participation	Community participation	D	+		H	
8	Rural development and Infrastructure	Roads	B	-	L		In general in the EU there is not a problem with infrastructure. Although stakeholders in Hungary reported that roads are not good for transport of feedstock in the suggested region for a biorefinery plant. As a mitigation measure alternative routes, site or storage sites..
9	Job creation and wages	Labour involved on feedstock production	D	+ & -	L	H	It can be a risk for the producers (farms and forestry) to sign contracts for long periods A third party could be involved to guarantee the investment
		Labour involved in production	D	+		L	
		Wages paid according to national/regional regulation	D	N		L	
		Rural development	D	+		H	.
10	Gender equity	Inclusion of women	D				
11	Labour conditions	ILO conventions	D	+ & -	L	H	
12	Health and safety	Compliance with health and safety regulations	D		L	M	Low negative impacts are considered as few reports exist about this mainly in rural areas. In the industry sector this is regulated.
13	Competition with other sectors	Competition of residues use for biorefinery and impact on other industries and sectors	D	+ & -	M	M	This could have a medium negative impact in some regions where competition with the raw material is foreseen or already exist.

Type of impact: D direct; B background; Impact + positive; - negative; N neutral; Risk/Benefits: L low; M, Medium; H high; VH very high

5.3.6 Policy recommendations

One of the important recommendations that emerge from the above findings is to have a proper procurement pricing strategy for feedstock as well as for products. Since there is relatively more biomass competition in Europe than in India in the short run, such decision is important from the sustainability point of view. However, with regard to India, it may not experience any competition in the short run however, from a medium to long term perspective, it is important to have appropriate feedstock pricing strategy in place.

For a biorefinery to be set up, although there may be enough production and availability of feedstock and employment would be generated for the biorefinery setup, however, research and development and rural development are causes of concern. A biorefinery may need to invest in these two aspects for it to be sustainable. Alternatively, research and development and rural development could affect a biorefinery setup. With improved technologies and employment created, a biorefinery setup may be able to contribute to an improved research and development and the overall growth and development of the area.

Health and occupational safety is a key issue across various industries and for a social sustainability perspective it is important to have independent third party audits for health and occupational safety. Furthermore, as the investment required is estimated to be significant, it is advisable to consider the application of the Equator Principles mainly for the biorefinery to comply with international sustainability standards.

5.4 Summary: SWOT and biomass competition analysis

Detailed results and a description of the methodological approach of this task are described in the final report on SWOT analysis and biomass competition /Kretschmer et al. 2013/. This chapter summarises the main results and conclusions.

5.4.1 Biomass competition analysis

Biomass potentials for biorefining in Europe

The estimations related to future use of biomass and related land use include many assumptions and uncertainties, and can be considered as indicative only. According to a review of literature, approximately 20 – 30 Mha of former arable land could become available by 2030 in Europe for growing biorefinery feedstocks. Additionally there is growth potential in the use of forest and agro residues compared to current use levels. Agro residues and primary forest residues sum up to about 1/3 of the total EU biomass potential in 2030 /Elbersen et al. 2012/. However, the available biomass would be entirely needed or even insufficient to meet the European bioenergy targets /Junginger et al. 2010/, /Böttcher et al. 2012/. Hence, imports from outside EU are required.

According to estimations presented by /Dornburg et al. 2008/ the production of bio-based chemicals from fermentable sugar made of starch could require 1.0 – 38.2 Mha of land in

2050. In case lignocellulose would be used as raw material, the corresponding land requirements would be 0.4 – 15.6 Mha. Hence, even if lignocellulose would be used as a feedstock, with a high market share and production of bio-based chemicals, the land requirements would use half or more of the land that is estimated to become available in Europe by 2030. But, most of the land demand for biopolymers would most likely occur outside Europe, close to production sites that are mainly located in Asia and South America. This might relieve the land use pressures in Europe, but lead to increasing competition for land in other parts of the world. Considering the estimated future growth potential in the markets of bio-based chemicals and biopolymers, together with the rising demands for food and bioenergy, high pressures related to land use can be expected in future.

Regional differences

Results from all the reviewed studies indicate big differences in regional availability of biomass resources. Currently, the competition, demand and price for biomass can, in many cases, be defined locally, which can cause big varieties between local conditions and country or Europe scale assessments /Alakangas et al. 2011/, /Kretschmer et al. 2012/.

It is important to notice that much of the European biomass potential is located in Eastern Europe and Ukraine, due to higher expectations in yield increases and large agricultural areas. But, most of the current or planned biorefinery sites in Europe are located in Western Europe, close to good infrastructure and existing chemical industry /Biorefinery Euroview & BIOPOL 2009/. Thus there might be geographic challenges in meeting with the potential supply and demand for biomass.

The issues of direct and indirect land use change

Imports from outside the EU would be required to be able to fulfill the European bioenergy targets, see /Alakangas et al. 2011/. The growing imports of biomass might pose a risk of indirect land use change (ILUC).

Changes in land use or land cover category can happen either between different land use categories, such as from forest to agricultural land or as a change in the intensity of the land use within the given category, such as agricultural intensification. Direct land use change (DLUC) refers to a situation in which land cover and land use are changed from one category to another. This can happen for example through the reforestation of former agricultural land or through clearing a forest to agricultural land or urban area. Land use and land cover change (LULCC) may lead to habitat destruction which causes damage to biodiversity. Additionally, intensification of land use may cause damage to ecosystem services. One of the most important environmental impacts relates to loss of carbon sinks due to soil disturbance, see /EEA 2010/.

Indirect land use change (ILUC) has been discussed especially in the context of biofuels. In the case of biofuels, indirect land use change refers to a situation in which increased demand for biofuels leads to change from current agricultural crops to biofuel crops. The change from food or feed production to biofuel cropping in a certain area, might lead to further expansion of agricultural area (or intensification) elsewhere. In addition to associated GHG emissions, changes from food to biofuel cropping may threaten food security, see e.g. /UNEP 2009/.

ILUC impacts outside EU members states related to the RES directive and increasing demand for biofuels are estimated between 3-7 Mha /Bowyer 2010/, /von Witzke & Noleppa 2010/. Demands related to material biomass use purposes would be added to this figure.

Increasing need for imports of biomass highlight that many of the potential impacts occur outside Europe where they are more difficult to evaluate and control. Although it has been estimated that in Europe, there is currently unused agricultural land and more land will be freed up in the future, it should be considered that according to estimates, Europeans already occupy more land for agricultural purposes than is available globally per capita. /Bringezu et al. 2012/ estimate that in 2007 Europeans required 0.31 ha per capita of cropland worldwide for its overall consumption of agricultural goods. Thus, the citizens of EU-27 consume one-third more than the globally available cropland per capita of world population, i.e. 0.23 ha (ibid.). Estimated area needed to feed one person is 0.22 ha /FAO 2011/.

Constraints on biomass mobilisation

The biomass availability is highly affected by what type of environmental policy or sustainability criteria will be in use. In addition, several economic, social and technical constraints might hinder the mobilisation potential of the wood resources /Verkerk et al. 2010/. These include e.g. the availability of skilled labour and machinery, the ownership structure of forests and the cost of the supply of biomass. While harvesting more wood would require trade-offs between the principles of forest management, also a significant increase in labour workforce and machinery would be required. Thus, the investment costs for the machinery might be one of the preventing factors, together with the availability of skilled work force to use the machinery.

For extracting the amount of wood that was assumed in the EUWood project for 2030, an increase of 50% in the number of workers, compared to figures of 2005, would be required /Verkerk et al. 2010/. If other wood than stemwood would be included, the labour needs in different mobilisation scenarios would be even higher.

The results of a recent study by IIEP /Kretschmer et al. 2012/ state that, when concerning straw availability for biorefineries, one of the challenges is estimating the amount going to different competing uses, that include animal bedding, soil improvement and mulch for use in vegetable and mushroom production. The amounts used for different purposes change between the years, but there are also cases were significant straw surplus can be existing. However, flexible arrangements are needed to secure the straw availability for a biorefinery. Underdeveloped markets, competing uses that have been developed over centuries, lack of infrastructure and investment in appropriate on-farm machinery, and a lack of workers in harvest time might hinder straw mobilisation.

Due to big local differences in biomass availability, functioning biomass markets might help biorefineries in securing a stable feedstock supply, in case of big yearly changes in local availability of feedstock. Currently, only a small amount of total biomass used in EU is traded internationally, but this amount is expected to grow rapidly /Junginger et al. 2010/. Obstacles for the development of biomass markets are logistical issues and uncertainty related to biomass quality and sustainability criteria /Junginger et al. 2010/.

Table 5-4 Summary of the main findings related to biomass availability and biomass competition in Europe

Wood residues and stem wood	Agro residues	SRC
	Current situation	
- Unused wood resources available, but much less hardwood than soft wood - Hardwood availability focused on few areas - Locally determined price & competition between different uses of wood	- Unused straw potential available - Most of the straw potential focused on few countries - Existing uses of straw as energy, animal bedding, SOC maintenance & mulch for mushroom & vegetable cultivation - Missing supply chain for collecting, storing and selling straw to biorefineries	- Not much feedstock is currently available - Area under SRC cultivation in Europe is less than 100 000 ha
	Future availability	
- Energy uses will likely exceed material uses of wood and a wood deficit is expected in Europe - Increasing competition - Investments in harvesting operations required to mobilise more wood	- Climate change & extreme weather conditions might affect straw yields - Energy uses of straw might increase - Expected increase in the area of organic farming and systems based on longer crop rotations and soil cover reduces straw availability	- Ca. 20-30 Mha (or more) of former agricultural land is expected to become available for energy crops by 2030 in Europe, due to increasing productivity - Contaminated land & former mining sites provide additional possibilities for SRC cultivation - Uncertainty in feedstock availability in larger scale
	Potential challenges and restricting factors	
- For the CIMV process, wood has to be bark free - High competition for wood raw material - Willingness of forest owners to sell wood - Environmental impacts from more intensive forest management	- Farmers need to be convinced about the advantages of selling straw to biorefineries with a long term contract (5 to 10 years) - More information about amount of straw needed for SOC maintenance and for soil micro-organisms feeding is required - Yearly changes in straw availability due to weather conditions	- Different crops are suitable for different climatic conditions - Rapid changes in land use would be required to ensure SRC availability - Move to SRC cultivation requires big changes in farming practices & investments

Cascading use of biomass as an option to lower pressure on land use

The cascading use of biomass, meaning using biomass to produce material first and then recovering the energy content of the resulting waste, has been suggested as a solution to maximise the CO_2 mitigation potential of biomass /UNEP 2009/. This way, also the demand for land to produce biomass could be reduced. While the material uses of biomass still exceed the energy uses, it has been estimated that the energy uses of wood will exceed the material use in EU already in the near future (between 2015 – 2020) /Mantau et al. 2010/. Active coordination activities would be required between different industrial sectors, to be able to better utilise principles of cascading use of biomass.

Table 5-5 Summary of the main findings related to biomass availability and biomass competition in India

Rice and wheat straw
Current availability - High availability of rice and wheat straw, but wheat straw with important alternative uses is not available in surplus - Existing uses of wheat straw as animal bedding and fodder for cattle - Rice straw can be sold to the industry that uses it as a fuel for furnace - Locally determined price & competition for straw - Weak supply chain for collecting, storing and selling to biorefineries
Future availability - Investments in harvesting operations required to mobilise more rice straw - Additional machines and employees will be required to harvest large amounts of straw - Climate change & extreme weather conditions might affect straw yields - Energy uses of straw are likely to increase - Expected increase in the area of organic farming reduces straw availability
Potential challenges and restricting factors - High competition by paper industry in the region for wheat straw - Time gap between harvesting of rice and sowing of wheat seldom leaves the farmers with any other choice than to burn the residues on field to be able to clear them overnight - Farmers need to be convinced about the advantages of selling to biorefineries - More information about amount of straw available for different alternative uses is required - Yearly changes in straw availability due to weather conditions

Summary and conclusions

The main findings related to biomass availability and biomass competition in Europe and India are summarised in Table 5-3 and Table 5-4.

5.4.2 SWOT analysis

Introduction and approach

The aim of SWOT analysis in BIOCORE is to detect, and thus account for, success and failure factors that are not fully covered by the other sustainability assessment tasks (on environmental, economic and social performance). Hence the function of the SWOT analysis within BIOCORE was to make sure that no key factors for success or failure are omitted in the final assessment, to deliver a broader picture on success and failure factors and to identify "hot spots". The aim of SWOT analysis in BIOCORE was not to sum up results from environmental, social and economic assessments.

The SWOT analysis in BIOCORE was carried out in a four step approach:

(1) Internal SWOT analysis: Review of BIOCORE reports and literature, consultation of consortium members and SAB

(2) External SWOT: Consultation of external stakeholders

(3) Workshop: Discussion of preliminary SWOT results with consortium members and external stakeholders

(4) Finalisation and conclusions.

The SWOT analysis was divided into two parts: A SWOT on biomass provision and a SWOT on biomass conversion.

Main findings regarding biomass provision

The biomass provision was the more intensely discussed part of the SWOT analysis. This was mostly due to the fact that external stakeholders hat little knowledge about the specific success and failure factors of BIOCORE technologies, but a strong knowledge on agriculture, forestry or competing industries. Most important SWOT arguments regarding biomass provision for BIOCORE refineries in general, straw provision, forest wood provision and SRC wood provision are summarised in Table 5-6 to Table 5-10.

Table 5-6 Summary: Most important general SWOT arguments regarding biomass provision for BIOCORE

	Success factors	Failure factors
Internal factors	**Strengths** ▪ Providing an alternative to the increasingly scarce fossil carbon sources ▪ Contribution to rural development: Job and income creation in rural areas (agriculture and forestry, logistics, processing) ▪ Runs on non-food biomass: No direct competition to food ▪ Runs on residues (straw): No direct competition for land use	**Weaknesses** ▪ Only debarked hardwood is suitable ▪ Softwood can be used as pellets only ▪ Infrastructure not yet fully available ▪ Scarcity of land in Europe, except for eastern Europe ▪ Some created jobs are only seasonal jobs.
External factors	**Opportunities** ▪ Higher energy- and resource security for EU ▪ Making farmers biorefinery shareholders could facilitate cooperation and rural development	**Threats** ▪ Higher biomass prices affect other biomass users ▪ Indirect effects on land use patterns: Increased demand for cultivated biomass because of higher efficiency (c.f. the current situation of German biogas industry, which operates using maize silage) ▪ In case of biomass import: long transport and associated burdens, lower transparency regarding sustainability issues ▪ Small scale ownership structure put a hurdle on mobilisation

Table 5-7 Summary: Most important SWOT arguments regarding straw provision

	Success factors	Failure factors
Internal factors	**Strengths** ▪ Income opportunity for farmers ▪ Cheap biomass ▪ No direct competition for food ▪ No competition for land use	**Weaknesses** ▪ Harvest only once a year ▪ Seasonal workers and new machinery needed because harvest is done during the busiest period for farmers ▪ Drain from conventional uses ▪ "Temptation" to extract unsustainably high rates if no mandatory environmental sustainability criteria applied ▪ Variance in straw availability depending on grain harvest, risks for harvest failures
External factors	**Opportunities** ▪ Farmers go back to long stem varieties	**Threats** ▪ Loss of soil productivity in case of too high extraction rates ▪ Feedstock shortages likely in case of harvest failures or changing grain production patterns; long term contracts with farmers difficult.

Table 5-8 Summary: Most important SWOT arguments regarding forest wood provision

	Success factors	Failure factors
Internal factors	**Strengths** ▪ Income opportunity for forestry sector ▪ Market for early thinning wood with low diameters (<6 cm) ▪ Forest provide many ecosystem services	**Weaknesses** ▪ Only hardwood suitable, but low hardwood potential in Europe ▪ Little margins for increase in wood supply in Europe expected ▪ Forest ownership structure in Europe hinders wood mobilisation for centralised processing (many private owners of small forests; village want to become energy independent)
External factors	**Opportunities** ▪ In some regions, paper mills and pellet plants closing down and set biomass free for user uses ▪ Cascading use of wood residues could increase availability of woody biomass	**Threats** ▪ Wood could be withdrawn from more sustainable uses ▪ Increased demand for wood could be an incentive for unsustainable forest management practices

Table 5-9 Summary: Most important SWOT arguments regarding SRC wood provision

	Success factors	Failure factors
Internal factors	**Strengths** ▪ Income opportunity for farmers / forestry ▪ Stable biomass properties and low risks for shortages in biomass availability once plantations are established	**Weaknesses** ▪ Requires land for cultivation ▪ Little knowledge on SRC cultivation and its market opportunities amongst farmers ▪ Bind farmers for many years
External factors	**Opportunities** ▪ SRC on industrial waste land or other marginal lands ▪ Lower environmental impacts compared to most annual crops (positive impacts on soil and water resources and biodiversity) ▪ Successful trials are available → knowledge on regional performance and best cultivation practices could be spread amongst farmers ▪ Long term contracts can be an advantage both for farmers and processors	**Threats** ▪ Negative environmental and social impacts if cultivated in unsuitable locations ▪ Displacement of other crops if cultivated on agricultural land → direct and indirect land use change effects

Table 5-10 Summary: Most important SWOT arguments regarding BIOCORE biomass provision in India

	Success factors	Failure factors
Internal factors	**Strengths** ▪ High biomass potential ▪ Residue biomass: No competition to food, no land needed for cultivation ▪ Avoidance of rice straw burning lowers environmental burdens and health impacts ▪ Contribution to rural development: Income opportunity for farmers, jobs at biorefineries, added value in rural areas by production of high value products	**Weaknesses** ▪ Infrastructure not yet fully available ▪ Short time span for straw harvest ▪ Low level of mechanisation in Indian agriculture is a problem for harvest, drying and densification
External factors	**Opportunities** ▪ Higher energy- and resource security for India ▪ Use biomass cultivated on areas not suitable for food production because of wild animals	**Threats** ▪ Indirect effects on land use patterns possible ▪ Negative effects on soil fertility possible through nutrient depletion

Main findings regarding biomass conversion and use

An issue controversially discussed was the issue of production scale. Some stakeholders question the scale of the biorefineries proposed by BIOCORE. They recommend a more decentralised approach with biorefineries of smaller scale. They considered that in this way transport needs would be reduced, more jobs in local areas could be created, and the risk of unsustainable biomass supply could be reduced. However, the current majority view is that smaller production scales are considered uneconomic. Likewise, preliminary results indicate that the CIMV process may require a critical minimum size to be viable. Overall, it is recommended to further analyse what is the most suitable production scale.

Furthermore, the importance of legal aspects was highlighted by the stakeholders. Bio-based products are subject to different areas of legislation (waste, chemical industry, agriculture and forestry, environment). These different areas of legislation are in some countries not well harmonised. There are difficulties to achieve a consistent and efficient legislative system for biomass. A consistent legal framework is a prerequisite for legal certainty, favours investment and lowers bureaucratic burdens. Furthermore, there are already some cases of products labelled as bio-based though they were proven to contain a remarkable amount of fossil carbon. Hence legislation and certification systems are needed to avoid frauds in product chains achieving green premium price. Public acceptance is also considered an important issue. Critical response by NGOs and environmental groups can hinder implementation of bio-plants; therefore efforts on public relation are needed.

These and further most relevant arguments are summarised in Table 5-11 (in an abbreviated version).

Table 5-11 Summary: Most important SWOT arguments regarding biomass processing and use

	Success factors	Failure factors
Internal factors	**Strengths** ▪ Contribution to economic development: Jobs, income opportunities ▪ Flexible technology: different types of lignocellulosic biomass can be used ▪ Production of high value products	**Weaknesses** ▪ The high investment costs for biorefineries → price of the final products will be decisive for the economic success of the products. In many cases consumers will not pay a green premium. ▪ Many process chains require a high energy demand for product separation, which is a disadvantage from an economic and environmental point of view. ▪ The fall-back option “pulp” is probably not viable because of too low quality. ▪ The BIOCORE C5 stream contains a lot of impurities which limit the use options for this stream. ▪ Biorefining economically still depends on subsidies
External factors	**Opportunities** ▪ Subsidies for biorefining might increase economic performance ▪ Technologies and certification schemes to prevent fake bio-based products on the market might increase willingness to pay a green premium ▪ Increase in performance in the years to come by research and development is very likely, because technologies are still immature. ▪ (Further) test runs with pulp as feedstock could help to establish markets. This could be an option in particular for India because there is a high demand for low price feedstock. ▪ Technologies for purification of C5 stream are available but costly; they could become more economically feasible by further research and development. ▪ Residues from fermentation can be used as fertiliser but have to be sterilised, in particular if they contain GMO.	**Threats** ▪ In case of large scales: Higher risk for unsustainable biomass supply ▪ Fast development of large scale biorefineries does not leave time to react on unpredicted negative effects and develop legal framework ▪ Subsidies for other biomass uses (bioenergy!) may make BIOCORE biorefining uneconomic ▪ Negative public perception can come up and put a hurdle for biorefinery implementation ▪ Skilled personnel could be scarce in remote areas

5.5 Integrated assessment

The integrated sustainability assessment joins and connects results on individual sustainability aspects to give an integrated view on sustainability of the BIOCORE biorefining concept.

In a first step (chapter 5.5.1), indicators and results for relevant scenarios are collected from the assessments of individual sustainability aspects. All these scenarios and all this data are based on life cycle comparisons of potential biorefineries according to the BIOCORE concept with conventional (mostly petroleum-based) systems that would be replaced. Where applicable, additional integrating indicators such as CO_2 avoidance costs are added. This results in an integrated comparison of BIOCORE with conventional systems and in comparisons among BIOCORE scenarios.

In a second step (chapter 5.5.2), potential biorefineries according to the BIOCORE concept are compared to competing alternative biomass-based systems because the supply of biomass is expected to be a limiting factor. This is done via specific benchmarking procedures for each aspect to be analysed.

5.5.1 BIOCORE vs. conventional systems

Selection of indicators

Various aspects of environmental, economic and social sustainability have been studied in individual assessments, which form the basis of this integrated sustainability assessment. The impact of the BIOCORE life cycles and the conventional reference systems on all these aspects is quantified or qualitatively rated using various indicators. The suitability and scientific validity of the indicators has been verified in the individual assessments. In the integrated sustainability assessment, those indicators were chosen from the set of available indicators, which give additional information that is relevant for decisions between the assessed options (Table 5-13). This selection does not contain several qualitative indicators from the more comprehensive set, which show the same values for all assessed scenarios or were rated less important for decisions between the assessed options by the respective experts. For completeness, they are shown in the annex in Table 10-1. Furthermore, related specific (qualitative) indicators were merged into a more general indicator if values showed similar patterns for the assessed scenarios. For an overview and a short description of the indicators see Table 5-12. Results for these indicators and selected scenarios under standard conditions are shown in Table 5-13 and bandwidths under favourable and less favourable conditions are shown in Table 5-14.

Table 5-12 Overview of sustainability indicators

Impact category	Short description
Technology	
Maturity	Technical maturity of involved processes.
Availability of infrastructure for logistics and storage	This indicator refers to logistics as well as short-term and seasonal storage of biomass.
Use of GMOs	Use of genetically modified organisms (here: microbes) in closed fermentation facilities within the biorefinery. Release of GMOs like genetically modified plants to the environment is not intended.
Risk of explosions and fires	Risk of explosions and fires within industrial facilities like biorefineries.
Development of legislative framework and bureaucratic hurdles	Potential legislative and bureaucratic hurdles for the implementation of the scenario.
Feedstock flexibility of conversion technologies	The capability of the core process to use several different feedstocks interchangeably or in a mixture.
Environment	
Resource depletion: energy	Depletion of non-renewable energy resources, i.e. fossil fuels such as mineral oil, natural gas, coal and uranium ore.
Climate change	Global warming as a consequence of the anthropogenic release of greenhouse gases. Besides carbon dioxide (CO_2), a number of other gases like methane (CH_4) and nitrous oxide (N_2O) are included.
Terrestrial acidification	Shift of the acid / base equilibrium in soils by acidifying gases like sulphur dioxide, nitrogen oxides and ammonia (keyword 'acid rain').
Marine / freshwater eutrophication	Input of nutrients into surface water (marine and freshwater) directly or via input into soils and gaseous emissions. E.g. nitrogen and phosphorous species 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').
Respiratory inorganics (particulate matter emissions)	Damage to human health due to air pollutants such as fine, primary particles and secondary particles (mainly from NO_X, NH_3 and SO_2, keyword 'winter smog' or 'London 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').
Direct additional land use	Occupation of agricultural land by production of dedicated crops. Extraction of residues from already cultivated land is not included.
Indirect land use	Here: Agricultural land that may not be cultivated anymore elsewhere (e.g. in the EU or South America, SA) because co-products of the assessed process like feed replace competing products.
Water	Local water availability for ecosystems and its quality.
Soil	Soil quality is affected e.g. by erosion, compaction or organic matter content.
Fauna	Local biodiversity among animals is affected e.g. by the presence of diverse habitats.
Flora	Biodiversity among plants on and around cultivated areas is affected e.g. by weed control measures.
Landscape	Characteristics and diversity of the landscape.

Impact category	Short description
Economy	
Total capital investment	Sum of invested capital for the biorefinery facility including utilities.
NPV (5 %)	The net present value is the sum of expenses and future returns discounted at a rate of 5 % per year (in this case).
Variants: no GP / incl. GP	Several economic indicators were calculated under the boundary conditions that Green Premium prices can be obtained or not.
IRR (Internal Rate of Return)	The Internal Rate of Return is defined as the discount rate at which the NPV is just equal to zero. The higher the IRR, the more favourable the investment project appears.
Price support	Support of product prices (in %) that is necessary to reach the indicated IRR. Product price support is one option to make projects economically feasible that are considered valuable for other effects.
Access to markets	Access to markets is determined by demand for the final product and by restrictions like the adaptation of manufacturers to new chemicals.
CO_2 avoidance costs	Monetary losses (or profits if indicator result is negative) per unit of avoided greenhouse gas emissions. This indicator is not defined if no greenhouse gas emissions are avoided.
Energy resource savings costs	Monetary losses per unit of saved non-renewable energy resources (analogous to CO_2 avoidance costs).
Society	
Please see Table 5-3 and /Diaz-Chavez 2013a/ for details.	

Additional indicators

There are indicators like CO_2 avoidance costs, which connect aspects of more than one pillar of sustainability (here: environment and economy) so that they can only be added in the integrated assessment.

CO_2 avoidance costs[3] are based on greenhouse gas emission savings and the support per tonne of biomass that is needed to make an investment in a biorefinery attractive (i.e. an internal rate of return of 25% is reached without expecting green premium prices for the products). CO_2 avoidance costs are not applicable if there are no greenhouse gas emission savings. As another example, energy resource savings costs are derived in the same way from the indicator “Resource savings: energy” (energy demand from non-renewable resources).

Such indicators can give additional information but may also lead to wrong conclusions if they are not interpreted carefully (see chapter 3.3 for details). In this case, it is very important that both avoidance / savings costs indicators can only indicate the efficiency of reaching a certain target (e.g.: How expensive is it to avoid greenhouse gas emissions under certain conditions?) but not the efficacy of reaching it (e.g.: How certain is that such emissions are avoided at all?). For political decisions, however, the latter question should be more important.

[3] The name of this indicator is applied here because of its common use. Nevertheless, greenhouse gases besides CO_2 are taken into account as well for its calculation.

Table 5-13 Overview of selected indicators and results for BIOCORE and alternative scenarios in comparison to conventional systems under standard conditions. GMO: genetically modified organism, SA: South America, NPV: net present value, IRR: internal rate of return, GP: green premium, N/A: not applicable, N/D: no data.

			Standard								
			BIOCORE scenarios								
	Indicator	Unit or subcateg.	Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Wheat straw (Ethanol to PVC)	Wheat straw (Fallback options)	Wheat straw (IA material recycling)	Wheat straw (Straw powered)	Wheat straw (Lignin to energy)
Technology	Maturity	-	- -	- -	- -	- -	- -	-	- -	- -	- -
	Availability of infrastructure for logistics and storage	-	-	-	-	-	-	-	-	-	-
	Use of GMOs	-	- -	- -	-	-	-	0	- -	- -	- -
	Risk of explosions and fires	-	0	0	0	0	0	0	0	0	0
	Development of legislative framework and bureaucratic hurdles	-	-	-	-	-	-	-	-	-	-
	Feedstock flexibility of conversion technologies	-	+	+	+	+	+	+	+	+	+
Environment	Resource depletion: energy	GJ / t biomass (dry)	-14	-4	17	16	14	12	-11	-15	-9
	Climate change	t CO_2 eq. / t biomass (dry)	-0,9	-0,5	0,3	0,2	0,2	0,5	-0,8	-0,7	-0,4
	Terrestrial acidification	kg SO_2 eq. / t biomass (dry)	-0,3	0,7	5,2	4,9	4,9	1,5	-0,1	1,0	0,9
	Marine eutrophication	kg N eq. / t biomass (dry)	-4,3	-4,3	1,4	1,7	1,6	N/D	-4,4	-1,8	-4,3
	Freshwater eutrophication	kg P eq. / t biomass (dry)	-0,4	-0,4	0,1	0,1	0,1	N/D	-0,4	-0,1	-0,4
	Photochemical ozone formation	kg NMVOC eq. / t biomass (dry)	-1,9	-1,4	0,7	0,3	0,2	-0,5	-1,7	-0,6	-0,5
	Respiratory inorganics	kg PM10 eq. / t biomass (dry)	-0,7	-0,4	1,0	0,8	0,7	-0,1	-0,6	-0,1	-0,3
	Ozone depletion	g R11 eq. / t biomass (dry)	2,4	1,9	2,9	2,8	2,9	-0,2	2,4	4,4	3,1
	Direct additional land use	(ha · a) / t biomass (dry)	0	0	0	0	0	0	0	0	0
	Indirect land use (EU)	(ha · a) / t biomass (dry)	0	0	0	0	0	0	0	0	0
	Indirect land use (SA)	(ha · a) / t biomass (dry)	0	0	0	0	0	0	0	0	0
	Water	-	0	0	0	0	0	0	0	0	0
	Soil	-	0	0	0	0	0	0	0	0	0
	Fauna	-	0	0	0	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
Economy	Total capital investment	Million €	150	144	156	149	161	123	157	138	144
	NPV (5%, no GP)	Million €	-159	-311	-629	-686	-852	-641	-209	-114	-410
	NPV (5%, incl. GP)	Million €	6	-311	-464	-686	-787	-641	-38	51	-252
	Profit / loss (no GP)	€ / t biomass (dry)	-11	-114	-324	-370	-459	-353	-40	12	-520
	Profit / loss (incl. GP)	€ / t biomass (dry)	123	-114	-114	-370	-328	-353	103	139	-458
	IRR (no GP)	%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	IRR (incl. GP)	%	6%	N/A	N/A	N/A	N/A	N/A	1%	10%	N/A
	Price support (no GP, 25% IRR)	%	37%	56%	127%	159%	219%	238%	42%	31%	84%
	Price support (no GP, 15% IRR)	%	25%	43%	108%	137%	191%	208%	29%	20%	68%
	Price support (incl. GP, 25% IRR)	%	19%	56%	83%	159%	182%	238%	23%	14%	53%
	Access to markets	-	0	+	0	+	+	+	0	0	0
	CO_2 avoidance costs	€ / t CO_2 eq.	294	793	N/A	N/A	N/A	N/A	397	305	1194
	Energy resource savings costs	€ / GJ	19	97	N/A	N/A	N/A	N/A	29	15	50
Society	Production of feedstock	Incentives	+	+	+	+	+	0	+	+	+
		Barriers	-	-	-	-	-	0	-	-	-
	Identification of stakeholders	Producers (farmers)	+	+	+	+	+	+	+	+	+
		Business	+	+	+	+	+	+	+	+	+
		Traders	+	+	+	+	+	+	+	+	+
	Rural development and infrastructure	Road	0	0	0	0	0	0	0	0	0
		Water (availability and quality) for the local population	0	0	0	0	0	0	0	0	0
	Labour conditions (enforcement)	ILO conventions	0	0	0	0	0	0	0	0	0
	Competition with other sectors	Competition for residues	-	-	-	-	-	- -	-	-	-

Table 5-13 (continued)

Standard						Standard							
BIOCORE scenarios						Alternatives to BIOCORE							
Hardwood (Xyl / IA)	Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Wheat straw, India (Xyl / IA)	Rice straw, India (Xyl / IA)	Rice straw, India 500 kt (Xyl / IA)	Direct combustion (Wheat straw)	Synfuel (Wheat straw)	Wheat ethanol	Beet ethanol	Maize ethanol	Triticale direct combustion	Rape seed biodiesel	Maize biogas
- -	- -	- -	- -	- -	- -	0	0	+	+	+	0	+	+
-	-	-	-	- -	- -	-	-	0	0	0	0	0	0
- -	- -	- -	- -	-	-	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-	0	0	0	0	0	0
-	-	-	-	-	-	0	-	-	-	-	0	-	0
+	+	+	+	+	+	+	+	-	-	-	+	-	+
-22	-16	-15	-14	-10	-10	-18	-3	-11	-5	-5	-7	-14	-12
-1,5	-1,2	-1,1	-0,9	-1,0	-1,0	-1,0	-0,1	-0,7	-0,4	-0,2	-0,3	-0,7	-0,4
-2,6	-1,5	-1,1	-0,3	-2,9	-2,9	0,5	1,0	1,6	0,0	3,4	3,3	5,9	2,3
-6,2	-4,2	-3,7	-4,3	-4,4	-4,4	0,5	0,5	N/D	N/D	N/D	1,2	N/D	N/D
-0,6	-0,4	-0,3	-0,4	-0,3	-0,3	0,1	0,1	N/D	N/D	N/D	0,1	N/D	N/D
-3,2	-2,5	-2,2	-1,9	-23,9	-23,9	-0,5	0,1	-0,8	-0,4	-0,1	1,0	0,3	-0,3
-1,3	-0,9	-0,7	-0,7	-18,1	-18,1	0,0	0,0	0,1	0,0	0,5	0,7	0,8	0,2
-1,1	0,2	0,4	2,4	-14,1	-14,1	5,7	2,3	3,6	-2,5	10,2	9,6	18,9	7,6
0	0,09	0,09	0	0	0	0	0	0,20	0,05	0,15	0,09	0,33	0,07
0	0	0	0	0	0	0	0	0	-0,03	0	0	N/D	0,0
0	0	0	0	0	0	0	0	-0,06	-0,07	-0,06	0	N/D	0,0
0	0	- -	0	+	+	0	0	0	-	-	0	-	-
0	+	+	0	++	++	0	0	-	- -	- -	-	- -	- -
0	+	-	0	++	++	0	0	-	-	-	-	-	-
0	+	0	0	++	++	0	0	-	- -	- -	-	-	- -
0	0	0	0	+	+	0	0	0	0	0	0	0	0
158	158	147	N/D	146	284	N/D							
20	7	-131	N/D	-229	110								
239	224	46	N/D	-78	616								
115	106	6	N/D	-61	77								
263	253	147	N/D	75	147								
7%	6%	N/A	N/D	N/A	11%								
24%	23%	10%	N/D	N/A	31%								
18%	19%	34%	N/D	49%	11%	N/D	N/D	60%*	60%*	60%*	N/D	40%*	70%*
8%	9%	22%	N/D	36%	3%	N/D	N/D	60%*	60%*	60%*	N/D	40%*	70%*
1%	2%	15%	N/D	28%	0%	N/D	N/D	60%*	60%*	60%*	N/D	40%*	70%*
0	0	0	0	0	0	0	-	+	+	+	0	+	+
107	135	218	N/D	314	70	N/D							
7	10	16	N/D	32	7								
++	+	+	N/D	++	++	N/D							
-	-	-	N/D	-	-								
++	+	+	N/D	++	++								
++	+	+	N/D	++	++								
+	+	+	N/D	+	+								
0	+	+	N/D	+	+								
0	0	-	N/D	0	0								
0	0	0	N/D	+	+								
-	0	0	N/D	-	-								

Table 5-14 Bandwidths of results for BIOCORE and alternative scenarios in comparison to conventional (mostly petroleum-based) systems (under favourable and less favourable conditions), for abbreviations see Table 5-13.

			Favourable									
			BIOCORE scenarios									
	Indicator	Unit or subcateg.	Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Hardwood (Xyl / IA)	Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Wheat straw, India (Xyl / IA)	Rice straw, India (Xyl / IA)	Rice straw, India 500 kt (Xyl / IA)
Techn.	see scenarios under standard conditions		see scenarios under standard conditions									
Environment	Resource depletion: energy	GJ / t biomass (dry)	-82	-67	-13	-5	-107	-88	-78	-82	-72	-72
	Climate change	t CO_2 eq. / t biomass (dry)	-4,0	-3,2	-1,1	-0,7	-5,3	-4,5	-4,0	-4,0	-3,8	-3,8
	Terrestrial acidification	kg SO_2 eq. / t biomass (dry)	-12,0	-10,8	1,7	1,9	-17,2	-13,4	-11,8	-12,0	-13,3	-13,3
	Marine eutrophication	kg N eq. / t biomass (dry)	-16,4	-16,4	0,1	0,2	-21,2	-15,6	-13,9	-16,4	-15,0	-15,0
	Freshwater eutrophication	kg P eq. / t biomass (dry)	-1,5	-1,5	0,0	0,0	-1,9	-1,4	-1,3	-1,5	-1,3	-1,3
	Photochemical ozone formation	kg NMVOC eq. / t biomass (dry)	-8,6	-7,8	-2,0	-1,8	-11,5	-9,5	-8,5	-8,6	-29,9	-29,9
	Respiratory inorganics	kg PM10 eq. / t biomass (dry)	-5,5	-5,2	-1,3	-1,3	-7,4	-6,2	-5,6	-5,5	-22,4	-22,4
	Ozone depletion	g R11 eq. / t biomass (dry)	-0,2	-0,6	2,0	2,0	-4,2	-2,2	-1,9	-0,2	-16,5	-16,5
	Direct additional land use	(ha · a) / t biomass (dry)	0	0	0	0	0	0,09	0,09	0	0	0
	Indirect land use (EU)	(ha · a) / t biomass (dry)	0	0	0	0	0	0	0	0	0	0
	Indirect land use (SA)	(ha · a) / t biomass (dry)	0	0	0	0	0	0	0	0	0	0
	Water	-	0	0	0	0	0	0	- -	0	+	+
	Soil	-	+	+	+	+	0	+	+	0	++	++
	Fauna	-	+	+	+	+	0	+	+	0	++	++
	Flora	-	0	0	0	0	0	+	0	0	++	++
	Landscape	-	0	0	0	0	0	+	+	0	+	+
Economy	Total capital investment	Million €	150	144	156	149	158	158	147	N/D	146	284
	NPV (5%, no GP)	Million €	412	180	-265	-441	626	605	414	N/D	310	1907
	NPV (5%, incl. GP)	Million €	620	180	-57	-441	896	875	642	N/D	505	2557
	Profit / loss (no GP)	€ / t biomass (dry)	374	217	-79	-205	524	510	374	N/D	303	440
	Profit / loss (incl. GP)	€ / t biomass (dry)	374	219	108	-207	524	510	374	N/D	303	440
	IRR (no GP)	%	37%	21%	N/A	N/A	50%	48%	38%	N/D	30%	78%
	IRR (incl. GP)	%	51%	21%	N/A	N/A	67%	66%	54%	N/D	44%	101%
	Price support (no GP, 25% IRR)	%	0%	5%	63%	108%	0%	0%	0%	N/D	0%	0%
	Price support (no GP, 15% IRR)	%	0%	0%	46%	88%	0%	0%	0%	N/D	0%	0%
	Price support (incl. GP, 25% IRR)	%	0%	5%	30%	108%	0%	0%	0%	N/D	0%	0%
	Access to markets	-	0	+	0	+	0	0	0	0	0	0
	CO_2 avoidance costs	€ / t CO_2 eq.	0	13	315	632	0	0	0	N/D	0	0
	Energy resource savings costs	€ / GJ	0	1	27	86	0	0	0	N/D	0	0
Society	see scenarios under standard conditions		see scenarios under standard conditions									

Table 5-14 (continued)

Less favourable									
BIOCORE scenarios									
Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Hardwood (Xyl / IA)	Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Wheat straw, India (Xyl / IA)	Rice straw, India (Xyl / IA)	Rice straw, India 500 kt (Xyl / IA)
see scenarios under standard conditions									
32	35	41	35	36	34	28	32	33	33
1,2	1,3	1,6	1,3	1,2	1,1	0,9	1,2	1,0	1,0
6,2	6,6	7,0	6,8	5,6	5,4	4,9	6,2	3,1	3,1
1,6	1,6	1,7	2,3	1,3	1,4	1,2	1,6	0,9	0,9
0,2	0,2	0,2	0,2	0,1	0,2	0,1	0,2	0,1	0,1
2,3	2,3	2,8	2,1	2,0	1,9	1,7	2,3	-20,0	-20,0
1,5	1,6	1,7	1,4	1,4	1,4	1,2	1,5	-16,2	-16,1
4,7	4,2	4,5	4,7	1,6	2,5	2,4	4,7	-11,9	-11,9
0	0	0	0	0	0,09	0,09	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	- -	0	+	+
-	-	-	-	0	+	+	0	++	++
0	0	0	0	0	+	-	0	++	++
0	0	0	0	0	+	0	0	++	++
0	0	0	0	0	0	0	0	+	+
150	144	156	149	158	158	147	N/D	146	284
-871	-891	-1104	-1024	-770	-778	-817	N/D	-897	-2113
-764	-891	-997	-1024	-623	-632	-707	N/D	-801	-1795
-492	-505	-644	-598	-418	-423	-456	N/D	-511	-373
-326	-505	-424	-598	-231	-237	-295	N/D	-346	-244
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/D	N/A	N/A
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/D	N/A	N/A
164%	174%	263%	247%	118%	119%	148%	N/D	195%	133%
144%	154%	237%	222%	102%	103%	130%	N/D	173%	120%
128%	174%	201%	247%	86%	88%	115%	N/D	153%	100%
0	+	0	+	0	0	0	0	0	0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
see scenarios under standard conditions									

For all BIOCORE scenarios, additional environmental burdens arise from a realisation under less favourable conditions (Table 5-14). Therefore, avoidance or savings costs are secondary in this context. Furthermore, the uncertainty of avoidance / savings costs is very high because uncertainties of both underlying indicators accumulate. Thus, comparisons of the scenarios assessed here regarding their avoidance / savings costs do not yield conclusive and stable results and therefore are not relevant for decision support. Avoidance / savings costs are not shown in further tables in this chapter.

Categorisation

For comparability to qualitative indicators, quantitative indicators are categorised and the table is coloured accordingly (Table 5-13 and Table 5-14). Results are rated advantageous (green) if the difference of the assessed scenario to the respective conventional reference scenario is bigger than 10 % of the bandwidth of results for this indicator under standard conditions. Disadvantageous results are rated analogously and the rest is rated neutral. The investment sum is not categorised because there is no reference value.

Analysis for patterns of impacts

Within the technical and environmental indicators, several typical strengths and weaknesses can be found for BIOCORE scenarios compared to the assessed alternatives:

- BIOCORE scenarios are less mature
- BIOCORE scenarios and alternatives that use wheat straw as feedstock cannot rely on existing infrastructure for feedstock logistics and transport
- BIOCORE scenarios and few alternatives show some degree of feedstock flexibility unlike first generation biofuels
- Some first generation biofuels may cause the release of agricultural land elsewhere due to the production of feed as co-products.[4]
- Lignocellulosic feedstocks as used by BIOCORE show lower local environmental impacts especially on soil, fauna and flora (exception: Miscanthus shows negative impacts on fauna and water).

Regarding social indicators, the following properties are found for BIOCORE scenarios while alternatives were not assessed (see also Table 10-1 for indicators for which results are identical for all scenarios):

- Stakeholders identify themselves with BIOCORE
- Competition about biomass is a disadvantage for BIOCORE scenarios
- BIOCORE biorefineries are expected to create jobs

There are no typical patterns regarding economic indicators. Nevertheless, the presented economic indicators show a rather high correlation to each other. This is to be expected for

4 The given numbers are dependent on market effects and are of low certainty. They represent upper boundaries of the achievable effects.

the indicators net present value (NPV), profit / loss, internal rate of return (IRR) and the complementary necessary product to reach 25 % of IRR, because these indicators address several aspects of the same underlying concept, which is profitability. Furthermore, results with expected green premium prices and without show some correlation, too. This indicates that profitability is influenced but not dominated by green premium prices for bio-based products.

Correlations of results can be found for the environmental impact categories resource depletion: energy and climate change with the economic indicators. A main reason for this is the strong influence of energy efficiency on these indicators.

Definition of a relevant threshold for comparisons

BIOCORE scenarios are compared to each other using the benchmarking method described in chapter 3.4. As a first step, a suitable threshold for minimal differences in quantitative results between scenarios is determined. The threshold is a percentage of the overall bandwidth of results taking into account all BIOCORE and alternative scenarios under standard conditions. As many sources of variability and uncertainty are shared by related scenarios, differences in results can be relevant for decisions even if they are much smaller than the overall bandwidths of results of all scenarios under standard conditions and if the bandwidths of these two scenarios under favourable, standard and less favourable conditions overlap considerably. Thus, the threshold was set to 5 %. Exemplarily, the comparison shown in Table 5-15 with thresholds of 1 % and 10 %, respectively, can be found the annex (Table 10-2 and Table 10-3).

Comparisons among BIOCORE scenarios

Comparisons among BIOCORE scenarios were performed for three different decisions contexts (see also objectives in chapter 2). In each case, all parameters that are not subject of the decision were left constant. Results are displayed for one exemplary combination of the constant parameters.

- Which biorefinery configuration including product portfolio should be chosen for a given feedstock? This comparison is shown for wheat straw as feedstock in Table 5-15.
- Which biorefinery concept regarding feedstock and scale is preferable in India considering specific opportunities existing in this location? This comparison is shown in Table 5-16 for the biorefinery configuration (including product portfolio) as in the scenario Xyl / IA.
- Which biomass should be chosen as feedstock for a given biorefinery? This comparison is shown in Table 5-17 for the biorefinery configuration (including product portfolio) as in the scenario Xyl / IA.

Table 5-15 Comparison of scenarios with various biorefinery configurations vs. the scenario Xyl / IA based on the input of identical amounts of the feedstock wheat straw. For abbreviations see Table 5-13.

Benchmark: Wheat straw (Xyl / IA), feedstock basis		BIOCORE scenarios							
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Wheat straw (Ethanol to PVC)	Wheat straw (Fallback options)	Wheat straw (Straw powered)	Wheat straw (Lignin to energy)
Technology	Maturity		0	0	0	0	++	0	0
	Availability of infrastructure for logistics		0	0	0	0	0	0	0
	Use of GMOs		0	++	++	++	++	0	0
	Risk of explosions and fires		0	0	0	0	0	0	0
	Development of legislative framework and bureaucratic hurdles		0	0	0	0	0	0	0
	Feedstock flexibility of conversion technologies		0	0	0	0	0	0	0
Environment	Resource depletion: energy		-	-	- -	-	-	0	-
	Climate change		-	-	0	-	-	-	-
	Terrestrial acidification		0	- -	- -	-	-	-	-
	Marine eutrophication		0	0	- -	-	N/D	-	0
	Freshwater eutrophication		0	0	0	-	N/D	-	0
	Photochemical ozone formation		0	0	0	-	-	-	-
	Respiratory inorganics		0	0	0	-	0	0	0
	Ozone depletion		0	0	0	0	+	-	0
	Direct additional land use		0	0	0	0	0	0	0
	Indirect land use (EU)		0	0	0	0	0	0	0
	Indirect land use (SA)		0	0	0	0	0	0	0
	Water		0	0	0	0	0	0	0
	Soil		0	0	0	0	0	0	0
	Fauna		0	0	0	0	0	0	0
	Flora		0	0	0	0	0	0	0
	Landscape		0	0	0	0	0	0	0
Economy	Total capital investment		0	0	0	- -	++	++	0
	NPV (5%, no GP)		0	- -	- -	-	-	0	-
	NPV (5%, incl. GP)		-	-	- -	-	-	0	-
	Profit / loss (no GP)		0	- -	- -	-	-	0	-
	Profit / loss (incl. GP)		-	-	- -	-	-	0	- -
	IRR (no GP)		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	IRR (incl. GP)		N/A	N/A	N/A	N/A	N/A	+	N/A
	Price support (no GP, 25% IRR)		0	- -	- -	- -	- -	0	-
	Price support (no GP, 15% IRR)		0	- -	- -	- -	- -	0	-
	Price support (incl. GP, 25% IRR)		0	-	- -	- -	- -	0	-
	Access to markets		++	0	++	++	++	0	0
Society	Feedstock prod.: Incentives		0	0	0	0	- -	0	0
	Feedstock prod.: Barriers		0	0	0	0	++	0	0
	Identification: Producers		0	0	0	0	0	0	0
	Identification: Business		0	0	0	0	0	0	0
	Identification: Traders		0	0	0	0	0	0	0
	Rural development: Road		0	0	0	0	0	0	0
	Rural development: Water		0	0	0	0	0	0	0
	Labour conditions (ILO)		0	0	0	0	0	0	0
	Competition for residues		0	0	0	0	- -	0	0

Table 5-16 Comparison of biorefinery scenarios in India with the feedstocks wheat straw and rice straw at different scales but identical product portfolios based on the input of identical amounts of straw. Unless indicated otherwise, the scale is 150 kt biomass (dry mass) input per year. For abbreviations see Table 5-13.

	Benchmark: Rice straw, India (Xyl / IA), feedstock basis	**BIOCORE scenarios** Wheat straw, India (Xyl / IA)	Rice straw, India (Xyl / IA)	Rice straw, India 500 kt (Xyl / IA)
Technology	Maturity	0		0
	Availability of infrastructure for logistics and storage	++		0
	Use of GMOs	- -		0
	Risk of explosions and fires	0		0
	Development of legislative framework and bureaucratic hurdles	0		0
	Feedstock flexibility of conversion technologies	0		0
Environment	Resource depletion: energy	0		0
	Climate change	0		0
	Terrestrial acidification	-		0
	Marine eutrophication	0		0
	Freshwater eutrophication	0		0
	Photochemical ozone formation	- -		0
	Respiratory inorganics	- -		0
	Ozone depletion	- -		0
	Direct additional land use	0		0
	Indirect land use (EU)	0		0
	Indirect land use (SA)	0		0
	Water	- -		0
	Soil	- -		0
	Fauna	- -		0
	Flora	- -		0
	Landscape	- -		0
Economy	Total capital investment	N/D		- -
	NPV (5%, no GP)	N/D		0
	NPV (5%, incl. GP)	N/D		0
	Profit / loss (no GP)	N/D		+
	Profit / loss (incl. GP)	N/D		+
	IRR (no GP)	N/D		N/A
	IRR (incl. GP)	N/D		N/A
	Price support (no GP, 25% IRR)	N/D		0
	Price support (no GP, 15% IRR)	N/D		0
	Price support (incl. GP, 25% IRR)	N/D		0
	Access to markets	0		0
Society	Feedstock prod.: Incentives	N/D		0
	Feedstock prod.: Barriers	N/D		0
	Identification: Producers	N/D		0
	Identification: Business	N/D		0
	Identification: Traders	N/D		0
	Rural development: Road	N/D		0
	Rural development: Water	N/D		0
	Labour conditions (ILO)	N/D		0
	Competition for residues	N/D		0

Table 5-17 Comparison of scenarios with various feedstocks vs. the feedstock wheat straw for identical product portfolios based on the input of identical amounts of feedstock. For abbreviations see Table 5-13.

Benchmark: Wheat straw (Xyl / IA), feedstock basis		BIOCORE scenarios						
		Wheat straw (Xyl / IA)	Hardwood (Xyl / IA)	Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Wheat straw, India (Xyl / IA)	Rice straw, India (Xyl / IA)	Rice straw, India 500 kt (Xyl / IA)
Technology	Maturity		0	0	0	0	0	0
Technology	Availability of infrastructure for logistics and storage		0	0	0	0	- -	- -
Technology	Use of GMOs		0	0	0	0	++	++
Technology	Risk of explosions and fires		0	0	0	0	0	0
Technology	Development of legislative framework and bureaucratic hurdles		0	0	0	0	0	0
Technology	Feedstock flexibility of conversion technologies		0	0	0	0	0	0
Environment	Resource depletion: energy		0	0	0	0	0	0
Environment	Climate change		0	0	0	0	0	0
Environment	Terrestrial acidification		+	+	0	0	+	+
Environment	Marine eutrophication		0	0	0	0	0	0
Environment	Freshwater eutrophication		+	0	0	0	0	0
Environment	Photochemical ozone formation		0	0	0	0	++	++
Environment	Respiratory inorganics		0	0	0	0	++	++
Environment	Ozone depletion		+	+	0	0	++	++
Environment	Direct additional land use		0	- -	- -	0	0	0
Environment	Indirect land use (EU)		0	0	0	0	0	0
Environment	Indirect land use (SA)		0	0	0	0	0	0
Environment	Water		0	0	- -	0	++	++
Environment	Soil		0	0	0	0	++	++
Environment	Fauna		0	0	0	0	++	++
Environment	Flora		0	++	0	0	++	++
Environment	Landscape		0	0	0	0	++	++
Economy	Total capital investment		- -	- -	0	N/D	0	- -
Economy	NPV (5%, no GP)		+	+	0	N/D	0	0
Economy	NPV (5%, incl. GP)		+	+	0	N/D	0	0
Economy	Profit / loss (no GP)		+	+	0	N/D	0	+
Economy	Profit / loss (incl. GP)		+	+	0	N/D	0	0
Economy	IRR (no GP)		N/A	N/A	N/A	N/D	N/A	N/A
Economy	IRR (incl. GP)		N/A	N/A	N/A	N/D	N/A	N/A
Economy	Price support (no GP, 25% IRR)		0	0	0	N/D	0	0
Economy	Price support (no GP, 15% IRR)		0	0	0	N/D	0	0
Economy	Price support (incl. GP, 25% IRR)		0	0	0	N/D	0	0
Economy	Access to markets		0	0	0	0	0	0
Society	Feedstock prod.: Incentives		++	0	0	N/D	++	++
Society	Feedstock prod.: Barriers		0	0	0	N/D	0	0
Society	Identification: Producers		++	0	0	N/D	++	++
Society	Identification: Business		++	0	0	N/D	++	++
Society	Identification: Traders		0	0	0	N/D	0	0
Society	Rural development: Road		0	++	++	N/D	++	++
Society	Rural development: Water		0	0	- -	N/D	0	0
Society	Labour conditions (ILO)		0	0	0	N/D	++	++
Society	Competition for residues		0	++	++	N/D	0	0

5.5.2 BIOCORE vs. other biomass-based systems

Selection of suitable comparison metric

When comparing BIOCORE scenarios to mostly established, alternative biomass based systems, a fundamental difference between these scenarios has to be taken into account: Future scenarios on established systems are based on systems successfully realised in practise, which are projected into the future. In contrast, BIOCORE scenarios are based on possible industrial-scale implementations of processes tested on demonstration or partially also lab scale. Thus, BIOCORE scenarios include implementation options, which will not be realisable in practise. For example, any BIOCORE biorefinery that is not thoroughly optimised (less favourable conditions) causes substantial additional environmental burdens and economic losses (Table 5-14). Such scenarios under less favourable conditions are important to highlight risks. However, these scenarios are not expected to be realised ("self-destroying prophecies") and thus are of limited value for comparisons to competing technologies, which are already established. Therefore, a different comparison metric termed potential analysis is applied in this case. It basically answers the question how favourable the conditions and e.g. how thorough the optimisation for a scenario have to be able to outperform a given benchmark scenario (see chapter 3.4 for details). To display the influence of the metric on the results, the comparison performed in Table 5-18 using potential analysis is exemplarily shown in the annex using the standard benchmarking procedure (Table 10-4).

Comparisons relevant in the given decision context

Comparisons of BIOCORE scenarios to alternative use options of the same biomass and agricultural area were performed for three different decisions contexts (see also objectives in chapter 2). In each case, all parameters that are not subject of the decision were left constant. Results are displayed for one exemplary combination of the constant parameters.

- Which use option of a given kind of biomass is most sustainable? This potential analysis is shown for wheat straw as feedstock in Table 5-18. It is especially relevant for residues, which are available independent of the decision which crop to cultivate or not.
- Which kind of biomass should be cultivated for the use in a BIOCORE biorefinery? As the limiting factor for the provision of dedicated crops is the availability of agricultural land, the potential analysis is based on the impacts per area of occupied agricultural land (e.g. hectare and year, Table 5-19). The shown biorefinery scenarios all employ the most promising product portfolio as in the scenario Xyl / IA.
- Which are the general advantages and disadvantages of BIOCORE biorefineries using lignocellulosic biomass vs. technologies using sugar-, starch- or oil-rich biomass? This potential analysis is shown in Table 5-20 exemplarily for sugar beet ethanol as a benchmark. Further potential analysis with other benchmarks are shown in the annex (Table 10-1 - Table 10-4). Please note that not all results from Table 5-20 can be generalised and need to be discussed carefully because they're depending on the benchmark.

The following comparisons do not include social aspects due to the lack of data for alternative scenarios.

Table 5-18 Potential analysis with the scenario "direct combustion of wheat straw" as benchmark based on the input of identical amounts of feedstock. For abbreviations see Table 5-13.

Potential analysis: Direct combustion (Wheat straw), feedstock basis		**BIOCORE scenarios**				**Alternatives**	
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Direct combustion (Wheat straw)	Synfuel (Wheat straw)
Technology	Maturity	-	-	-	-		0
	Availability of infrastructure for logistics and storage	0	0	0	0		0
	Use of GMOs	-	-	-	-		0
	Risk of explosions and fires	0	0	0	0		-
	Development of legislative framework and bureaucratic hurdles	-	-	-	-		-
	Feedstock flexibility of conversion technologies	0	0	0	0		0
Environment	Resource depletion: energy	(+)	(+)	-	-		-
	Climate change	(+)	(+)	(+)	0		-
	Terrestrial acidification	+	(+)	-	-		-
	Marine eutrophication	+	+	(+)	0		0
	Freshwater eutrophication	+	+	(+)	(+)		0
	Photochemical ozone formation	+	(+)	(+)	(+)		0
	Respiratory inorganics	(+)	(+)	(+)	(+)		0
	Ozone depletion	+	+	+	+		+
	Direct additional land use	0	0	0	0		0
	Indirect land use (EU)	0	0	0	0		0
	Indirect land use (SA)	0	0	0	0		0
	Water	0	0	0	0		0
	Soil	0	0	0	0		0
	Fauna	0	0	0	0		0
	Flora	0	0	0	0		0
	Landscape	0	0	0	0		0
Economy	Total capital investment					N/D	
	NPV (5%, no GP)					N/D	
	NPV (5%, incl. GP)					N/D	
	Profit / loss (no GP)					N/D	
	Profit / loss (incl. GP)					N/D	
	IRR (no GP)					N/D	
	IRR (incl. GP)					N/D	
	Price support (no GP, 25% IRR)					N/D	
	Price support (no GP, 15% IRR)					N/D	
	Price support (incl. GP, 25% IRR)					N/D	
	Access to markets	0	+	0	+		-

Table 5-19 Potential analysis with the scenario "sugar beet bioethanol" as benchmark based on the cultivation of the same amount of agricultural land. For abbreviations see Table 5-13.

Potential analysis: Beet ethanol, area basis		BIOCORE		Alternatives					
		Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Wheat ethanol	Beet ethanol	Maize ethanol	Triticale direct combustion	Rape seed biodiesel	Maize biogas
Technology	Maturity	-	-	0		0	-	0	0
	Availability of infrastructure for logistics	-	-	0		0	0	0	0
	Use of GMOs	-	-	0		0	0	0	0
	Risk of explosions and	0	0	0		0	0	0	0
	Development of legislative framework and bureaucratic hurdles	0	0	0		0	+	0	+
	Feedstock flexibility of conversion technologies	+	+	0		0	+	0	+
Environment	Resource depletion: energy	+	+	-		-	-	-	+
	Climate change	+	+	-		-	-	-	-
	Terrestrial acidification	+	+	-		-	-	-	-
	Marine eutrophication				N/D				
	Freshwater eutrophication				N/D				
	Photochemical ozone formation	+	+	-		-	-	-	-
	Respiratory inorganics	+	+	0		-	-	-	-
	Ozone depletion	-	-	-		-	-	-	-
	Direct additional land use	0	0	0		0	0	0	0
	Indirect land use (EU)	-	-	-		-	-	N/D	-
	Indirect land use (SA)	-	-	-		-	-	N/D	-
	Water	+	-	+		0	+	0	0
	Soil	+	+	+		0	+	0	0
	Fauna	+	(+)	0		0	0	0	0
	Flora	+	+	+		0	+	+	0
	Landscape	(+)	(+)	0		0	0	0	0
Economy	Total capital investment				N/D				
	NPV (5%, no GP)				N/D				
	NPV (5%, incl. GP)				N/D				
	Profit / loss (no GP)				N/D				
	Profit / loss (incl. GP)				N/D				
	IRR (no GP)				N/D				
	IRR (incl. GP)				N/D				
	Price support (no GP, 25% IRR)	+	+	0		0	N/D	+	-
	Price support (no GP, 15% IRR)	+	+	0		0	N/D	+	-
	Price support (incl. GP, 25% IRR)	+	+	0		0	N/D	+	-
	Access to markets	-	-	0		0	-	0	0

Table 5-20 Potential analysis with the scenario "sugar beet bioethanol" as exemplary benchmark based on the input of identical amounts of feedstock. For abbreviations see Table 5-13.

Potential analysis: Beet ethanol, feedstock basis		BIOCORE scenarios				Altern.
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Beet ethanol
Technology	Maturity	-	-	-	-	
	Availability of infrastructure for logistics	-	-	-	-	
	Use of GMOs	-	-	-	-	
	Risk of explosions and fires	0	0	0	0	
	Development of legislative framework and bureaucratic hurdles	0	0	0	0	
	Feedstock flexibility of conversion technologies	+	+	+	+	
Environment	Resource depletion: energy	+	(+)	(+)	0	
	Climate change	+	(+)	(+)	(+)	
	Terrestrial acidification	(+)	(+)	-	-	
	Marine eutrophication					N/D
	Freshwater eutrophication					N/D
	Photochemical ozone formation	+	(+)	(+)	(+)	
	Respiratory inorganics	(+)	(+)	(+)	(+)	
	Ozone depletion	-	-	-	-	
	Direct additional land use	+	+	+	+	
	Indirect land use (EU)	-	-	-	-	
	Indirect land use (SA)	-	-	-	-	
	Water	+	+	+	+	
	Soil	+	+	+	+	
	Fauna	+	+	+	+	
	Flora	+	+	+	+	
	Landscape	0	0	0	0	
Economy	Total capital investment					N/D
	NPV (5%, no GP)					N/D
	NPV (5%, incl. GP)					N/D
	Profit / loss (no GP)					N/D
	Profit / loss (incl. GP)					N/D
	IRR (no GP)					N/D
	IRR (incl. GP)					N/D
	Price support (no GP, 25% IRR)	+	(+)	0	-	
	Price support (no GP, 15% IRR)	+	+	(+)	-	
	Price support (incl. GP, 25% IRR)	+	(+)	(+)	-	

6 Conclusions, recommendations and perspectives

The EU project BIOCORE conceives and analyses the industrial feasibility of a biorefinery concept for the processing of agricultural co-products (straw etc.), forest biomass and perennial agricultural biomass into a broad spectrum of products such as biofuels, chemical intermediates and polymers. At the core of this concept is the pretreatment of such biomass with organic acids in a specific variant of the Organosolv process. This study assesses the environmental, economic and social sustainability of the proposed biorefinery concept on the basis of scenarios, which reflect possible implementations of the concept with mature technology in the year 2025. The scenarios were defined based on data from BIOCORE pilot plants[5]. The entire life cycles of the biorefinery products are compared with those of equivalent conventional (reference) products and competing use options for biomass and agricultural land.

Key conclusions from the assessments of individual sustainability aspects as well as conclusions on the interplay of these dimensions are presented in chapter 6.1. They are drawn based on direct influences (differences between scenarios in one or more indicators, see references to result tables) or on indirect / more complex interactions (see references to result summaries with more details) as indicated after the conclusion paragraphs. Recommendations based on these conclusions follow in chapter 6.2.

6.1 Summary and conclusions

The sustainability of biorefineries according to the BIOCORE concept is heavily influenced by their concrete implementation.

- The BIOCORE concept facilitates the production of a wide range of potential products from the three major biomass components (cellulose, lignin and hemicellulose). These products can be combined into hundreds of different product portfolios. Unsurprisingly, the **overall sustainability impacts can be either positive or negative** depending on the product portfolio[6], especially regarding environmental and economic indicators (Table 5-13, compare product portfolios). Furthermore, there is a big bandwidth of possible results for any given product portfolio because there are many options of how to im-

[5] No prognoses or predictions can be made to which extent the BIOCORE scenarios can be realised in practise in industrial scale. A corridor of parameters according to expectations of experts in the respective fields (e.g. regarding yields and energy consumption) is reflected in bandwidths for each BIOCORE scenario (favourable / standard / less favourable conditions). Furthermore, individual critical sources of uncertainty / variability are investigated in sensitivity analyses.

[6] In analogy, there could not be any typical sustainability assessment result for a chemical plant based on the concept of using steam cracking independent of its product portfolio.

plement such a biorefinery and because the performance of the processes on industrial scale is to some degree uncertain at the current stage of development[5] (compare corresponding scenarios in Table 5-13 and Table 5-14).

- For some but not all product portfolios, **biorefineries according to the BIOCORE concept can be very sustainable** regarding almost all indicators if certain conditions can be achieved (Table 5-14, favourable conditions). These biorefineries have a high potential to have lower impacts than conventional (mostly petroleum-based) products regarding most environmental aspects and in some cases even generate profits. However, additional burdens will arise for other environmental aspects and the expected profits will most likely not be attractive enough for investors to take the risks associated with a new technology. Of those products assessed in detail, **xylitol**, **itaconic acid-based polymers**, and **lignin-based polymers increase the potential of a biorefinery to be environmentally and economically sustainable.** In contrast, the production of ethanol (including its derivatives ethylene and PVC), bioenergy, animal feed and paper do not show such potentials (Table 5-15). Thus, the choice of a suitable product portfolio is very important for the sustainability of the biorefinery.
- Dozens of other products have been investigated on lab scale within the BIOCORE project and even more seem feasible to be produced based on the BIOCORE concept. However, it is not possible to deduce from these results, which of these can be produced sustainably. In all cases, high environmental and economic expenditures have to be offset by high savings or revenues, respectively. Additionally, both expenditures and savings / revenues are highly dependent such diverse physicochemical properties (influencing expenditures) and use options (influencing offsets) as e.g. for the sweetener xylitol and for a lignin-based resin used in electrical devices. Nevertheless, **some conclusions concerning potentially favourable products may be applied in a wider context** and narrow down the number of options before starting specific investigations (see also chapter 5.1):
  - Virtually any biotechnological process requires an **energy-intensive step for separation and purification of the product**. Thus, a product is promising if the energy demand of this particular step can be kept low or met by waste heat generated in other processes in the biorefinery.
  - As a rule of thumb, advantages of bio-based chemicals increase with the **size of the smallest intermediate** across the entire process chain. This is because synthesis work performed by nature is wasted biomass is broken down into small intermediates such as ethylene or syngas. In contrast, particular benefits may be achieved if complex conventional molecules that require elaborate synthesis are substituted from biogenic sources, as in the case of lignin components substituting phenol derivatives.
- To achieve positive effects, several aspects of the biorefinery besides the product portfolio have to be carefully chosen and optimised. Many important parameters have been successfully identified ex ante in the assessments of individual sustainability aspects:
  - A key aspect is **energy efficiency**, which is crucially determined by energy integration and energy demands for purification steps. This is due to the fact that the Organosolv

technology used for biomass fractionation is energy intensive but at the same time produces high-quality biomass fractions (although C5 requires additional purification) and considerable quantities of residual steam that may be used for subsequent processes. This also implies that a distributed biomass fractionation is not an option due to less heat integration possibilities. Furthermore, this is the reason why it is essential that the high-quality biomass fractions are converted into high-quality products that replace energy-intensive conventional products to outweigh the upfront monetary and environmental expenditures. Hence, using part of the high-quality biomass fractions for energy generation is not sustainable.
(see chapters 4.2.5.1 and 4.2.5.3 in /Rettenmaier et al. 2013/, similar dependencies are also seen in the economic assessment /Piotrowski et al. 2013/.)

- Another vital aspect is the quantity of product obtained per t of biomass input. A higher **product yield** generates higher revenues and facilitates substitution of conventional products, and thus environmental impacts due to their provision. The resulting decrease in the quantity of co-products available for energy use is negligible.
(see chapter 4.2.5.5 in /Rettenmaier et al. 2013/)
- A bigger **plant size** considerably improves profitability through the economy of scale. However, sustainable and stable biomass supply may become problematic for biorefineries much above 150,000 t dry biomass per year in European locations (standard scale for all scenarios unless indicated otherwise).
(see Table 5-16)
- **Energy supply from energy use of additionally harvested biomass** instead of natural gas combustion is of limited merit. It more or less doubles biomass demand (at limited profitability gains) or reduces the product output to half if biomass supply limits plant size (at economic disadvantages). From an environmental angle, there are better use options for limited biomass than the replacement of heat and power generated from natural gas, which causes relatively low burdens compared e.g. to coal.
(see Table 5-15, see scenario “Wheat straw (straw powered)”)
- Depending on water availability in the region where the biorefinery is located, optimisation of **water recycling** within the biorefinery may be important although this most likely increases the energy demand (see also chapter 5.1).
- Please see reports for further optimisation options specific to some impact categories and scenarios /Rettenmaier et al. 2013/, /Piotrowski et al. 2013/, /Kretschmer et al. 2013/.

- Any BIOCORE biorefinery that is not optimised causes substantial additional environmental burdens and economic losses (Table 5-14). Such scenarios under less favourable conditions are important to highlight risks. However, these scenarios are not expected to be realised (“self-destroying prophecies”) and thus are of limited value for comparisons to competing technologies.
- The **selection of biomass** should be made primarily under **consideration of competition with other use options, local environmental impacts and economic aspects**. Both extraction of residues and cultivation of perennial crops can be accomplished with

relatively low environmental burdens if the conditions on the specific site are suitable. Nevertheless, site-specific restrictions such as soil-dependent extraction levels for straw or water availability for Miscanthus cultivation have to be respected. The feedstock flexibility of the BIOCORE technology, which is one of its important strengths, thus allows for choosing between several generally sustainable feedstocks.

- Undesired effects can arise if biomass or land is not available any more for competing use options. Thus, currently **underutilised residues** such as rice straw in India or wheat straw in Europe **should be preferred** over cultivated biomass such as Miscanthus or poplar short rotation coppice, which require additional agricultural land (Table 5-17, see indicator “direct additional land use”). For hardwood, multiple environmentally and socially sustainable use options are established in many places although underutilised potentials may exist elsewhere. As availability of hardwood residues and co-products (e.g. small diameter logs from thinnings) might be a challenge, it is important to ensure that no kinds of hardwood are used that qualify for material use in the form of solid wood e.g. for furniture or in construction.
- In case no residues but several other feedstocks are available, biomass should be favoured that promises the maximum biorefinery product output due to its composition. Of the assessed scenarios, this primarily applies to hardwood and poplar SRC. This increases profitability and in tendency reduces global and regional environmental impacts (Table 5-17).
- An exception is **rice straw in India**: It **should be used preferentially** from an environmental perspective if it would otherwise be burned in the field and from an economic perspective if its availability allows for a bigger plant size (Table 5-17 and Table 5-16).
- If cultivated feedstocks are used, the **nitrogen content of the harvested biomass** is an important optimisation parameter because nitrogen has to be replaced by fertilisation, which causes considerable environmental impacts. In contrast to the majority of other crops, 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 can considerably improve the environmental impacts of biomass provision, see /Rettenmaier et al. 2013/, section on environmental impacts of material inputs (chapter 5.2.1.3).

- Some **external influences offer extraordinary opportunities** for BIOCORE biorefineries although these might be limited in time or to the first biorefineries established. Such first mover opportunities include obtaining higher product prices for bio-based products (termed green premium) on the economic side and initiating the replacement of established practises that are very harmful to the environment such as inefficient xylitol plants or open field burning of rice straw (Table 5-13 and Table 5-14, see economic indicators “incl. GP” and scenarios on xylitol production and rice straw use). Burning of rice straw, for example, is already prohibited in many places but compliance is not very high due to the lack of enforcement or incentives such as sales opportunities for the straw.

Sustainability is not just a question of resolving technological challenges

- The sustainability of a biorefinery is not just a question of technology (especially important for global / regional environmental and economic impacts) but is also critically influenced by other aspects such as biomass availability (important for all impacts), biomass production by farmers / forest owners and their involvement as stakeholders (especially important for local environmental and social impacts) and political framework (important for all impacts). Stakeholders raised concerns that feedstock pricing may lead to conflicts where cooperation along the value chain would be needed. In situations of low competition about biomass resources as it currently is the case for rice straw in India, this will be a severe disadvantage for farmers and in a situation of high and increasing competition this can become a disadvantage for biorefinery profitability. Furthermore, concerns are that often featured beneficial extended effects on rural development remain marginal as it has previously been experienced with non-bio industrialisation initiatives and that health and occupational safety is not adequately taken care of.
(see Table 5-13 for an overview and chapters 5.2.5, 5.3 and 5.4.1 for more details)

Bio-based products from BIOCORE biorefineries have the potential to be more environmentally friendly than competing uses of biomass or land

- Compared to established biomass and land use options for bioenergy and biofuel production, BIOCORE biorefineries have the potential to be substantially more environmentally friendly and succeed with less product price support – similarly depending on the product portfolio (Table 5-18 and Table 5-19). Under favourable conditions and with suitable product portfolios, BIOCORE biorefineries have e.g. the potential to save more greenhouse gas emissions than the competing combustion of the same biomass for combined heat and power generation even if the bioenergy would substitute considerable shares of coal power.
- The use of land for cultivating biomass for BIOCORE biorefineries can be more sustainable under certain condition than its use for first generation biofuel production. Under those conditions, the feedstock mix of a BIOCORE biorefinery could be supplemented with cultivated biomass. Nevertheless, the net land use of first generation biofuels is reduced compared to the direct land use because feed is produced as co-product, which indirectly reduces land use elsewhere. Depending on concrete conditions and complex market interactions, this effect may range from negligible to substantial – for sugar beet ethanol, even a negative net land occupation is theoretically possible. Compared to all other assessed first generation biofuels (even with high indirect land use reductions due to feed co-products), BIOCORE biorefineries using perennial crops have the potential to achieve higher environmental advantages per area if optimised sufficiently (Table 5-19).

Competition for feedstocks limits establishment of biorefineries and requires coordinating policies

- A main bottleneck for establishing biorefineries in general is the supply of sustainable biomass. Potential locations for BIOCORE biorefineries in Europe and India have been identified, which support sufficient biomass supply. However, residues, forestry biomass and agricultural land are all limited and increasingly competed for by producers of bioenergy, biofuels, bio-based materials and chemicals, feed and food as well as nature conservation. A meta-analysis of various studies in the biomass competition analysis concludes that more or less the whole expected European biomass potential in 2030 including agro and forest residues could be required to meet European biofuels and bioenergy targets. Thus, any non-negligible market share of biopolymers and hence demand by biopolymer industry would lead to competition with other use options. If increasing imports are used to meet this demand then conflicts with food security and indirect land use changes including logging of rainforests are plausible consequences.
(see chapter 5.4.1)

- Apart from feedstock potentials, its actual availability will also be influenced by many involved stakeholders (e.g. farmers / forest owners). Their willingness to sell biomass will be affected by their perception if their share of benefits along value chain is fair. Furthermore, depending on the region, infrastructure is partly not in place, polices are unfavourable and the legal framework may not be stable enough (see chapters 5.2.5 and 5.3.3).

- Suitable policies are needed to coordinate all interests in biomass and land and maximise the social, environmental and economic benefits from using these limited resources. The necessary prioritisation needs to be based on an independent assessment of such benefits achieved in practise after an initial grace period for the establishment of novel technology. For this purpose, standardised sustainability criteria for all biomass use options, in particular bio-based materials, are currently being established by the European Committee for Standardization. Prioritisation according to sustainability is currently counteracted by the EU biofuels policy that channels biomass into the biofuels route e.g. by a rigid quota. A level playing field for all biomass use options is needed to maximise the overall sustainability (Fig. 5-8 in chapter 5.2.5).

- General advantages of BIOCORE biorefineries using lignocellulosic biomass vs. technologies using sugar-, starch- or oil-rich biomass are i) that currently underutilised resources such as straw can be used, ii) feedstock supply can be shifted with some flexibility between residues, agricultural sector and forestry sector depending on availability (although this may cause downtimes and limit heat integration) iii) agricultural production of lignocellulosic biomass causes relatively low environmental impacts and high yields. A disadvantage is that no protein-rich animal feed is produced as co-product as it is the case when sugar-, starch- or oil-rich biomass is converted into biofuels or bio-based chemicals. In a situation of massive feed imports into the EU, such co-products may relieve pressure on agricultural land domestically and overseas although indirect effects in a complex network of co-production and competition could reduce the net effect.
(see Table 5-20)

- A stable political framework can additionally have the effect of reducing the costs to be covered by society because risks for companies are reduced. In a reduced risk setting, investments could appear attractive at a lower profitability threshold (internal rate of return), which requires e.g. less price support paid for by society (compare indicators on price support at 15 and 25 % IRR in Table 5-13).

Methodological achievements and challenges

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 BIOCORE 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-oriented assessment of local aspects termed life cycle environmental impact assessment (LC-EIA), which uses methods originating from environmental impact assessment (EIA). In doing so, LC-EIA does not only complement LCA in regard to local environmental impacts but also indicates major environmental issues that have to be solved during the approval process for BIOCORE biorefineries, e.g. species conservation issues in the EU according to the EU habitat directive.

Another challenge is the dependence of the future economic performance of biorefineries on political decisions not yet taken, which hence cannot be part of the economic assessment. Therefore, current policies are additionally analysed in the social, legal and political assessment and the economic assessment is supplemented by a qualitative analysis of how changes in policies could affect an economically sustainable development of biorefineries. This interlinkages of political and economic aspects permits qualitative recommendations to politicians how a sustainable development can be supported.

Furthermore, a SWOT analysis (strengths, weaknesses, opportunities, threats) qualitatively examines all sustainability aspects not covered by environmental, economic and social assessment. Additionally, the topic of biomass competition, which affects all pillars of sustainability, was studied in a separate analysis. 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 biorefinery 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.

The methodology applied for the social sustainability is an innovative combined methodology using the social Life Cycle Assessment tool hotspot database (HSDB) and social impact assessment. The combination of the methodologies allows for better assessment that covers the national and the local level. Despite that the HSDB considers sectors, the weighting of indicators is done at a national level. It should be noted that the HSDB has been improved and a new portal is on use that is different to the original portal that was used for this assessment. Therefore, an update will be required. Additionally, a combination of qualitative and quantitative data enabled a more robust assessment.

In general terms, the social sustainability assessment seems to be positive for the case studies and it is possible to mitigate or prevent some of the possible negative impacts. The local conditions are those that need to be better considered for the establishment of a biorefinery. The overall benefits on job creation and rural development are some examples of the possibilities regarding social issues that a biorefinery can bring. Some of the main issues to consider on the negative aspects are the possible competition with other sectors and the willingness to sell the feedstock to a biorefinery. These issues will need to be further considered if a biorefinery should be implemented.

There are still challenges in the sustainability assessment of biorefineries especially if such a variety of products – mainly bio-based materials and chemicals – is assessed. Results are greatly influenced by the agreed methods used, boundary conditions, technology development depicted in the scenarios and data available for also assessed competing markets. Thus, comparisons are only valid within the same framework of setting, which are uniformly applied to all scenarios within this study. Comparisons to results from other studies are very difficult and require extensive adjustments in most cases. However, future sustainability-oriented politics requires reliable indicators as a basis for decisions. A first step towards increased comparability was done by harmonising settings of LCA and economic assessment between the FP 7 biorefinery projects BIOCORE, SUPRABIO and EUROBIOREF[7]. On a wider basis, this challenge is currently being addressed by a work group of the European Committee for Standardization (CEN/TC 411/WG 4). It adds specifications to existing environmental LCA standards for the purpose of a more comparable assessment of bio-based products. Ultimately, work should be continued towards uniform sustainability standards for all biomass uses including feed and food.

The following table (Table 6-1) summarises key aspects of the BIOCORE biorefinery concept that influence its sustainability, which are extracted from the conclusions above. Specific recommendations on how to positively influence these aspects can be found in chapter 6.2.

[7] Despite these methodological harmonisation achievements, it has to be kept in mind for comparisons that very different pathways and products are studied in these projects and scenario definitions are inevitably subjective if such innovative technologies are studied, for which future performance is necessarily uncertain.

Table 6-1 Key aspects of the BIOCORE biorefinery concept that influence its sustainability in form of a SWOT table (not included: further aspects on technical properties and progress)

Strengths	Weaknesses

• The opportunity to use **underutilised residues** avoids competition and thus additional indirect impacts.
• **Lignocellulosic biomass** can be used that can be produced at low environmental impacts and high yields.
• BIOCORE biorefineries can be constructed **feedstock flexible** to handle supply shortages (which may somewhat limit optimisation).
• The used Organosolv process yields **high quality C6 and lignin fractions**.
• The BIOCORE concept can be the basis for producing a **great variety of products**.
• Breaking down biomass into molecules with **less than five carbon atoms is not required**.
• For certain product portfolios and under certain conditions, BIOCORE biorefineries can achieve substantially higher **environmental benefits** than existing biomass and land use options.
• **Optimisation parameters and promising products** have been identified.
	• When using cultivated crops, **land use competition** may occur.
	• The used Organosolv process is **very energy intensive:**
	  • Particular need for integration and optimisation
	  • Energy expenditures only pay off if energy-intensive conventional products are replaced.
	• **C5 fraction** requires purification.
	• For certain product portfolios and under certain conditions, BIOCORE biorefineries may cause **additional environmental burdens**.
	• The extraordinary variety of options requires **individual sustainability assessments** for each biorefinery.
	• **Minimum plant sizes** (economy of scale) cause high investments and high local biomass demand.

Opportunities	**Threats**
• **Green premium prices** may be obtained. • **Rice straw use** may cause extraordinary environmental advantages. • **Replacement of inefficiently produced conventional products** may cause additional environmental benefits. • **New policies** may manage biomass competition and thus support sustainable biorefineries. • **Standardisation** of indicators may promote sustainability-based policies.	• Sustainable **biomass potentials** may become even more limited. • Unfair competition with **highly subsidised biofuels and bioenergy.** • A rapidly **changing political framework** may make investments unattractive. • **Technical performance** on industrial scale **may no reach expectations.**

6.2 Recommendations

To policy makers

Since biomass potentials are limited (not only land for dedicated crops but also residues and wastes), the scarce resource biomass needs to be used as efficiently as possible. Our results confirm that under certain conditions higher GHG savings can be achieved and more value added can be created if biomass is used for bio-based materials instead of biofuels / bioenergy. However, the current political framework diverts huge amounts of biomass towards energy use. This practise is already creating unwanted and disadvantageous environmental and social effects elsewhere because former uses of this biomass are replaced. This applies to cultivated biomass (iLUC, indirect land use change) and increasingly also to residues (iRUC, indirect residue use change). It is apparent that lignocellulose-based biorefineries will not be able to compete with highly subsidised and regulated biomass and land use options (i.e. biofuel and bioenergy production) in the foreseeable future without considerable changes regarding the political and economic framework conditions. Therefore, policymakers have a special responsibility in the design and organisation of future options.

Emerging technologies, biorefineries among them, are likely to increase the demand for biomass. Therefore, the conflicts resulting from the competition between bio-based materials, chemicals, biofuels and bioenergy carriers as well as food / feed production and nature conservation require active management with clear aims and targets. We recommend the following specific measures:

- In the mid- to long-term, national and European **biomass and land use allocation plans** should be compiled[8]. Because environmental burdens and social impacts of resource scarcity in particular do not possess an adequate price, market mechanisms cannot replace these plans.
- Based on these national or European plans, **regional plans,** which include regulations for project planning, should be developed. In this context, the cultivation of crops adapted to local conditions should be supported. For instance, the environmental impacts of the cultivation of a crop with a high water demand depend on water availability at the specific 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 and its disadvantageous indirect effects can and must be mitigated by appropriate planning. Additionally, we expect regional plans to be beneficial for future approval processes for biorefineries. A regional plan for land allocation has to include other aspects, e.g. nature conservation or soil conservation, and thereby helps to prevent conflicts, e.g. with species conservation issues. This helps to create a safer environment for future investments.
- As a first step, it is necessary to create a level playing field between bioenergy and bio-based materials. Among other measures, the 10 % biofuels target in the RED should be abandoned to this end. Furthermore, support of second generation biofuels should be rethought and differentiated as this technology can lead to environmental benefits but also to additional burdens if iRUC is caused. Instead, policy support should be based on achieved benefits such as GHG savings.
- Mandatory area- and cultivation-specific sustainability criteria should be uniformly defined for all biomass applications, i.e. for bio-based materials, chemicals, fuels and energy, and ideally also for food and feed. Furthermore, standardisation activities (CEN) for bio-based products including labelling should be supported.

8 Such plans need to include binding biomass and land use limits to avoid increasing imports, and prioritisation schemes to allocate these resources to the most sustainable use options. This is recommended by many experts and institutions including the UNEP /UNEP 2014/.

In addition to the management of competition for biomass, we recommend the following measures:

- Find ways to ensure a stable investment climate (political framework) so that new technologies with high investment requirements can be introduced in an environment of constantly adapted policies and regulations, which is unavoidable and required for a transition towards a more sustainable economy.
- Specifically, the **development** of **value chains for biorefineries** and associated technologies that display considerable potential for the reduction of environmental burdens **should receive support**. In practice, funding should be awarded according to clear targets (sustainability criteria) and through the establishment of an evaluation system aiming for these targets, e.g. analogous to the EU Renewable Energy Directive. This would enable strategic decisions, e.g. for or against certain platform chemicals. The long-term process of establishment should be initiated through the funding of demonstration plants.
- Do not raise too high expectations regarding positive effects of biorefineries on job creation and consider rural development. Direct effects by biorefineries such as employment will not be very high and "spillover" effects have often been estimated too high or have even been instrumentalised in the past.

To the industry

- Strategic decisions concerning **the selection of the product portfolio** in particular determine early on whether a BIOCORE biorefinery has the potential to produce environmentally friendly products and to be economically viable. A multitude of factors and influences has to be considered for the selection of the product portfolio. Therefore, a rigorous specific analysis of the associated environmental impacts in the planning stage of a biorefinery project is as important as a thorough financial analysis. This especially applies if public and politics have to be convinced to provide support (e.g. subsidies) and secure access to biomass. Guiding principles identified in this study can support the initial selection of potential products:
    - Processes that avoid the fractionation of intermediates into small molecules (e.g. 1 – 2 carbon atoms) and require low energy input for product separation and purification should be favoured.
    - Biorefineries in the early stages of realisation in particular should place their focus on such bio-based products that excel in their inherent properties compared to conventional counterparts. One example assessed here are bio-based superabsorbers from itaconic acid that may be able to bind more water than conventional superabsorbers. Thus, in individual cases, additional advantages of the biomass may be exploited. In addition, extraordinary effects should be taken advantage of wherever possible. These e.g. concern goods that are currently produced with extraordinary inefficiency.
- The planning of a biorefinery should pay attention to very high **energy and material efficiency**. In this context, combined heat and power production and the careful optimisation of heat integration are of paramount importance.

- **Biomass potentials at the proposed biorefinery site** should exceed projected demands. In all likelihood, the demand for biomass from several sectors, including bioenergy production, will increase considerably in the near future.
- Particularly in cases where the supply of biomass from sustainable production is already scarce, bottlenecks due to poor harvests may put pressure on operators of biorefineries to switch to feedstocks from non-sustainable sources. This may be counteracted by a **flexible** biorefinery design that allows the processing of **several types of biomass** if necessary.
- The **selection of biomass** should be made primarily under **consideration of the local conditions**. Both residues and perennial crops can be provided with relatively low environmental burdens if the conditions on the specific site are suitable. In cases with several available options, depending on the product portfolio, selection should favour the type of biomass whose composition promises the maximum production volume.
- Consider making **local stakeholders** and especially biomass producers (farmers / forest owners) shareholders of the biorefinery to promote a long term stability of biomass supply and prices. This will need to consider new business models in the EU as well as in developing countries.
- Involve independent **third party auditors** to ensure health and occupational safety especially in plants outside of the EU.

To biomass producers

- 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, who already have more experience in growing perennial crops and cooperating with biorefineries.
- Especially the **use of nitrogen fertilisers** should be reduced. On way is the optimisation of farming practices towards low nitrogen content in the harvested biomass. In contrast to the majority of other crops, lower nitrogen content is a positive and not a negative quality criterion for lignocellulosic biomass. As shown for some energy crops in field trials, this can considerably improve the environmental impacts of biomass provision through reduction of fertiliser demand. Thus, efforts should be made to apply this new knowledge in practise wherever possible.

To researchers

- Research and development should particularly focus on **value chains** that avoid intermediate fractionation into small molecules**. Intermediates with 4 – 6 or more carbon atoms** achieve significantly better results in LCAs than intermediates with 1 – 3 carbon atoms.

- **Energy-efficient separation and purification** should be the subject of research and development. One option may be selective procedures via membranes or adsorption processes.
- **Developers** of conversion processes (e.g. fermentation specialists) and developers of separation and purification treatments **should collaborate at an early stage** in order to minimise energy consumption during purification. Value chains that combine particularly efficient conversion techniques with optimised purification measures have a distinct capacity for significant reduction of environmental burdens.
- Initial applications demonstrated significant environmental benefits in the case of utilisation of **lignin components instead of petrochemical phenol derivatives**. However, considerable additional research is required to extend the application of lignin, and for the production of colourless substances, for instance.
- Sustainability research should continue to work towards a **standardisation of established sustainability indicators**. This will improve the comparability of sustainability assessments and make them a more robust basis for political decisions.
- Sustainability assessments should always **aim at covering every relevant aspect of sustainability** to avoid shifting of burdens. If there is no established quantitative indicator available or data needed for producing reliable results using a particular indicator is lacking, a qualitative approach should be followed instead.

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8 Abbreviations and glossary

8.1 Abbreviations

AHP	The Analytical Hierarchical Process is a decision support tool that can be used to solve complex decision problems taking into account tangible and intangible aspects
C5	Five carbon sugar (e.g. from hemicellulose)
C6	Six carbon sugar (e.g. from cellulose)
CHP	Combined heat and power plant; co-generation of electricity and heat (air, steam)
CIMV	Compagnie industrielle de la matière végétale (BIOCORE consortium member)
EIA	Environmental impact assessment
GHG	Greenhouse gas
GMO	Genetically modified organism
HSDB	Hotspot database
IA	Itaconic acid
LCA	Life cycle assessment
LC-EIA	Life cycle Environmental impact assessment (assessment of local environmental impacts taking into account the stages during the whole life cycle of a product from cradle to grave)
MCA	Multi-criteria analysis is a decision-making tool which is primarily developed for complex multi-criteria problems
MNRE	Ministry of New and Renewable Energy of India
PAA	Poly(acrylic acid)
PIA	Poly(itaconic acid)
PF resin	Phenol formaldehyde resin
PU	Polyurethane
PVC	Polyvinyl chloride

SHF	Generally: Separate hydrolysis and fermentation; related to BIOCORE always referring to the variant separate hydrolysis and co-fermentation
SIA	Social impact assessment
sLCA	Social life cycle assessment
SRC	Short rotation coppice, cultivation form for woody biomass
SWOT	Analysis of strenghts, weaknesses, opportunities and threats
WP	Work package
Xyl	Xylitol

8.2 Glossary

Annual crops	Feedstock plants surviving one vegetation period (usually planted and harvested within the same); germinating, flowering and bearing fruits once a year (e.g. wheat, rapeseed)
Green Premium	The extra-price market actors are willing to pay for a product just for the fact that it is “green” or in this specific case bio-based (= derived from biomass).
Greenfield scenario	Construction / implementation of a potential refinery on unsealed / not compacted soil without major anthropogenic impacts
Organosolv process	This process solubilises biomass using organic acids (hence the name) and fractionates it into lignin, hemicellulose and cellulose. The BIOCORE biorefinery concept is based on this process.
Perennial crops	Feedstock plants living more than two years; harvesting is possible several times within the plants’ life time (e.g. all trees, Miscanthus)
Reference product	Conventional product of identical utility, which is compared to an assessed product. It is often but not always made from fossil resources.

9 Annex 1: Detailed system description

The sustainability assessment analyses the impacts of substituting conventional, mostly petroleum-based products (reference products) by novel bio-based products using a life cycle comparison approach. All scenarios and life cycle steps that need to be assessed according to this approach are described in this chapter. As a first step, the whole life cycles of **potential BIOCORE biorefineries** and their products are assessed from cradle to grave. They are described in detail in chapter 4.1. In the next step, they are compared to **alternative means of providing the same products**, or more general the same utility, by conventional established means. The life cycles of these alternative products are described in chapter 9.2. Finally, **alternative ways of using limited biomass or agricultural land** are assessed and compared to the use of these resources by BIOCORE. The life cycles studied in this step are outlined in chapter 4.3. Further **general specifications** regarding time, geography and technology are provided in chapter 4.4.

Background data used to assess the described scenarios is specific for each kind of assessment. Please refer to the individual reports for details /Rettenmaier et al. 2013/, /Piotrowski et al. 2013/, /Kretschmer et al. 2013/.

9.1 The BIOCORE biorefinery concept

The biorefineries according to the BIOCORE concept can produce multiple products including biomaterials and biofuels from various lignocellulosic feedstocks. Fig. 4-1 gives a generic overview of its whole life cycle, which can be implemented in many different variations. This sustainability assessment is based on analysing scenarios, which depict potential implementations, and compare them with each other to determine the effects of choices to be made. For a better orientation, four of these scenarios were chosen as main scenarios and many others are introduced as their variations (for an overview see Table 4-2). These scenarios are described in the next chapters following their life cycle steps. The first step is the **production of biomass and other inputs**, which includes agriculture and forestry for the main feedstock as well as fossil resource extraction and processing for additional material and energy inputs to the biorefinery (chapter 9.1.1). All **storage and transport** processes throughout the whole life cycle are subject of chapter 9.1.2. The **BIOCORE biorefinery** includes all steps of biomass pretreatment and conversion, which take place on the main site of the biorefinery (chapter 9.1.3). **Further chemical conversion** of produced intermediates in the chemical industry is described in chapter 9.1.4, and the **use and end of life** are detailed in chapter 9.1.5.

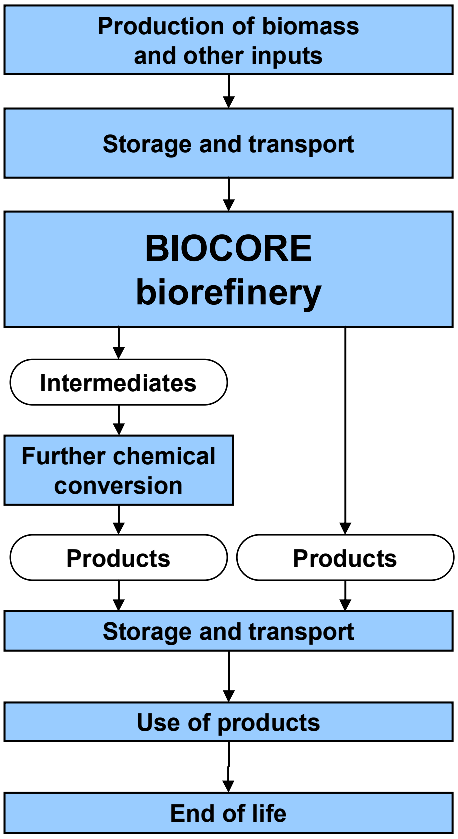

Fig. 9-1 Generic life cycle of a biorefinery according to the BIOCORE concept

9.1.1 Production of biomass and other inputs

The first step in the life cycle of a BIOCORE biorefinery is the raw material production, which is agriculture or forestry for the main feedstocks and the extraction of crude oil, natural gas and minerals etc. for additional material inputs and energy provision.

The BIOCORE biorefinery can utilise many different kinds of lignocellulosic biomass as primary feedstock. This biomass can be an agricultural residue (co-product), a forestry product or an agricultural product. Representatives from each class were chosen according to availability in the reference regions Europe and India. The assessed feedstocks of the BIOCORE biorefinery concept itself are wheat straw, rice straw, hardwood, poplar short rotation coppice (SRC) and Miscanthus (Fig. 9-2).

BIOCORE mainly targets residues as feedstock. Therefore, the main scenarios are based on wheat straw. Furthermore, it is an agricultural residue, which is available in many parts of the reference regions at comparatively low expenditures. Straw harvest from arable land, which is already cultivated for wheat grain production, only causes limited additional work and material inputs related to the extraction itself.

The hardwood scenarios are based on extracting wood that becomes available through thinning.

For agricultural biomass, two crops were chosen that provide high yields. A big advantage of lignocellulosic biomass as a feedstock is that there are several perennial crops available that fulfil this requirement while demanding only low expenditures. Poplar SRC and Miscanthus were selected as woody crop or perennial grass species, respectively. Like for most perennial crops, both require crop protection only directly after replanting after years. Fertilisation is limited if the crops are harvested in winter time because most nutrients are then stored in the roots. Miscanthus is harvested every year and poplar SRC every few years depending on the management practise.

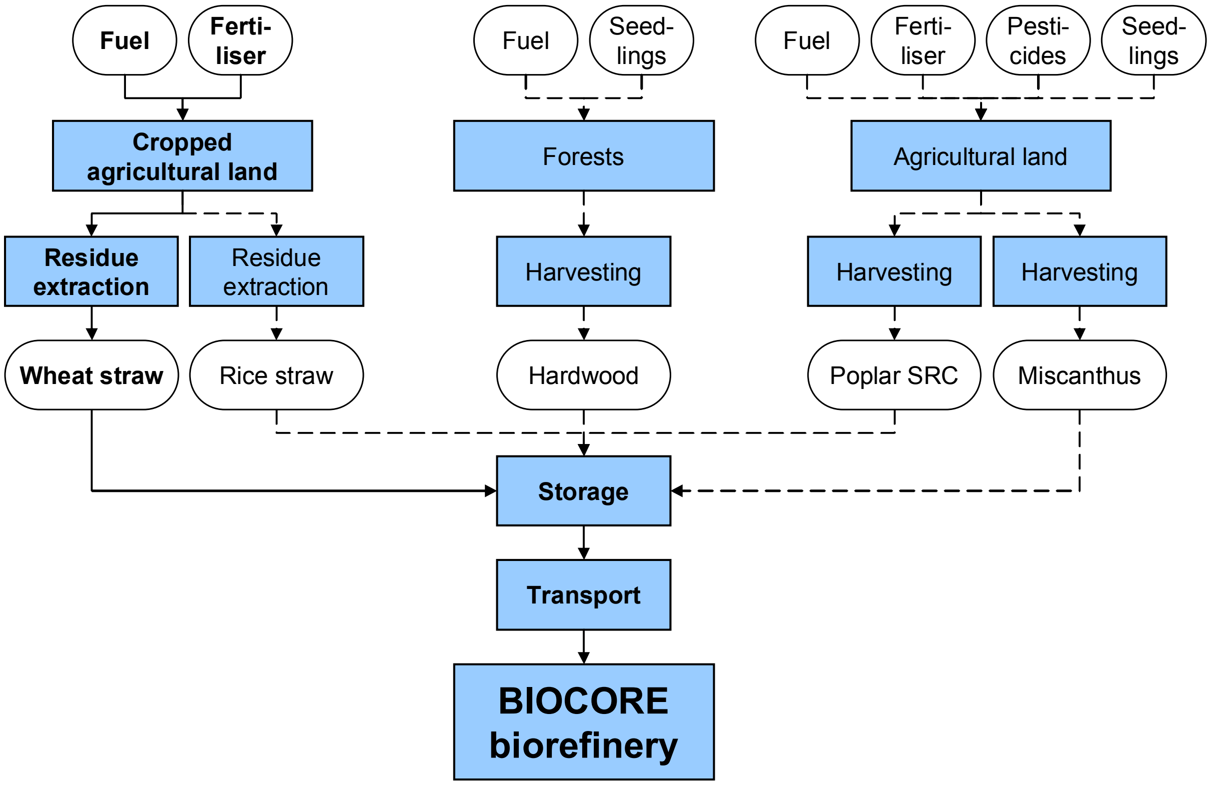

Fig. 9-2 Biomass provision to the BIOCORE biorefinery. The main scenario is displayed with solid arrows and in bold print, additional scenarios are displayed with dashed arrows and in regular print. SRC = short rotation coppice

The compositions of feedstocks can vary within a certain range depending on the year, time of harvest, cultivar, region, etc. Scenarios are based on average values given in Table 9-1.

Table 9-1 Composition of assessed feedstocks (components may not add up to 100% due to rounding differences)

Component	Wheat straw	Rice straw	Hardwood	Poplar SRC	Miscanthus
Hemicellulose / xylose	24%	21%	29%	21%	19%
Cellulose / glucose	38%	36%	46%	48%	42%
Lignin	18%	15%	23%	24%	23%
Sum of usable components	79%	72%	98%	93%	84%
Ash	4%	15%	0.5%	2%	2%
Others	18%	13%	1.5%	5%	14%

Besides the main feedstock, several other inputs are needed for biomass conversion (e.g. natural gas for energy provision and enzymes). The same applies to biomass production (e.g. phosphorous fertiliser and seedlings). All (mostly fossil) resources and land needed for their production as well as the impacts of the production processes are taken into account in the sustainability assessment.

9.1.2 Storage and transport

Storage and transport occurs at many stages during the life cycles of the BIOCORE scenarios. Transportation takes place on roads, rails and waterways. The most important is the storage and transport of the biomass due to its amount / volume.

The logistics of biomass provision is an important challenge for a big scale biorefinery such as modelled in BIOCORE. The lower energy and carbon density compared to fossil feedstocks such as natural gas and petroleum causes a high transport volume and pipelines are not an option. Furthermore, most biomass is not available year-round but has to be stored between seasonal harvests. This storage takes place close to the origin of the biomass (e.g. baled straw on the fields, wood in the forests). The logistics of various case studies on the BIOCORE biorefinery concept have been optimised in work package 1 (see /Patel et al. 2013/ for more details). Since the results of this optimisation are highly specific for the location of the respective case study, generalised settings based on these specific results are used in the sustainability assessment.

In contrast to the feedstock, the storage and transportation of biorefinery products can be assessed based on generic logistics models.

9.1.3 BIOCORE biorefinery

In BIOCORE, a big variety of options were studied how to convert lignocellulosic biomass into biomaterials and biofuels with help of the Organosolv process. The list of products, which were studied on various levels of detail, such as further polymer precursors, food additives, complexing agents etc., are listed in Table 9-2. The levels of detail ranged from literature research on potential use options and lab scale experiments on individual conversion steps to pilot scale testing of the most promising processes and manufacturing of product samples for communication with potential customers. The most promising products were selected for manufacturing on pilot scale (underlined in Table 4-1). Detailed models of how potential biorefineries can look like on industrial scale were designed covering all pilot scale products. The models include Aspen flow sheets and energy integration of all steps from biomass fractionation to product purification /Mountraki et al. 2012/, /Pyrgakis et al. 2012/ and are the basis for the detailed sustainability assessment.

The first step of the biomass conversion in BIOCORE (Fig. 9-3) is the biomass **pretreatment** consisting of comminution and if necessary drying (see /Benjelloun-Mlayah et al. 2011/ for more details). Straw is dry enough already so that the drying step can be omitted. All co-products like straw fines and dust from wood chipping are combusted for energy generation. The next step, the **Organosolv process**, solubilises biomass using organic acids (hence the name) and fractionates it into lignin, hemicellulose and cellulose. After their separation, polymeric sugars present in hemicellulose and cellulose are hydrolysed and purified if necessary. The resulting biomass fractions for standard applications are **C5** (five carbon sugars from hemicellulose), **C6** (six carbon sugars from cellulose) and **lignin**. The last step within the biorefinery is the **processing** of these biomass fractions mainly by biochemical steps (e.g. fermentation) but also by some thermochemical steps.

Table 9-2 Products studied within BIOCORE

C5 fraction	C6 fraction	Lignin fraction
1,2,4-butanetriol	2,5-FDCA ester	Activated carbon
1,2,4-butanetriol-trinitrate	Dichloroethane	Biochar
Difurfuryl diisocyanate	Ethanol	Carbon black
Ethanol	Ethylene glycol	Lignin based PF resin
Ethylene	Glucarate	Lignin based PU
Furfural	Glucose	Phenols
Hydrogel	Isopropanol	Pyrolysis oil
New polyamide	Isosorbide	Vanillin
Polypropylene	New polyester 1	
PVC	New polyester 2	
Xylitol	Paper	
Xylonic acid	PEF	
Xylooligosaccharides	PEIF	
	Polyacrylate	
	Polyamide (2,5-FDCA)	
	Polyamide (Glucarate)	
	PVC	
	Sorbitan esters	
	Sorbitol	
	Wood adhesive	

PEF: Poly(ethylene furandicarboxylate)
PEIF: Poly(ethylene isosorbide furandicarboxylate)
FDCA: Furandicarboxylic acid

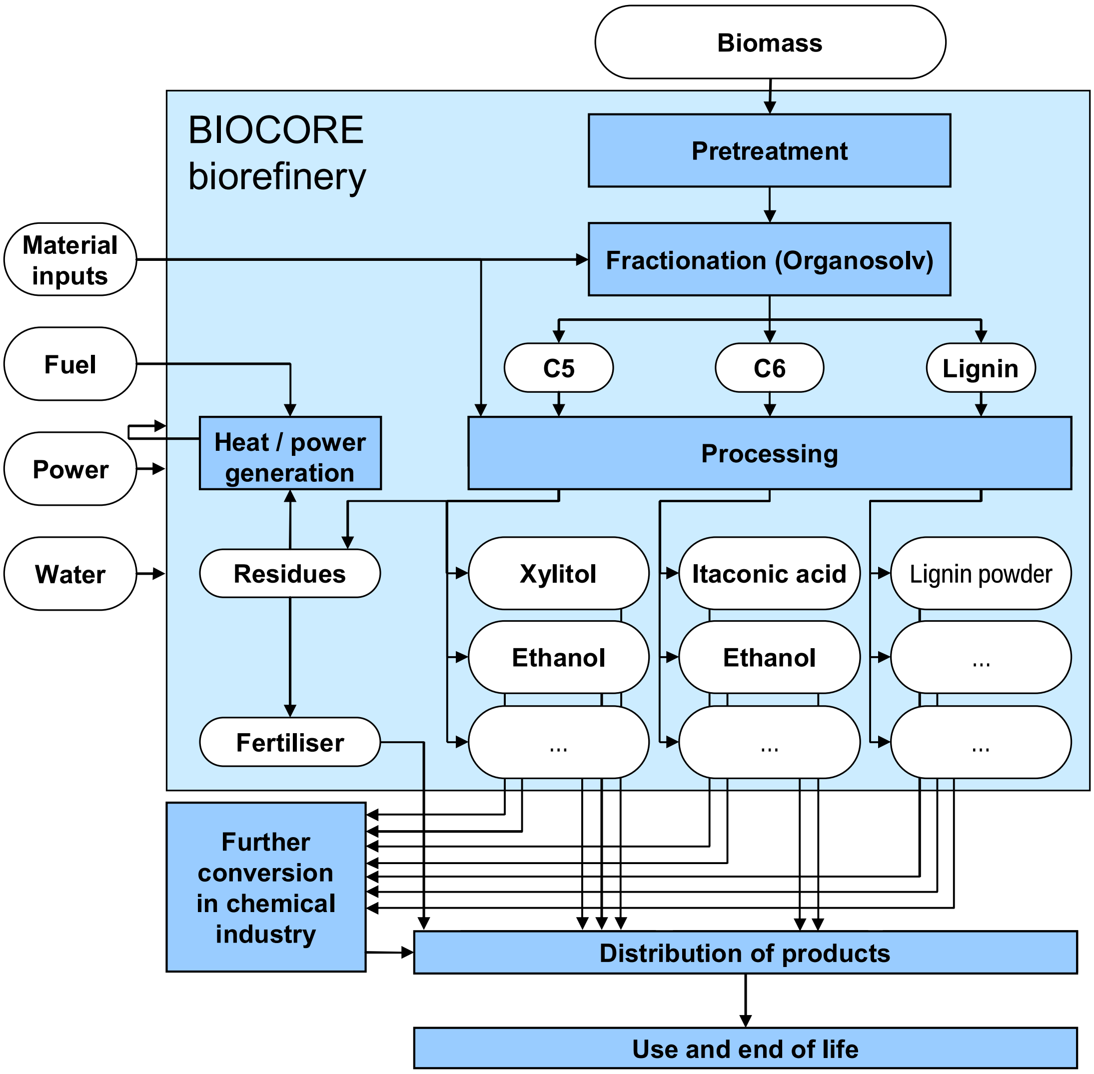

Fig. 9-3 Scheme of the processes within the BIOCORE biorefinery. C5 / C6: five and six carbon sugars from hemicellulose and cellulose, respectively.

The **biorefinery products** shown in Fig. 9-3 are produced in the so-called main scenarios. In so-called additional scenarios, ethanol is converted further into ethylene and a fallback option is assessed for each primary biomass fraction with as little as possible conventional processing (Table 4-1). This allows to analyse if additional processing steps increase the overall performance of the biorefinery. These biorefinery products are mostly intermediates, which are sold to the chemical industry (see also chapter 9.1.4), but some like xylitol are used in end consumer products without further chemical modification.

In the scenarios assessed in this report, each biomass fraction is used to produce only one product because implementations of the BIOCORE biorefinery concept will be limited by investment capital and size. All scenarios with their respective product combinations are summarised in Table 4-2.

Besides the main products, BIOCORE biorefineries produce several co-product streams such as fermentation **residues**. The co-products are pooled according to their water content.

Rather dry output streams are combusted for energy provision and the wet streams are used to produce biogas via anaerobic digestion. The biogas is used for energy provision. The digestate (anaerobic digestion residue) is sterilised, dewatered, and used as **fertiliser** on farms in the vicinity of the biorefinery because of its high nitrogen and phosphorous contents. This is the only co-product that is used outside of the biorefinery. The extracted water is treated further in conventional wastewater treatment. Ashes from solid co-product combustion are landfilled. Furthermore, the biorefinery produces direct gaseous emissions. These are various emissions from co-product and fuel combustion as well as emissions of biogenic CO_2 and possibly odours from fermenters. There are no indications of or information on further direct emissions that are relevant for the sustainability assessment.

For its operation, the biorefinery needs **power**, **heat** in the form of steam at various temperatures, and **cooling**. Only a small part of the required steam can be provided by burning internally produced biogas and other co-products. The remaining steam demand is provided by combustion of natural gas in a combined heat and power (CHP) unit in the main scenarios (Table 9-3). In an additional scenario, additional biomass is acquired for energy provision. The combined heat and power (CHP) unit is operated at conditions optimal for heat use. Additional power, if necessary, is acquired from the grid. Cooling is provided by a cooling water network with excess heat discharge to a water body. Refrigeration is not provided as central utility but within the respective processing unit. Both cooling and refrigeration require additional power consumption for their operation.

Table 9-3 Potential sources of energy inputs, underlined: main scenario

Form of energy	Technology for provision	Energy source
Heat (steam)	Combined heat and power (CHP) unit	<u>Natural gas + co-products</u>, Additionally harvested biomass + co-products
Power	CHP	(as above)
	Additional: grid	<u>Mix of coal + natural gas + uranium + oil + renewables</u>

9.1.4 Further chemical conversion

Several of the biorefinery products are sold to the chemical industry, where they are further chemically converted. In the scenarios assessed in detail, these are

- Ethylene to bio-based polyvinyl chloride (PVC)
- Itaconic acid to poly(itaconic acid)
- Itaconic acid (+ other components) to polyester resins
- Lignin powder (+ phenol + formaldehyde) to bio-based phenol formaldehyde (PF) resins
- Lignin powder (+ polyols + isocyanates) to bio-based polyurethane (PU) resins

In principle, most of these steps could also take place within the biorefinery. Yet, whenever conventional facilities exist, in which the necessary equipment is already in place, then the processing step is not part of the biorefinery. This was set for the assessed scenarios because the availability of capital is a major limitation for the implementation of biorefineries.

Consequently, these processes have similar properties as established processes in the chemical industry even if biogenic intermediates are chemically related but not identical to the conventional intermediates.

9.1.5 Use and end of life

The biomaterials and biofuels leaving the biorefinery or chemical industry after further processing are sold to consumers as such or as part of more complex products (Table 4-1). After use, the products are disposed of unless they are already consumed like for fuels and food ingredients. The disposal is followed by recycling steps, incineration, and landfilling.

One main concept behind the sustainability assessment is that all assessed new bio-based products replace conventional products (termed reference products, see chapter 4.2 for details), which provide the same function. Therefore, the use phase and its impacts are very similar for product and reference product. The use phase and end of life is only modelled explicitly if the product and reference product are not chemically identical. In that case, potential differences between biorefinery product and reference product are taken into account regarding further processing (e.g. different moulding temperatures), use phase (e.g. energy content of fuels), or end of life (e.g. different recycling options).

9.2 Reference products

The sustainability assessment analyses the impacts of the substitution of conventional products (reference products) by novel bio-based products using a life cycle comparison approach (Fig. 4-2). Therefore, also the life cycles of these reference products are assessed from cradle to grave. Furthermore, it has to be specified, how much of which conventional product is replaced by the assessed bio-based product.

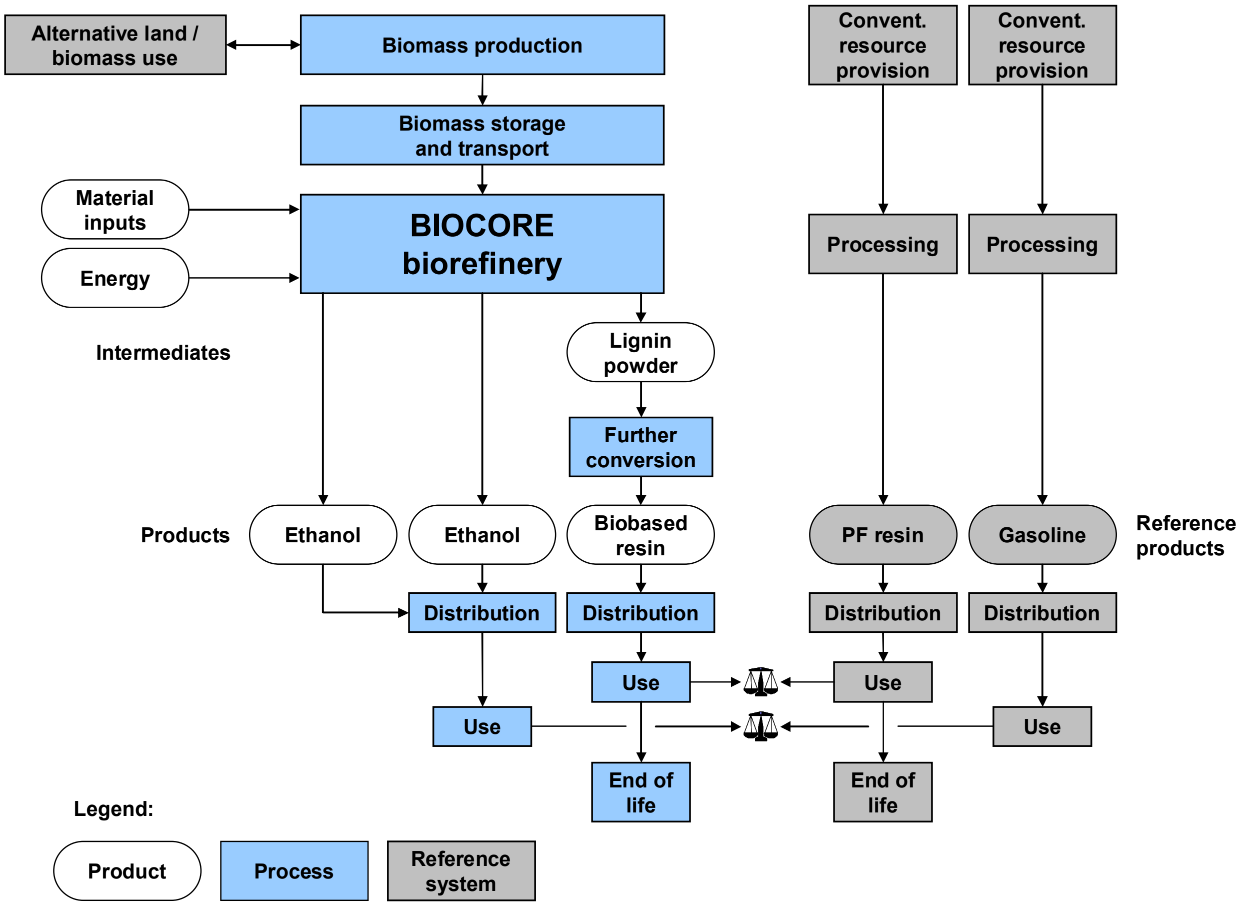

Fig. 9-4 Scheme of a life cycle comparison. This scheme exemplarily shows the products and reference products of the main scenario SHF ethanol. PF resin: phenol formaldehyde resin

The conventional products that are replaced by BIOCORE products are mainly produced from fossil resources. An exception is xylitol, which replaces other bio-based xylitol produced by conventional processes. Below, the reference products are listed for each use option of each biorefinery product. The alternative land / biomass use is covered in chapter 4.3.

Ethanol

Bioethanol is already being produced for the use as transportation fuel in first lignocellulose-based biorefineries today. The reference product is in this case gasoline, which is compared to bio-based ethanol on the basis of the energy content.

Ethylene / PVC

The BIOCORE biorefinery produces bio-based ethylene, a precursor of PVC (polyvinyl chloride), from bio-based ethanol. This intermediate replaces petroleum-based ethylene. Both are used for PVC production in existing external PVC plants. Therefore, all subsequent processing steps are identical. Properties of bio-based PVC might differ in some aspects from properties of petroleum-based PVC, which is not relevant for further processing but might limit the application range. To avoid model inconsistencies in the PVC production, bio-based ethylene is compared to petroleum-based ethylene on a mass basis taking into account that all following steps are identical.

Xylitol

Xylitol is used as a sweetener, which is claimed to have unique caries preventing properties. All available xylitol is bio-based. The most common process is to extract it via acid hydrolysis from corn cobs, an agricultural co-product. Alternatively, xylitol can be produced from black liquor, a co-product from paper production. In BIOCORE, xylitol is produced both via fermentation and via a thermochemical process. All types of xylitol fulfil the same industrial specifications and can therefore be compared on a mass basis. As a standard, the reference product for the BIOCORE xylitol is xylitol from corn cobs, which is mainly produced in China, which has the biggest share on the world market. Currently, xylitol production from corn cobs often demands a lot of energy. This can be as much as 10 times compared to xylitol from black liquor /Danisco 2010/. However, the xylitol market is growing dynamically and it seems that there are substantial efforts to increase the energy efficiency /Futaste 2008/. Thus the current situation is most likely quite different from the xylitol production in 2025, the reference year of this study (see chapter 4.4), which is taken into account in this study.

Itaconic acid

Itaconic acid is an intermediate, which can be produced rather easily from sugars but is complicated to synthesise from fossil resources. Therefore, it has not played any major role as chemical intermediate yet but has been proposed as an upcoming bio-based platform chemical /Werpy et al. 2004/ although future potentials are debated /Bozell & Petersen 2010/. Various options have been suggested to use for itaconic acid as a building blocks for polymers. Currently, it is only produced on a small scale and the major application is the production of poly(itaconic acid) (PIA). This can be used e.g. as superabsorber instead of poly(acrylic acid) (PAA) in hygiene products such as diapers or as builder (chelating agent) in detergents. As the future direction of use will most likely focus on polymers, PAA was chosen as reference product for PIA. The main scenarios are based on equal product properties of PIA and PAA as well as on an equal energy and material consumption for the polymerisation /Nuss & Gardner 2013/. An alternative promising option is the use of itaconic acid as a precursor of bio-based polyester resins. In this case, two related but different mineral oil-based chemicals can be functionally replaced. The exact composition of these polyester resins cannot be disclosed for confidentiality reasons.

Lignin-based phenol formaldehyde (PF) resins

PF resins are mostly used as wood adhesives. Plywood panels manufactured with lignin-containing PF resins show the same properties as panels with conventional PF resins up to a certain lignin content. The resin and panel production takes place in existing facilities with readily prepared lignin from the BIOCORE biorefinery. The used resin dry mass and the processing conditions are identical. Thus, lignin-containing PF resin has the same function as an equal mass of fossil resource based PF resin although their compositions are different. The resin and plywood production step is not explicitly modelled because it is identical for both the BIOCORE product and the reference product.

Lignin-based polyurethane (PU)

Chemically, lignin is an aromatic polyol. It can replace other polyols in polymers such as polyurethane (PU). PU mainly consist of polyols and diisocyanates in various mixing ratios. As a model application, PU casting resins were assessed as they are used e.g. to cover electrical components. It could be shown by BIOCORE partners that lignin-based PU resins have significantly better properties than conventional PU resins such as increased tensile strength, toughness, surface hardness and higher electrical resistance. Depending on the application, better properties may or may not lead to material savings as the design can be limited by other properties. Therefore, both cases are modelled.

Paper

The production of paper pulp from the raw Organosolv cellulose stream requires only few established processing steps. This product is a fallback option in case more advanced cellulose-based products cannot be realised. It is compared to conventional paper pulp from the kraft process (sulfate pulping process) on a mass basis. Following steps from pulp to paper are identical for both kinds of pulp.

Animal feed from C5 sugars

In contrast to the original lignocellulosic biomass, the Organosolv C5 stream has a high feed value. It can replace other conventional animal feed with a high carbohydrate content. In this case, it is compared to wheat grains as a reference product based on the nutritional value.

Bioenergy from lignin

The fallback option for lignin is its combustion for energy generation in a combined heat and power (CHP) unit within the biorefinery. This way, it provides steam and power to the process and replaces natural gas, which would otherwise be used instead. Both fuels are compared based on their energy content, which implies the same energy conversion efficiencies. Emissions from combustion are modelled separately for both fuels.

Fertiliser

The co-product fertiliser, which is produced from fermentation residues, replaces conventional mineral fertiliser. The use phase is assessed in detail because the two kinds of fertiliser have different properties. First, the bio-based fertiliser from the BIOCORE biorefinery contains the nitrogen in the form of different chemical compounds, which leads to higher emissions of ammonia from the fields. Second, the calcium content resulting mainly from CaO added during the sterilisation process is very high compared to typical mixtures of mineral fertilisers, which can be adjusted as needed. Therefore, the calcium in the BIOCORE fertiliser is set to replace only 5% of calcium of fossil origin, which takes overfertilisation into account.

9.3 Alternative uses of biomass or land

9.3.1 BIOCORE vs. conventional systems

The use of residual biomass like straw from agricultural land always has to be compared to a **reference system** because something will happen to the biomass or the land even if no BIOCORE biorefinery is implemented. In the initial part of the assessment focussing on the BIOCORE biorefinery concept is based on the precondition that sufficient biomass or agricultural land is available. Independent of how much unused biomass or agricultural land may be available in reality in 2025, this precondition allows to independently assess the BIOCORE biorefinery and its optimisation options before comparing it to alternative use options of the biomass or agricultural land in a second step. Thus, the implementation of the BIOCORE biorefinery concept is compared to not extracting the agricultural residues and forestry biomass or not using the agricultural land. Nevertheless, this reference system can still cause environmental benefits (e.g. remaining straw serves as fertiliser reducing the demand for mineral fertiliser) or environmental burdens (e.g. straw is burned in the field causing significant emissions). These environmental impacts of the reference system are credited to the BIOCORE biorefinery, which leads to the reduction of its environmental impacts (if burdens are avoided) or to additional impacts (if benefits are prevented). These reference systems are part of the life cycle of the BIOCORE biorefinery.

Table 9-4 Feedstocks for the BIOCORE biorefinery concept and their reference systems (main scenario underlined)

Feedstock type	Feedstock	Reference system
Agricultural residues	Wheat straw	Ploughing in, serves as fertiliser
	Rice straw	Burning in field
Forestry biomass	Hardwood stems from thinnings (diameter > 5 cm)	Remain in forest
Agricultural biomass	Miscanthus, poplar short rotation coppice (SRC)	No production, land is not used (non-rotational fallow land)

9.3.2 BIOCORE vs. other biomass-based systems

In most cases, a BIOCORE biorefinery will compete with other uses of the limited resources biomass and agricultural land. In this case, another life cycle comparison is necessary to assess the impacts (Fig. 4-3). To this end, products originating from alternative biomass or land uses like bioenergy are themselves compared to alternative fossil-based products like energy from natural gas. This leads to the situation that e.g. either the demand for chemicals is satisfied by biomass and the demand for energy is satisfied by fossil resources or vice versa. The underlying question is whether the BIOCORE biorefinery concept or alternative use options of the same biogenic resources are more sustainable.

The **alternative biomass use options** for all kinds of biomass assessed in this study are:

Direct combustion

Biomass is burned for energy generation in a combined heat and power (CHP) unit. The produced bioenergy replaces heat and power from a mix of conventional sources. For hardwood, a scenario is assessed additionally, in which the biorefinery competes with wood pellet production for domestic heating. In this scenario, the pellet production declines and more household continue using fossil-based domestic heating.

Synfuels

The lignocellulosic biomass is converted into synthetic fuel (synfuel) in a thermochemical biorefinery. First, the biomass is broken down into energy-rich syngas consisting of hydrogen, carbon monoxide and carbon dioxide via gasification. Then, the syngas is used to synthesise longer hydrocarbons via Fischer-Tropsch synthesis. The resulting bio-based synfuels resemble conventional fuels from petroleum.

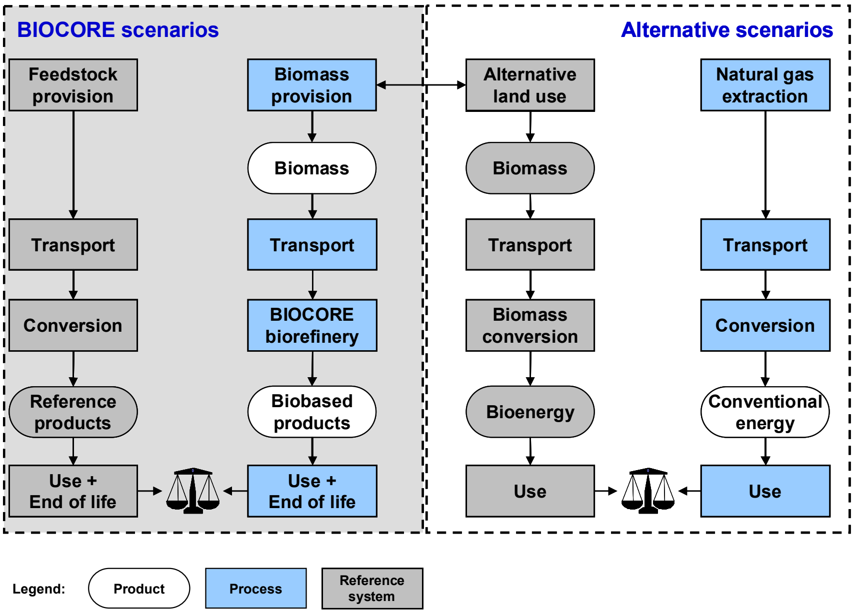

Fig. 9-5 Simplified exemplary scheme of the assessment of competing land use options. Please note that the BIOCORE biorefinery provides several products, which are each compared to a separate reference product.

The following **alternative land use options** are assessed for all biorefinery schemes, which are based on agricultural biomass (here: poplar SRC and Miscanthus):

Sugar beet, wheat grains and maize grains

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

Maize (whole plant)

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

Triticale (whole plant)

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

Rapeseed

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

9.4 Flowcharts

This chapter shows the flowcharts of all main scenarios as listed in Table 4-2.

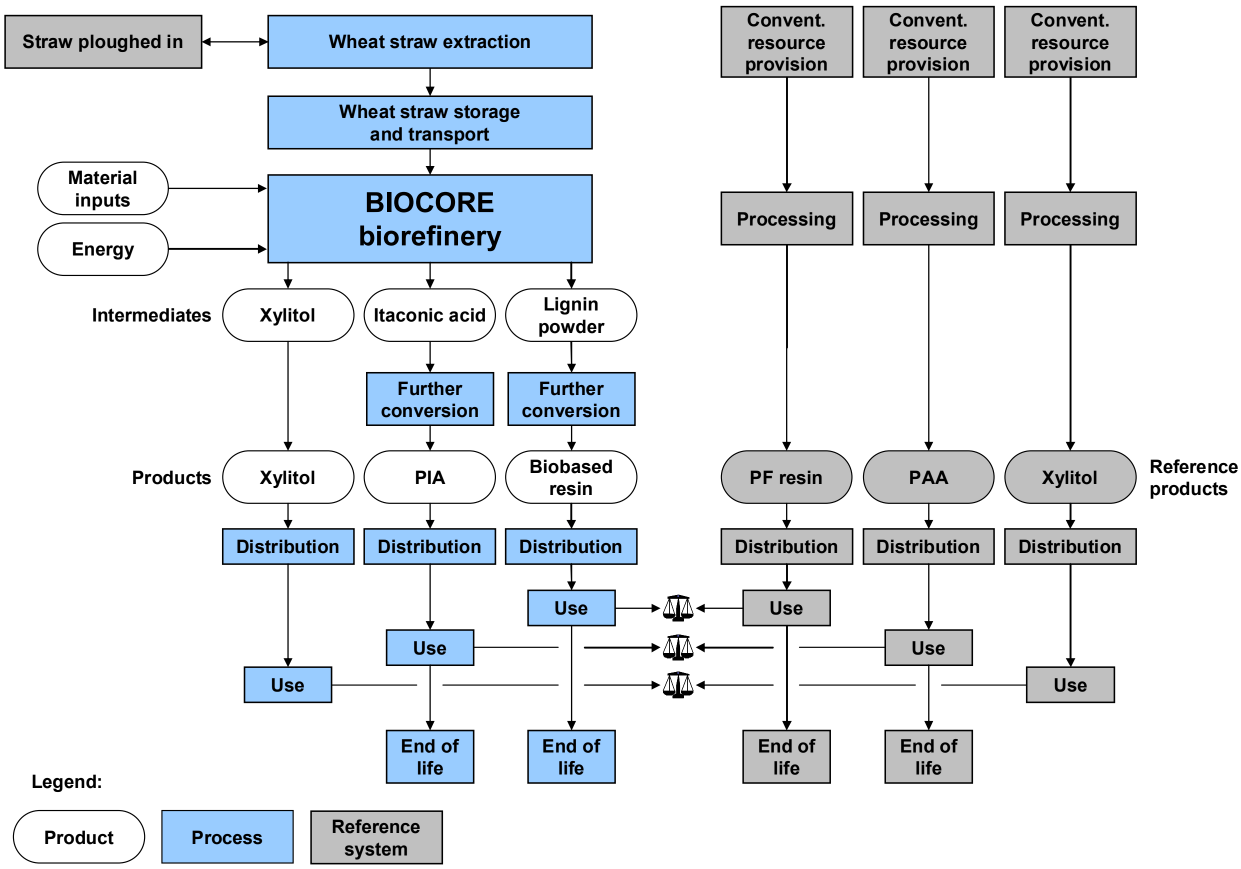

Fig. 9-6 Main scenario Xyl / IA: Production of xylitol (C5), itaconic acid (C6), and lignin powder (lignin). PIA: Poly(itaconic acid), PAA: Poly(acrylic acid), PF resin: Phenol formaldehyde resin

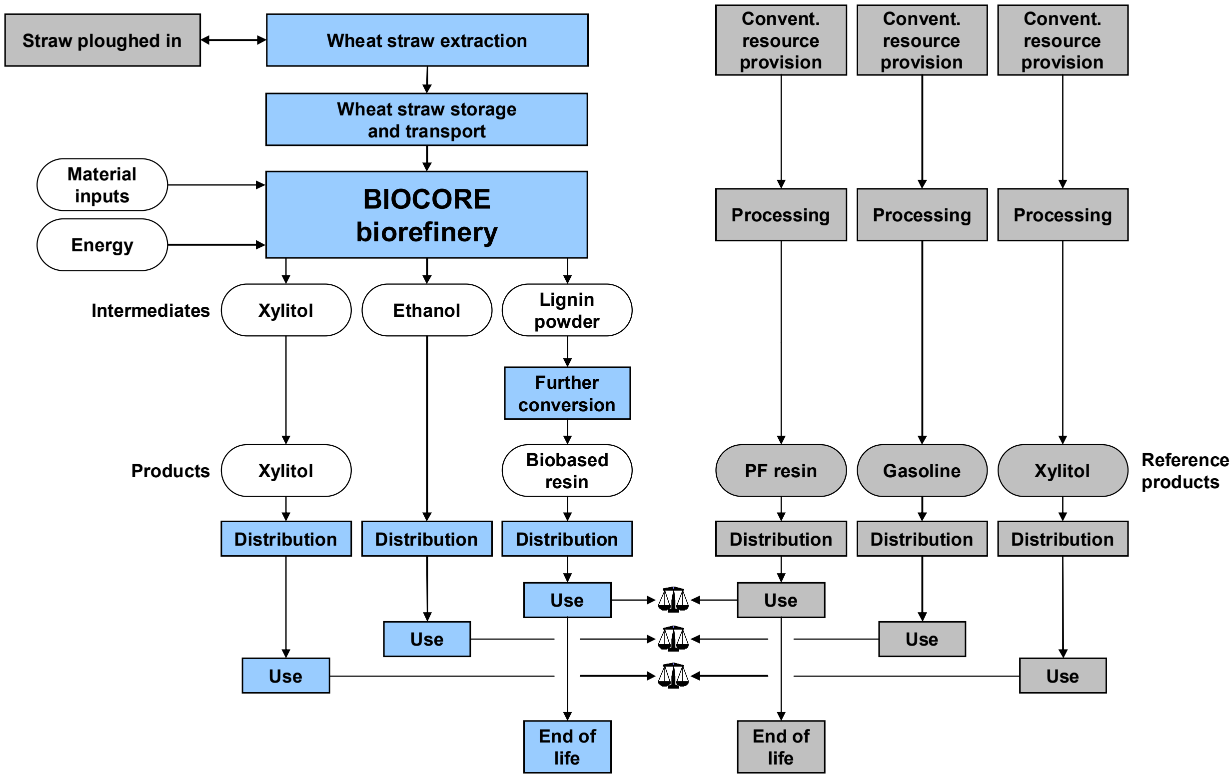

Fig. 9-7 Main scenario Xyl / ethanol: Production of xylitol (C5), ethanol (C6), and lignin powder (lignin)

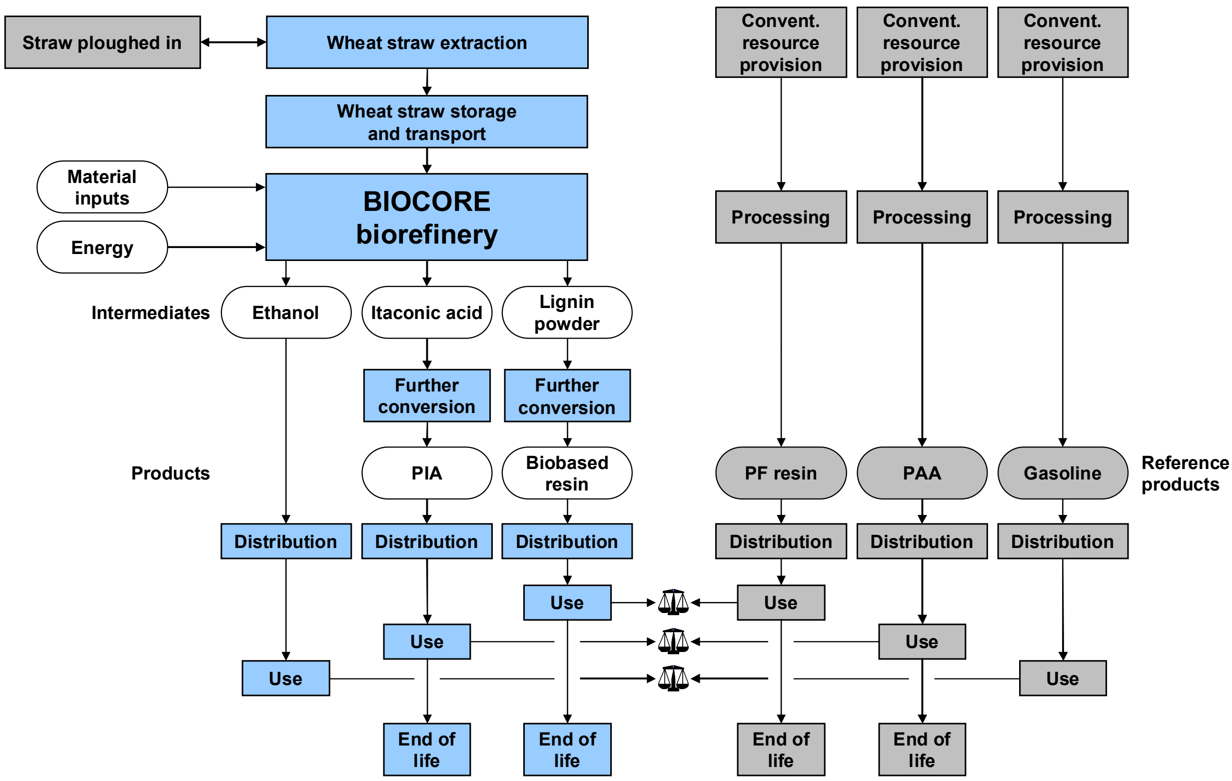

Fig. 9-8 Main scenario ethanol / IA: Production of ethanol (C5), itaconic acid (C6), and lignin powder (lignin)

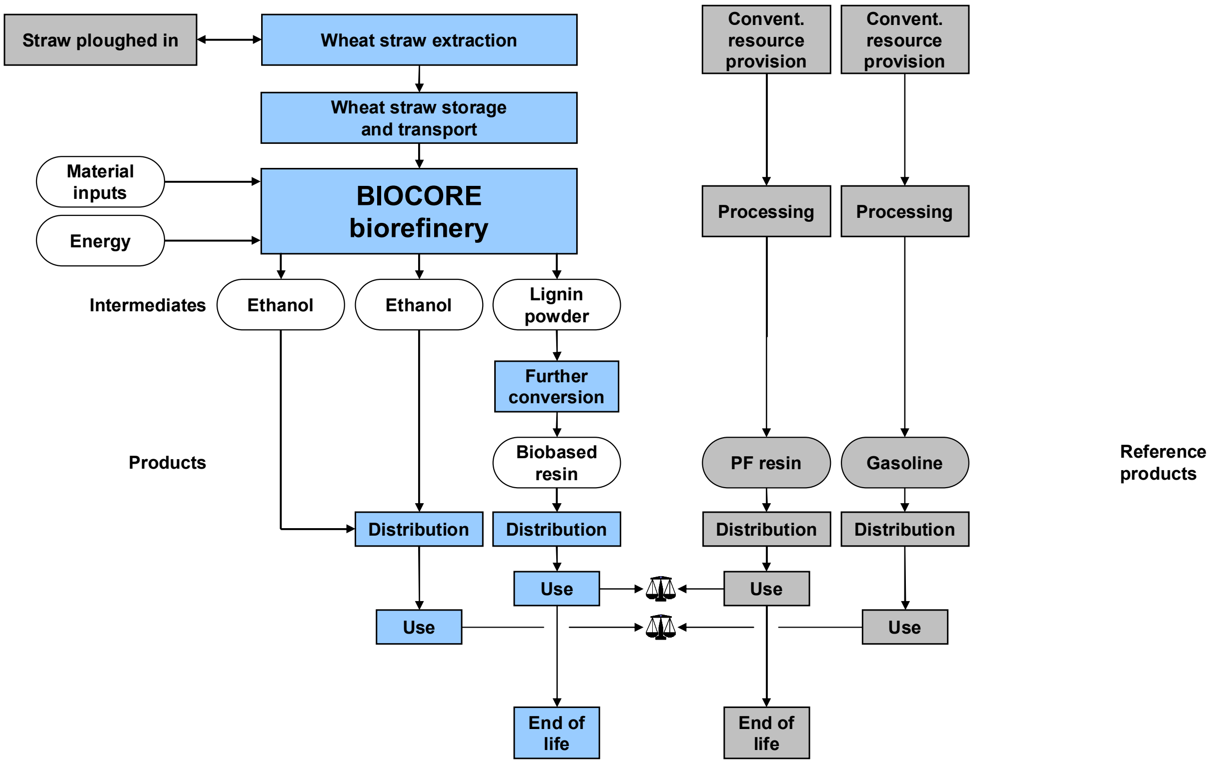

Fig. 9-9 Main scenario SHF ethanol: Production of ethanol from C5 and C6 in separate hydrolysis and co-fermentation (SHF), and lignin powder (lignin)

9.5 General specifications

9.5.1 Technical reference

The technical reference describes the technology to be assessed in terms of plant capacity and development status / maturity. The following plant capacities are assessed:

- 150,000 tonnes / year of dry matter input in the standard scenarios
- 500,000 tonnes / year of dry matter input in an excursus

The plant capacity of 500,000 tonnes / year is only assessed for a scenario in India with rice straw as feedstock because a sustainable supply of such an amount of biomass per year is questionable in Europe (see also /Kretschmer et al. 2013/ for an assessment of biomass potentials).

In addition to plant capacity, development status / maturity plays an important role. In order to evaluate whether the BIOCORE biorefinery concept is worth being developed / supported further, it is essential to know how future biorefineries perform as compared to established biomass use options, which are operated at industrial scale and with mature technology. Only mature technology is assessed in order to allow for a fair comparison of biorefineries to existing technologies.

9.5.2 Time frame

The time frame of the assessment determines e.g. the development status of biorefinery technology. 2025 is set as the reference time because a whole value-added chain of biomass provision, conversion technology and adaption of consumer products to new bio-based intermediates and polymers as raw materials will not be established in a few years from now. Besides the development status of the biomaterials sector, also other sectors will change until 2025. The most relevant impacts are to be expected from the change in the energy sector, which is taken into account in this study.

9.5.3 Geographical coverage

Geography plays a crucial role, determining e.g. agricultural productivity, transport systems and electricity generation. The BIOCORE project focuses on two world regions: Europe and India. The assessment only covers domestic biomass production, i.e. imported biomass from outside Europe and India, respectively, is not considered as feedstock for the BIOCORE biorefineries. The main scenarios are based on European conditions. The scenarios dealing with rice straw, which is a promising feedstock in India, are modelled according to Indian conditions.

10 Annex 2: Further results

This chapter contains further data for and results of the integrated assessment.

Table 10-1 Complete set of indicators and results from social assessment for relevant scenarios, N/D: not determined / no data. For selected results see Table 5-13.

			Standard								
			BIOCORE scenarios								
	Indicator	Unit or subcateg.	Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Wheat straw (Fallback options)	Hardwood (Xyl / IA)	Poplar SRC (Xyl / IA)	Miscanthus (Xyl / IA)	Rice straw, India (Xyl / IA)
Society	Production of feedstock	Incentives	+	+	+	+	0	++	+	+	++
		Barriers	-	-	-	-	0	-	-	-	-
	Identification of stakeholders	Producers (farmers)	+	+	+	+	+	++	+	+	++
		Regulators	N/D	N/D	N/D	N/D	0	N/D	N/D	N/D	N/D
		Business	+	+	+	+	+	++	+	+	++
		Traders	+	+	+	+	+	+	+	+	+
		Research	N/D	N/D	N/D	N/D	0	N/D	N/D	N/D	N/D
	Policies and regulations	National	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
		Enforcement	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
		International conventions and agreements	N/D	N/D	N/D	N/D	0	+	+	+	N/D
	Land use tenure	Land ownership rights	0	0	0	0	0	0	-	-	0
	Community participation	Community participation	+	+	+	+	0	+	+	+	+
	Rural development and infrastructure	Road	0	0	0	0	0	0	+	+	+
		Water (availability and quality) for the local population	0	0	0	0	0	0	0	-	0
		Sanitation infrastructure	+	+	+	+	+	+	+	+	+
		Risk of not having bed at hospital	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	Job creation and wages	Labour involved in feedstock gathering	+	+	+	+	+	+	+	+	+
		Labour involved in production	+	+	+	+	+	+	+	+	+
		Wages paid according to national/regional	+	+	+	+	+	+	+	+	+
		Poverty reduction	0	0	0	0	0	0	0	0	++
	Gender equity	Inclusion of women	+	+	+	+	+	+	+	+	+
	Labour conditions (enforcement)	ILO conventions	0	0	0	0	0	0	0	0	+
	Health and safety	Compliance with regulations (supply chain)	+	+	+	+	+	+	+	+	+
	Competition with other sectors	Competition for residues	-	-	-	-	- -	-	0	0	-

Table 10-2 Influence of the defined threshold on comparisons: Comparison of scenarios with various biorefinery configurations vs. the scenario Xyl / IA based on the input of identical amounts of the feedstock wheat straw at a minimum results difference of 1 % of the overall bandwidth of results. Compare to Table 5-15 and Table 10-3.

	Benchmark: Wheat straw (Xyl / IA), feedstock basis, threshold 1 %	**BIOCORE scenarios**							
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Wheat straw (Ethanol to PVC)	Wheat straw (Fallback options)	Wheat straw (Straw powered)	Wheat straw (Lignin to energy)
Technology	Maturity		0	0	0	0	++	0	0
	Availability of infrastructure for logistics and storage		0	0	0	0	0	0	0
	Use of GMOs		0	++	++	++	++	0	0
	Risk of explosions and fires		0	0	0	0	0	0	0
	Development of legislatory framework and bureaucratic hurdles		0	0	0	0	0	0	0
	Feedstock flexibility of conversion technologies		0	0	0	0	0	0	0
Environment	Resource depletion: energy		-	- -	- -	-	-	+	-
	Climate change		-	-	- -	-	-	-	-
	Terrestrial acidification		-	- -	- -	-	-	-	-
	Marine eutrophication		0	- -	- -	-	N/D	-	0
	Freshwater eutrophication		0	- -	0	-	N/D	-	-
	Photochemical ozone formation		0	-	0	-	-	-	-
	Respiratory inorganics		0	-	0	-	-	-	-
	Ozone depletion		+	0	0	-	+	-	-
	Direct additional land use		0	0	0	0	0	0	0
	Indirect land use (EU)		0	0	0	0	0	0	0
	Indirect land use (SA)		0	0	0	0	0	0	0
	Water		0	0	0	0	0	0	0
	Soil		0	0	0	0	0	0	0
	Fauna		0	0	0	0	0	0	0
	Flora		0	0	0	0	0	0	0
	Landscape		0	0	0	0	0	0	0
Economy	Total capital investment		++	- -	0	- -	++	++	++
	NPV (5%, no GP)		-	- -	- -	-	-	+	-
	NPV (5%, incl. GP)		-	- -	- -	- -	-	+	-
	Profit / loss (no GP)		-	- -	- -	-	-	+	- -
	Profit / loss (incl. GP)		-	- -	- -	-	- -	+	- -
	IRR (no GP)		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	IRR (incl. GP)		N/A	N/A	N/A	N/A	N/A	+	N/A
	Price support (no GP, 25% IRR)		-	- -	- -	- -	- -	+	-
	Price support (no GP, 15% IRR)		0	- -	- -	- -	- -	+	-
	Price support (incl. GP, 25% IRR)		-	- -	- -	- -	- -	+	-
	Access to markets		++	0	++	++	++	0	0
Society	Feedstock prod.: Incentives		0	0	0	0	- -	0	0
	Feedstock prod.: Barriers		0	0	0	0	++	0	0
	Identification: Producers		0	0	0	0	0	0	0
	Identification: Business		0	0	0	0	0	0	0
	Identification: Traders		0	0	0	0	0	0	0
	Rural development: Road		0	0	0	0	0	0	0
	Rural development: Water		0	0	0	0	0	0	0
	Labour conditions (ILO)		0	0	0	0	0	0	0
	Competition for residues		0	0	0	0	- -	0	0

Table 10-3 Influence of the defined threshold on comparisons: Comparison of scenarios with various biorefinery configurations vs. the scenario Xyl / IA based on the input of identical amounts of the feedstock wheat straw at a minimum results difference of 10 % of the overall bandwidth of results. Compare to Table 5-15 and Table 10-2.

	Benchmark: Wheat straw (Xyl / IA), feedstock basis, threshold 10 %	**BIOCORE scenarios**							
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Wheat straw (Ethanol to PVC)	Wheat straw (Fallback options)	Wheat straw (Straw powered)	Wheat straw (Lignin to energy)
Technology	Maturity		0	0	0	0	++	0	0
	Availability of infrastructure for logistics and storage		0	0	0	0	0	0	0
	Use of GMOs		0	++	++	++	++	0	0
	Risk of explosions and fires		0	0	0	0	0	0	0
	Development of legislatory framework and bureaucratic hurdles		0	0	0	0	0	0	0
	Feedstock flexibility of conversion technologies		0	0	0	0	0	0	0
Environment	Resource depletion: energy		0	-	0	-	-	0	-
	Climate change		0	-	0	-	-	0	-
	Terrestrial acidification		0	0	0	-	-	-	-
	Marine eutrophication		0	0	0	-	N/D	-	0
	Freshwater eutrophication		0	0	0	-	N/D	-	0
	Photochemical ozone formation		0	0	0	0	0	0	0
	Respiratory inorganics		0	0	0	0	0	0	0
	Ozone depletion		0	0	0	0	0	0	0
	Direct additional land use		0	0	0	0	0	0	0
	Indirect land use (EU)		0	0	0	0	0	0	0
	Indirect land use (SA)		0	0	0	0	0	0	0
	Water		0	0	0	0	0	0	0
	Soil		0	0	0	0	0	0	0
	Fauna		0	0	0	0	0	0	0
	Flora		0	0	0	0	0	0	0
	Landscape		0	0	0	0	0	0	0
Economy	Total capital investment		0	0	0	0	++	0	0
	NPV (5%, no GP)		0	- -	- -	-	-	0	-
	NPV (5%, incl. GP)		0	-	- -	-	-	0	-
	Profit / loss (no GP)		0	- -	- -	-	-	0	-
	Profit / loss (incl. GP)		-	-	- -	-	-	0	- -
	IRR (no GP)		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	IRR (incl. GP)		N/A	N/A	N/A	N/A	N/A	+	N/A
	Price support (no GP, 25% IRR)		0	- -	- -	- -	- -	0	-
	Price support (no GP, 15% IRR)		0	- -	- -	- -	- -	0	-
	Price support (incl. GP, 25% IRR)		0	-	- -	- -	- -	0	-
	Access to markets		++	0	++	++	++	0	0
Society	Feedstock prod.: Incentives		0	0	0	0	- -	0	0
	Feedstock prod.: Barriers		0	0	0	0	++	0	0
	Identification: Producers		0	0	0	0	0	0	0
	Identification: Business		0	0	0	0	0	0	0
	Identification: Traders		0	0	0	0	0	0	0
	Rural development: Road		0	0	0	0	0	0	0
	Rural development: Water		0	0	0	0	0	0	0
	Labour conditions (ILO)		0	0	0	0	0	0	0
	Competition for residues		0	0	0	0	- -	0	0

Table 10-4 Influence of the used comparison metric: Comparison with the scenario “direct combustion of wheat straw” as benchmark based on the input of identical amounts of feedstock using the standard benchmarking procedure. Compare to Table 5-18, which uses the comparison metric potential analysis.

Benchmark: Direct combustion (Wheat straw), feedstock basis		BIOCORE scenarios				Alternatives	
		Wheat straw (Xyl / IA)	Wheat straw (Xyl / ethanol)	Wheat straw (Ethanol / IA)	Wheat straw (SHF ethanol)	Direct combustion (Wheat straw)	Synfuel (Wheat straw)
Technology	Maturity	- -	- -	- -	- -		0
	Availability of infrastructure for logistics and storage	0	0	0	0		0
	Use of GMOs	- -	- -	- -	- -		0
	Risk of explosions and fires	0	0	0	0		- -
	Development of legislatory framework and bureaucratic hurdles	- -	- -	- -	- -		- -
	Feedstock flexibility of conversion technologies	0	0	0	0		0
Environment	Resource depletion: energy	0	0	- -	- -		- -
	Climate change	0	0	-	- -		- -
	Terrestrial acidification	0	0	- -	- -		0
	Marine eutrophication	0	0	0	0		0
	Freshwater eutrophication	0	0	0	0		0
	Photochemical ozone formation	0	0	0	0		0
	Respiratory inorganics	0	0	0	0		0
	Ozone depletion	0	0	0	0		++
	Direct additional land use	0	0	0	0		0
	Indirect land use (EU)	0	0	0	0		0
	Indirect land use (SA)	0	0	0	0		0
	Water	0	0	0	0		0
	Soil	0	0	0	0		0
	Fauna	0	0	0	0		0
	Flora	0	0	0	0		0
	Landscape	0	0	0	0		0
Economy	Total capital investment					N/D	
	NPV (5%, no GP)					N/D	
	NPV (5%, incl. GP)					N/D	
	Profit / loss (no GP)					N/D	
	Profit / loss (incl. GP)					N/D	
	IRR (no GP)					N/D	
	IRR (incl. GP)					N/D	
	Price support (no GP, 25% IRR)					N/D	
	Price support (no GP, 15% IRR)					N/D	
	Price support (incl. GP, 25% IRR)					N/D	
	Access to markets	0	++	0	++		- -

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Suggested citation:

Rettenmaier, N. *et al.*, Integrated sustainability assessment of the BIOCORE biorefinery concept, Report prepared for the BIOCORE project www.biocore-europe.org, Heidelberg, 2014