SWOT analysis and biomass competition analysis for SUPRABIO biorefineries



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Publishable summary

The SUPRABIO project researches, develops and demonstrates a toolkit of novel generic processes that can be applied to a range of biorefinery concepts. The project concentrates on critical unit operations that are at present limited by their economic feasibility and on currently the most economic feedstocks such as lignocellulose from sustainable forestry or agricultural residues. SUPRABIO focuses also on the process optimisation of material and waste flows within the biorefinery, water management and process energy requirements.

Since the success of such innovative biorefinery concepts might be limited e.g. by economic, environmental, social or ethical constraints, an **analysis on strengths, weaknesses, opportunities, and threats (SWOT)** was performed for all investigated SUPRABIO pathways to identify possible bottlenecks but also concepts that are particularly worth pursuing. The considered pathways basically include the biochemical as well as the thermochemical processing of lignocellulose into fuels. In addition, several advanced technology options (e.g. lignocellulose to mixed acids) as well as “add-ons” (e.g. hydrogenation of seed oils) that can be attached to the biorefinery were assessed. The SWOT analysis in this report was conducted on feedstock provision (lignocellulose feedstock and seed oils) and feedstock conversion and use (biochemical and thermochemical pathways as well as add-ons). In general, the results of the SWOT analysis are limited due to knowledge gaps especially regarding the advanced technology options and the add-on technologies. However, it was clearly shown that immaturity itself is a main threat since there is always the risk of a failure in development. In particular, success of SUPRABIO concepts in the area of feedstock provision is definitely dependent on whether a sustainable feedstock provision can be guaranteed. For feedstock conversion and use the success of SUPRABIO concepts is especially tied to the further development of immature technologies such as the SScF (**s**imultaneous **s**accharification and **c**o-**f**ermentation) technology that enables an uncomplicated usage of this technology also at industrial scale.

In addition, the sustainable **biomass potential** and the **competition** between different uses of the same type of biomass were investigated in this report in order to depict the numbers of biorefineries that could be fed in specific regions. For the analysis of biomass potentials within SUPRABIO and its degree of competition, a literature review was conducted, which considered the output relevant studies in this area. The analysis of biomass potential studies has shown that the availability of land and biomass is limited, i.e. that various land and biomass uses are competing with each other. It could be shown that the European biomass potential is significantly lower than the energy demand in the EU. Europe will therefore be dependent on the import of biomass, especially from tropical countries. This immediately raises questions in terms of security of supply and sustainability. Furthermore, competition about biomass or land use between bio-based materials, chemicals, fuels and energy, as well as foodstuffs, fodder and nature conservation will increase. New technologies such as 2nd generation biorefineries will further enhance the demand for biomass. Thus, it is recommended that national and European

biomass allocation and land use plans should be compiled in a participatory manner to reduce competition and guarantee a sustainable provision. Furthermore, regional planning should then also be based on this premise. In addition, binding area- and cultivation-specific sustainability criteria should be uniformly defined as preventive measures for all types of applications (e.g. bio-based materials, feed, food, etc.).

1 Introduction

SUPRABIO is a collaborative research project funded by the European Commission, through the project no 241640. The project researches, develops and demonstrates a toolkit of novel generic processes that can be applied to a range of biorefinery concepts. The project concentrates on critical unit operations that are at present limited by their economic feasibility and on currently the most economic feedstocks such as lignocellulose from sustainable forestry or agricultural residues. SUPRABIO focuses on the process optimisation of material and waste flows within the biorefinery, water management and process energy requirements. The aim is to couple optimum economic benefit to optimum usage of biogenic carbon and minimal greenhouse gas (GHG) emissions.

The project is split into nine work packages (WPs). The work packages mainly focus on different research areas within the SUPRABIO project regarding feedstock provision and conversion. WP 7 provides a multi-criteria evaluation of the sustainability of the entire value chain of SUPRABIO concepts by taking into account technological, environmental, economic, social, political and legal aspects.

The present report is the outcome of task 7.7 “SWOT analysis, biomass potentials and competition” as part of WP 7 “Sustainability: Environmental, Economic, Social, Technical, Market and Geographical Aspects” of the SUPRABIO project. Task 7.7 has two objectives (sub-tasks): The first objective of task 7.7 is to analyse the key internal and external factors that will determine the success of the SUPRABIO biorefinery concept. To do this, an analysis on strengths, weaknesses, opportunities, and threats (SWOT) was performed for the investigated pathways. The second objective of task 7.7 is to investigate the sustainable biomass potential and the competition between different uses of the same type of biomass, e.g. the competition for straw between biorefineries and conventional bioenergy pathways. In the light of this competition, biomass availability for SUPRABIO refineries was analysed in order to depict possible sites for biorefineries .

The structure of this report follows the structure of task 7.7: The report is divided into two parts: The SWOT analysis is addressed in chapter 2 and biomass potential in chapter 3. Detailed SWOT tables for the assessed SUPRABIO pathways are documented in the Annex (chapter 4).

2 SWOT analysis

The following sub-chapters describe the methodology of a SWOT analysis (sub-chapter 2.1) and the results of the SWOT analyses for feedstock provision (sub-chapter 2.2) and feedstock conversion and use (sub-chapter 2.3). Finally, some conclusions and recommendations are given (sub-chapter 2.4).

2.1 Methodology

First, in this sub-chapter the methodology of a SWOT analysis is described generally (sub-chapter 2.1.1) and then assigned to the SUPRABIO concept (sub-chapter 2.1.2). Afterwards, the structure of the SWOT analysis in SUPRABIO is described (sub-chapter 2.1.3).

2.1.1 Introduction to SWOT analysis

A SWOT analysis is a tool to assess the performance of a project, a product or a company. It originates from business management and it is a strategic planning tool to identify and assess the strengths (S), weaknesses (W), opportunities (O) and threats (T) of the surveyed product, project or corporation. Strengths and weaknesses are defined as internal characteristics of the evaluated system, while opportunities and threats are external factors determining the success or failure. The results of a SWOT analysis are generally summarized in a so-called SWOT matrix. The general structure of a SWOT matrix is shown in Fig. 2-1.

	Success factors	Failure factors
Internal	Strengths	Weaknesses
External	Opportunities	Threats

Fig. 2-1 Structure of a SWOT matrix

SWOT analysis is increasingly used to describe the advantages and disadvantages of technologies and policies, including biorefinery concepts. An example of a SWOT analysis regarding biorefineries in general is presented in Fig 2-2 /IEA 2012/ (see also /BMBF & BMELV 2012/, /Annevelink et al. 2012/).

In the SUPRABIO project, a SWOT analysis is used to describe the strengths, weaknesses, opportunities and threats of the SUPRABIO biorefining concepts.

2.1.2 Methodological approach for SWOT analysis in SUPRABIO

Goal and scope

The SWOT analysis in SUPRABIO is part of an overall sustainability assessment including a technological (task 7.1), an environmental (tasks 7.2 and 7.3), an economic (tasks 7.4 and 7.5) and a social and political assessment (task 7.6).

The objective of the SWOT analysis is to describe success and failure factors for SUPRABIO biorefining systems by catching up those factors of tasks 7.1 – 7.6 that have not been covered in the other tasks so far.

SWOT analysis forms a basis for the integrated assessment of sustainability in task 7.8. The final report considered the Sustainability SWOT approach developed by /Pesonen & Horn 2012/.

Data basis

The assessment relies on the available SUPRABIO deliverables and reports, IUS expert knowledge, partner contributions and literature.

Strengths	Weaknesses
• Adding value to the use of biomass • Maximising biomass conversion efficiency minimising raw material requirements • Production of a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power and/or heat) feeding entire bioeconomy • Strong knowledge infrastructure available to tackle technical and non-technical issues • Biorefinery is not new, it builds on agriculture, food and forestry industries • Stronger focus on drop-in chemicals facilitating market penetration	• Broad undefined and unclassified area • Involvement of stakeholders for different market sectors (agriculture, forestry, energy, chemical) over full biomass value chain necessary • Most promising biorefinery processes/concepts not clear • Most promising biomass value chains, including current/future market volumes/prices, not clear • Studying and concept development instead of real market implementation • Variability of quality and energy density of biomass
Opportunities	**Threats**
• Biorefineries can make a significant contribution to sustainable development • Challenging national and global policy goals, international focus on sustainable use of biomass for the production of bioenergy • International consensus on the fact that biomass availability is limited meaning that raw materials should be used as efficiently as possible – i.e. development of multi-purpose biorefineries in a framework of scarce raw materials and energy • International development of a portfolio of biorefinery concepts, including technical processes • Strengthening of the economic position of various market sectors (e.g. agriculture, forestry, chemical and energy) • Strong demand from brand owners for biobased chemicals	• Economic change and volatility in fossil fuel prices • Fast implementation of other renewable energy technologies feeding the market requests • Bio-based products and bioenergy are assessed to a higher standard than traditional products (no level playing field) • Availability and contractibility of raw materials (e.g. climate change, policies, logistics) • (High) investment capital for pilot and demo initiatives difficult to find, and undepreciated existing industrial infrastructure • Changing governmental policies • Questioning of food/feed/fuels (indirect land use competition) and sustainability of biomass production • Goals of end users often focused on single product

Fig 2-2 SWOT analysis on biorefineries in general. Source: /IEA 2012/

System boundaries: How to distinguish between internal and external factors

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

In the SWOT analyses for SUPRABIO, internal and external factors will be distinguished as follows:

- **Internal:** Inherent properties of SUPRABIO technologies and the performance under approved or most likely environmental, economic, political and legal circumstances.
- **External:** All aspects, which relate to
  - success/failure in development of immature technologies.
  - performance of SUPRABIO biorefineries under possibly other environmental, economic, political and legal circumstances.

2.1.3 Structure of SWOT analysis in SUPRABIO

The SWOT analysis in this report consists of two parts:

- SWOT analysis on feedstock provision
- SWOT analysis on feedstock conversion and use

Depending on the type of processing either lignocellulosic materials or seed oils are used for **feedstock provision** in SUPRABIO. The main lignocellulosic feedstocks are wheat straw and wood residues. In addition, also poplar wood from short rotation coppice (SRC) is analysed. Furthermore, seed oils are needed that are either imported (palm oil, Jatropha oil, soy oil) or domestically grown (rape seed oil).

SWOT matrices for the different types of feedstock used in SUPRABIO are presented in sub-chapter 2.2 and in the Annex, sub-chapter 4.1.

For **feedstock conversion and use** within SUPRABIO a set of different biorefinery concepts was analysed. The focus of the analyses was laid on the biochemical and thermochemical processing of lignocellulose to fuels. In addition, several advanced technology options (e.g. lignocellulose to mixed acids) as well as “add-ons” (e.g. hydrogenation of seed oils) that can be attached to the biorefinery were assessed. All these concepts were described in task 7.1 /Rettenmaier et al. 2011/. However, in the course of this project, some updates were necessary especially regarding the biorefinery pathways. Thus, in the following sections, conceptual changes of the pathways are described that are important for the final SWOT analysis.

Biochemical route

SUPRABIO covers a broad variety of different biochemical configurations that are only partially considered in the final SWOT analysis. Compared to /Rettenmaier et al. 2011/ and the interim SWOT report /Kretschmer et al. 2012/, some pathways were not assessed:

- Due to negative results of an initial evaluation, it was decided to change focus from **butanol to MEK** (methyl ethyl ketone) production. However, even though research on MEK production has already started, this route was not included in the final SWOT analysis, since final results have not been available until the completion of this report.
- **Chiral components**: A process concept was proposed for the production of sugar fatty acids but has not been successfully tested experimentally, so far. Furthermore, the process required a pure sugar feed, and it is uncertain whether it is a good solution to couple it with the present SUPRABIO concept. Thus, since there has been no detailed process description for this concept so far, a final SWOT analysis was not conducted.
- **High value lignin products**: The proposed procedures to extract lignin from biomass are still analytical procedures and are currently not suitable for large-scale

production of lignin products. Thus, this pathway was also not considered in the final SWOT analysis.

Due to technical restrictions, the product definition of the straw to acids pathway needed to be adapted compared to /Rettenmaier et al. 2011/ and /Kretschmer et al. 2012/:

- The products from the process are now a **mixture of organic acids**, including a substantial amount of water and not the pure products of propionic and butyric acids.

Thus, in total five different pathways were assessed in this analysis (see also Fig. 2-3):

I. Straw to Ethanol (2015) – Early implementation

II. Straw to Ethanol (2025) – Mature technology configuration

III. Poplar to Ethanol (2025) – Mature technology configuration

IV. Straw to Mixed acids (2025) – Mature technology configuration

The feedstock is either wheat straw or poplar from short rotation coppice (SRC). Generally, the final product is ethanol. In addition, mixed acids are also assessed as final products.

Scenario IV (production of mixed acids) was originally meant to be integrated with the fuel producing main processes. However, limited integration possibilities between the processes have been revealed. The processes are therefore evaluated as stand-alone processes from feedstock to final product.

Scenarios I (basic configuration) and the scenarios II to IV (mature configuration) vary with respect to several parameters describing the maturity level of the technology:

- The time frame for the **basic configuration** was set to 2015. A plant that can process 40 kt biomass (dry matter) per year is assessed. The input material is straw only. Ethanol is the only final product. Hydrolysis and fermentation processes are performed separately (SHF).
- The **mature configuration** is assessed for the time frame 2025. It is expected that until then the processes can be run at full industrial scale. A typical plant can process 400 kt dry biomass per year. Straw and poplar are used as feedstock. Instead of ethanol also mixed acids could be produced. In the case of ethanol, hydrolysis and fermentation are performed simultaneously (SScF).

Since there are only small differences, however, regarding SWOT arguments between the early implementation and the mature technology, there are no extra matrices for each scenario. However, if there are arguments regarding the one or the other maturity level necessary to mention, they are specially labelled in the matrix for the biochemical route.

Regarding the treatment of the solid waste streams, scenarios are divided into the following sub-scenarios:

Sub-scenario 1-A:	Sub-scenario 1-B:	
• Solids anaerobic digestion • Staged gasification • Gas turbine • Steam cycle	• Solids anaerobic digestion • Staged gasification • Gas engine • Steam cycle	
Sub-scenario 2-A:	**Sub-scenario 2-B:**	**Sub-scenario 2-C:**
• No solids anaerobic digestion • Staged gasification • Gas turbine • Steam cycle	• No solids anaerobic digestion • Staged gasification • Gas engine • Steam cycle	• No solids anaerobic digestion • Boiler • Steam cycle

However, since there are only small differences regarding SWOT arguments between these sub-scenarios, there are no extra matrices for each scenario. In case there are arguments regarding either of the two sub-scenarios, it is specially labelled in the matrix for the biochemical route.

Thus, in summary, there are two SWOT matrices for the biochemical route: one for ethanol production (see Table 2-9 and Table 4-4 in the Annex) and one for the alternative product mixed acids (Table 2-10 and Table 4-5 in the Annex). In the SWOT matrix for mixed acids, however, only those arguments are listed that are supplementary to those of the main product. For an overview on the feedstock used in the biochemical route see Table 2-1.

The biochemical conversion pathways (except scenario V) include the following life cycle steps (see also Fig. 2-3):

- Feedstock provision (straw, poplar)
- Pre-treatment and solid-liquid separation
- Enzymatic hydrolysis
- Fermentation
- Distillation / product separation
- Use of final product

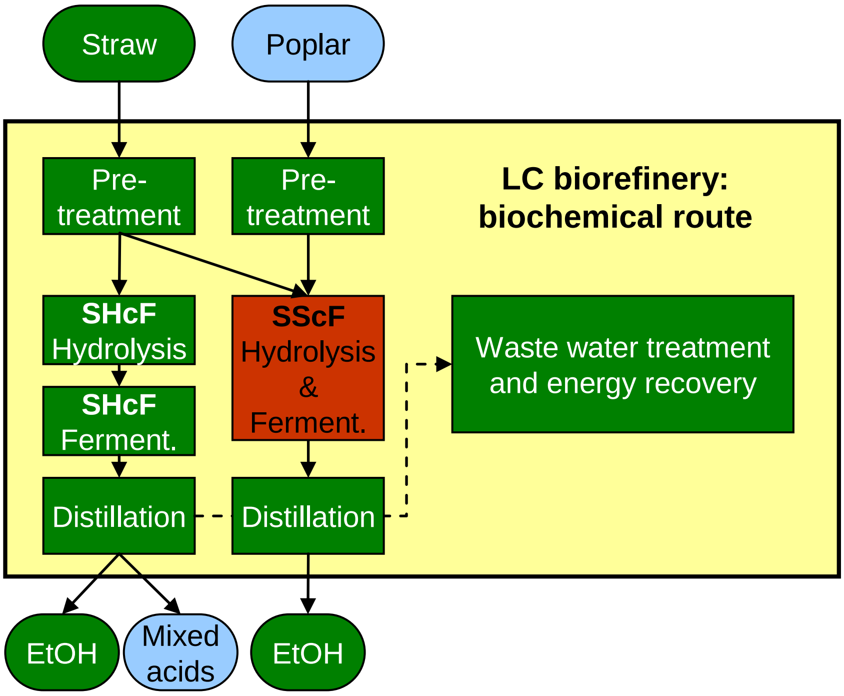

Fig. 2-3 **Biochemical SUPRABIO pathways. Green: Standard scenario, basic configurations. Red: Standard scenario, mature configuration. Blue: Alternative scenarios for feedstock and final product (mature configuration only)**

Thermochemical route

SUPRABIO covers a broad variety of different thermochemical configurations. However, in the course of this project several updates were necessary especially regarding the investigated pathways. Thus, slightly deviating from /Rettenmaier et al. 2011/ and /Kretschmer et al. 2012/, the following pathways were assessed in the final SWOT analysis.

I. Forest residues to Fischer Tropsch (FT) liquids (2015) – Early implementation
II. Forest residues to FT liquids (2025) – Mature configuration
III. Forest residues to Dimethyl ether (DME) (2025) – Mature configuration
IV. Straw to FT liquids (2025) – Mature configuration
V. Poplar to FT liquids (2025) – Mature configuration

Primarily, the used feedstocks are wood residues, and the final product is FT diesel. Straw and poplar from SRC are analysed as alternative feedstocks, and DME is analysed as an alternative synthesis product.

Scenarios I (basic configuration) and the scenarios II to V (mature configuration) vary with respect to several parameters determining the maturity level of the technology:

- The **basic configuration** is assessed for the time frame 2015. A typical early implementation plant processes 40 kt biomass (dry matter) per year in the pyrolysis step and an equivalent of 200 kt dry biomass per year in the gasification process.

Thus, five distributed pyrolysis units are feeding one centralised gasification unit. The input materials are wood residues. FT diesel is the only final product.

- The **mature configuration** is settled in the year 2025. It is expected that until then the processes can be run at full industrial scale. The plant can process 80 kt biomass (dry matter) per year in the pyrolysis step and an equivalent of 400 kt dry biomass per year in the gasification process. Straw, wood residues and poplar are used as feedstock. Besides FT diesel also DME is produced.

Since there are only small differences regarding SWOT arguments between the early implementation and the mature technology, there are no extra matrices for each scenario. However, if there are arguments regarding either of the two maturity levels necessary to mention, they are specially labelled in the matrix for the thermochemical route.

In addition, four other scenarios have been defined in the course of SUPRABIO in order to study the effect of different process parameters and configurations:

VI. Forest residues to FT liquids (2025) – Natural Gas – Mature configuration

VII. Forest residues to FT liquids (2025) – Centralised – Mature configuration

VIII. Forest residues to FT liquids (2025) – High pressure – Mature configuration

IX. Forest residues to FT liquids (2025) – High pressure and quenching temperature – Mature configuration

However, since there are no great differences regarding SWOT arguments between scenarios VI to IX and scenario II, there are no extra matrices for each of those scenarios. If there are arguments regarding one of these scenarios necessary to mention, they are specially labelled in the matrix for the thermochemical route.

Thus, in summary, there are two SWOT matrices for the thermochemical route: one for FT diesel production (see Table 2-11 and Table 4-6 in the Annex) and one for the alternative product DME (see Table 2-12 and Table 4-7 in the Annex). In the SWOT matrix for DME, however, only those arguments are listed that are supplementary to those of the main product. For an overview on feedstocks used in the thermochemical route see Table 2-1.

The assessed routes for the thermochemical conversion are shown in Fig. 2-4. The thermochemical conversion pathways include the following life cycle steps:

- Feedstock provision
- Pyrolysis (decentralised)
- Gasification (centralised)
- Use of final product

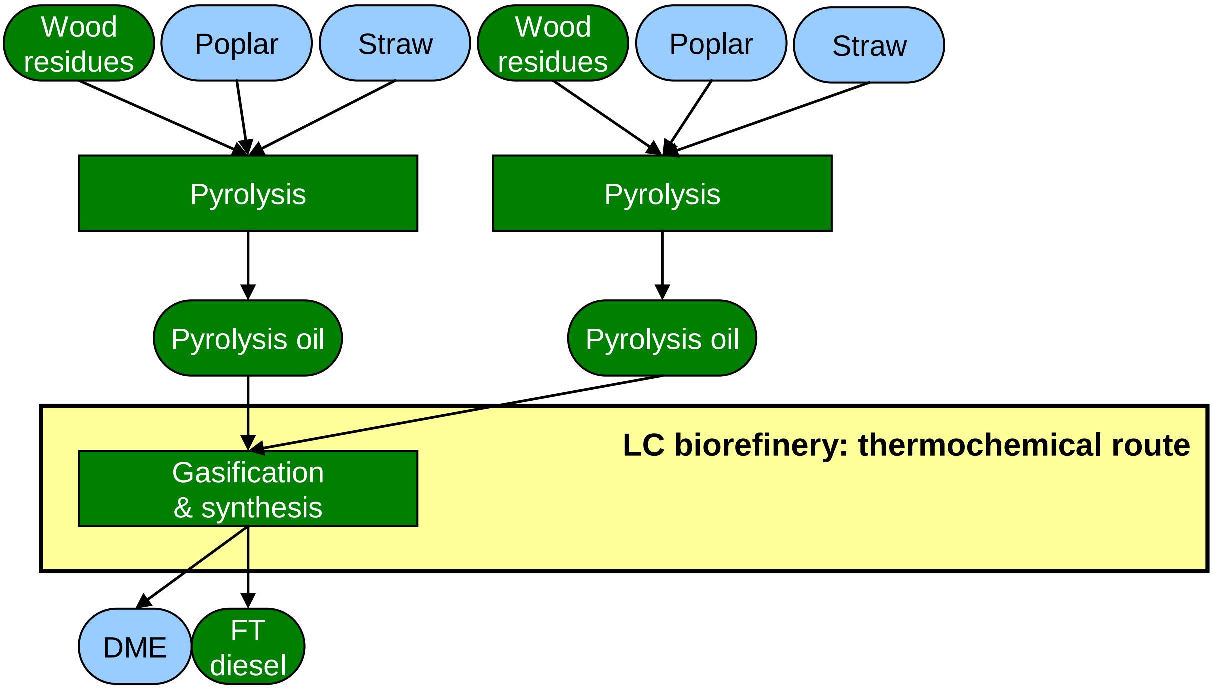

Fig. 2-4 **Thermochemical SUPRABIO pathways. Green: Standard scenario. Blue: Alternative scenarios**

Add-on technologies

In addition, the SUPRABIO project includes the assessment of the two add-on technologies algae production and fatty acid hydrogenation. The latter could be run on seed oils or on VFAs extracted from municipal waste. However, both the "algae" and the "waste to fuel" add-on concepts were never fully defined within the project and therefore could not be integrated within the two biorefinery concepts. The "seed oil to fuel" concept is established. Unfortunately, no techno-economic assessment was conducted for the process integration of all add-ons. In case of the "seed oil to fuel" concept this was mainly due to a delayed provision of detailed process information from the project partners. Therefore, a process integration, as formerly planned, was also not covered in the final SWOT analysis, thus, all add-ons were assessed as stand-alone technologies. In case of VFA extraction and hydrogenation there is evidence that from an energy point of view the process is not viable. Thus, this concept was not considered in the final SWOT analysis.

In conclusion, Fig. 2-5 shows the assessed add-on technologies of the final SWOT analysis.

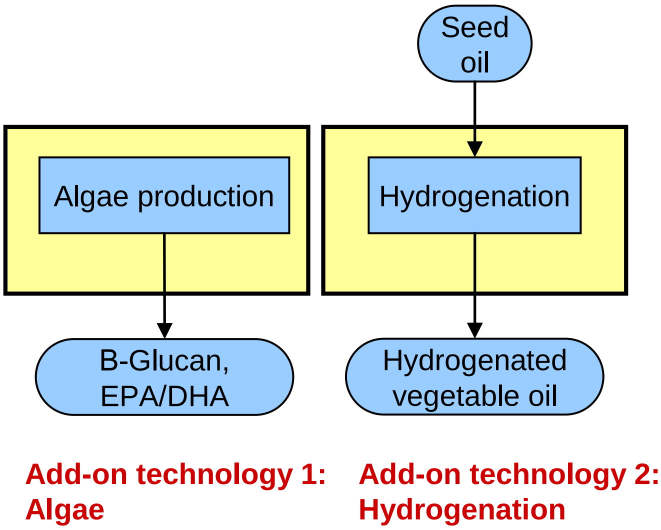

Fig. 2-5 **Overview on the assessed add-on technologies**

In summary, there are two SWOT matrices for the add-on technologies: one for algae production (Table 4-8) and one for seed oil hydrogenation (Table 4-9). For an overview which feedstock is used in which add-on technology see Table 2-1.

Table 2-1 **Overview on the feedstocks in the assessed routes and add-on technologies. Main scenarios in bold**

	Biochemical route		Thermochemical route		Add-ons
Lignocellulose feed-stock	Ethanol	Mixed ac-ids	FT Diesel	DME	Hydrogenation
Straw	**X**	X	X	X	
Wood residues			**X**	X	
Poplar (SRC)	X	X	X	X	
Seed oils					
Rapeseed (domestically grown)					X
Oil palm (imported)					X
Jatropha (imported)					X
Soy (imported)					X

2.2 SWOT analysis on feedstock provision

This section describes the results of the SWOT analysis regarding the provision of the feedstocks. A distinction is made between lignocellulosic feedstocks (sub-chapter 2.2.1) and seed oil provision (sub-chapter 2.2.2).

2.2.1 Lignocellulose feedstocks

In this sub-chapter the results of the SWOT analysis regarding the provision of lignocellulose feedstock are described. Lignocellulosic feedstock is needed for the biochemical and thermochemical routes of SUPRABIO biorefinery concepts. For an overview on feedstocks used in each route see Table 2-1.

Wheat straw

For the provision of wheat straw as feedstock the following SWOT arguments could be identified:

Straw is a residue of grain production and is therefore considered as a particularly sustainable feedstock. It can be gained without additional land use and, in contrast to other biomasses, its cultivation is not threatening food production. In addition, straw is comparable cheap since, so far, it has been mostly left on the field; thus, selling the straw to biorefineries might be a viable source of additional income for the farmers.

In contrast, if there is a new market for straw, traditional use options such as for animal bedding or forage production may be displaced. Furthermore, since bailed straw has only a low bulk density, transportation costs for straw might be higher than for the other investigated feedstocks. Another difficulty is that straw is only harvested once a year. Thus, large storage facilities are needed to enable a year-round processing. Moreover, straw yields are highly dependent on grain production patterns and used grain varieties. If there is any change in grain production, straw yields might also be affected.

Table 2-2 Most important SWOT factors regarding wheat straw provision

	Success factors	Failure factors
Internal factors	**Strengths** • Straw is an agricultural by-product → No additional land use • No direct competition to food production • Cheap biomass for biorefineries because of low competition (residues) • Farmers have an additional income since the straw is converted in a high value product	**Weaknesses** • Competition with traditional uses (bedding, material, forage, fertiliser) • Balled straw has only a low density → costly logistics • Straw is harvested only once a year → long storage, large stocking facilities • Straw availability depends on grain harvest → can hardly be influenced by biorefineries • Soil organic content decreases if high amounts of straw are harvested regularly
External factors	**Opportunities** • Long stem varieties could be used by the farmer	**Threats** • Soil fertility (soil biodiversity and soil carbon content) may be harmed if straw is extracted from fields excessively → may increase the erosion risk • Straw extraction from fields means also nutrient removal →need for more mineral fertilisers

Regarding straw extraction, a sustainable straw extraction rate should be pursued since straw residues are a source of soil organic carbon and thus, influence soil fertility. Intact soil fertility is important, since it is needed to sustain the filter and buffer functions of the soil and stabilises the soil structure. This leads to a lower risk of soil erosion and nutrient losses that, in turn, might decrease the input of mineral fertilisers (less costs and environmental burdens).

Straw harvest per hectare could be again increased if farmers return to long stem varieties.

Table 2-2 shows the most relevant SWOT arguments regarding wheat straw provision that are described above. For more detailed SWOT factors see Annex, Table 4-1.

Wood residues

For the provision of wood residues as feedstock the following SWOT arguments could be identified:

Wood residues are considered as a sustainable feedstock, at least if the wood is removed from forests with a sustainable management and if the wood is not taken away from other more sustainable use options (e.g. for construction or furniture).

A sustainable management of forests is particularly important since forests fulfil more ecosystem services compared to other types of land use. However, in case of an increase in wood demand due to a use of wood residues in biorefineries, forest management could be intensified, leading to a higher risk for environmental sustainability.

Furthermore, selling wood residues to biorefineries constitute a new market and income opportunity for the forest industry. However, if there is a new market for wood, other use options (direct use for energy, direct material use) may be displaced. A shift in the use pattern of wood residues might have undesirable effects such as rising wood prices that might affect other users economically and might prevent a more sustainable use of the wood (e.g. as building material). To avoid the risk of a use displacement a cascading use of wood including one or several direct material use phases followed by a biorefining of secondary wood residues is considered a recommendable option /Gärtner et al. 2013/.

A difficulty for the use of wood residues in Europe might be the ownership structures (many small scale forest owners) that may constitute a barrier for wood mobilisation.

Before wood residues can be used in the biorefinery, the wood needs to be chipped. Chipping the wood, on the one hand, leads to saw dust that can be pelletized and used as a by-product constituting an additional income opportunity. On the other hand, chipping the wood into small pieces which increases the energy demand and thus, the expenses compared to the use of e.g. wheat straw. Another difficulty might be that after chipping or pelletizing, it is difficult or impossible to distinguish between stem wood and wood residues. Thus, there is a high risk of mixing-up both types of wood. A certification system should therefore be established to make an explicit distinction between wood residues and stem wood possible.

Compared to straw, wood residues require no additional input of fertilisers, pesticides or water, thus, less expenses are necessary. Furthermore, the use of wood residues does not threaten food production compared to other biomasses such as maize or rape. In contrast, however, yields per hectare are lower for wood residues than for the other investigated feedstocks such as straw or poplar wood, i.e. a larger area is affected by feedstock provision.

Most relevant SWOT arguments regarding wood residue provision, as described before, are presented in Table 2-3, for more detailed SWOT factors see Annex, Table 4-2.

Table 2-3 Most important SWOT factors regarding wood residue provision

	Success factors	Failure factors
Internal factors	**Strengths** • Income opportunity for the forestry sector • No direct competition to food production • Low external inputs needed for forest trees • Many ecosystem services are provided by forests	**Weaknesses** • Low yields per hectare of forest trees compared to straw and SRC poplar • High competition: - direct energetic use - direct material use • Forest ownership structure in Europe hinders wood mobilisation for centralised processing (many private owners of small forests; village want to become energy independent) • Chipping into small pieces could be energy demanding
External factors	**Opportunities** • Saw dust can be pelletized and used as by-product • Cascading use of wood residues could increase availability of woody biomass	**Threats** • A more sustainable use could be prevented • An increased demand could be an incentive for unsustainable forest management practices • Risk of mixing-up stem wood and residues after chipping→ certification system necessary

Poplar wood (SRC)

For the provision of poplar wood as feedstock the following SWOT arguments could be identified:

Poplar wood is considered as an interesting option to increase biomass availability for biorefineries, because SRC plantations achieve high biomass yields combined with low environmental harms. In addition, selling the poplar wood to biorefineries may be a viable source of additional income for farmers. However, so far, only knowledge about SRC cultivation is low amongst farmers, thus, the opportunity to cultivate poplar wood as an energy crop is only rarely used. Furthermore, since some time is needed until poplar wood from SRC plantations can be harvested, SRC plantations bind the farmer for many years. Thus, long term contracts are needed to make the decision for SRCs reasonable to farmers since otherwise, the economic risk is too high, in case the purchasing party might lose the interest in poplar from SRC plantations as feedstock.

Compared to straw, harvest failures are much less likely as soon as the plantations are established. Thus, from a biorefinery operator point of view, SRC wood is highly attractive, since long term contracts are possible. In addition, a higher availability of poplar wood, allows planning larger conversion plant capacities and, thus, increasing conversion efficiency.

Compared to wood residues, poplar wood is more expensive since it needs dedicated cultivation. Nevertheless, as for the wood residues, it also needs to be pre-treated (chipped) before used in a biorefinery, thus, an additional energy demand compared to straw is required.

Environmental impacts are lower for poplar wood plantations than for annual crops, mainly due to less erosion effects, fertiliser inputs and pesticide input. Furthermore, compared to straw (wheat for food and feed production!), poplar wood production is more suitable for cultivation on marginal lands or even on industrially-polluted waste lands not suitable for food or feed production. However, it has to be kept in mind that poplar wood from industrially-polluted waste lands might bring undesirable contaminants into the sensitive processes of a biorefinery. In those cases, poplar wood from polluted waste lands might rather be used for direct combustion (combined with advanced filter technology).

Table 2-4 Most important SWOT factors regarding poplar wood (SRC) provision

	Success factors	**Failure factors**
Internal factors	**Strengths** • Increased feedstock availability by using SRC poplar and low risks for shortcoming • Income opportunity for forestry sector / farmers • Low input crop	**Weaknesses** • Little knowledge on SRC cultivation and its market opportunities amongst farmers • Bind farmers for many years • Probably higher price for cultivated feedstock compared to use of residues • Extra handling of biomass prior to pre-treatment may be needed → could be energy demanding • Cultivated biomass → direct and indirect land use change effects possible → risk of negative environmental and social effects • Biochemical route: results only modelled for batch processes
External factors	**Opportunities** • SRCs can be established on industrial waste or other marginal lands • Long term contracts can have positive effects for both, farmers and processors • Higher availability allows bigger plant capacities and hence a more efficient conversion • Environmental impacts are lower compared to most annual crops (positive impacts on soil, water resources and biodiversity)	**Threats** • Economic risk for farmers if another crop is preferred by the industry • Competition with other biomass crops and for land with food production

Another risk is that a SRC plantation is established on grasslands or croplands which are needed for food or feed production. This can lead to direct (in the case of grassland) or indirect land use change effects (in the case of cropland) and may have negative environmental or social consequences.

An important difficulty is that for the biochemical route, results for poplar as feedstock is only modelled for batch processes, thus there is still a great risk that this feedstock is not suitable for the biochemical route of the SUPRABIO biorefinery concept.

The most important SWOT arguments regarding poplar provision, as described before, are presented in Table 2-4. For more detailed SWOT factors see Annex, Table 4-3.

2.2.2 Seed oils

In SUPRABIO, it was contemplated to integrate several add-on concepts in the biorefinery. One of these add-ons is the hydrogenation of seed oils from several feedstocks such as rapeseed, Jatropha, oil palm or soy.

In the following sections, the results of the SWOT analysis regarding the provision of seed oils are described.

Rape seed oil

For the provision of rape seed oil as feedstock the following SWOT arguments could be identified (Table 2-5):

Table 2-5 SWOT factors regarding rape seed oil provision

	Success factors	Failure factors
Internal factors	**Strengths** • Short transportation distance • High expertise regarding cultivation and breeding • Valuable by-products (honey, rape seed cake as feed)	**Weaknesses** • Direct competition to food production • Additional land use • Rape seeds can be harvested only once a year • High fertiliser and plant protection product demand • Low yield per hectare compared to other seed oil crops
External factors	**Opportunities**	**Threats** • Additional land use might lead to indirect land use changes, in worst case to deforestations • High competition with other seed oils → insecure prices

One of the key cultivation areas of rape is Europe, thus, the transportation distance is usually shorter than for the other imported seed oils which causes fewer transportation costs and environmental burdens. Moreover, rape has a long breeding history, since former varieties were not suitable for consumption due to a bitter taste caused by high levels of glucosinolates. Even though rape has a short history as a food crop, cultivation experiences, however, are much higher than for newly developed dedicated energy crops. An issue of rape cultivation is that compared to other oil crops the yield per hectare is relatively low and the demand of fertilisers and plant protection products (pesticides) is comparatively high.

During rape seed cultivation and conversion several by-products occur such as rape seed cakes or rape honey that constitute additional income opportunities.

However, another issue of rape seed oil cultivation for bioenergy is the direct competition between food and fuel production. If plants dedicated for bioenergy are cultivated on the area that normally is used for food production, additional land is needed to further guarantee food security. This can lead to indirect land use changes. In addition, it is possible that the cultivation of rape by itself also leads to direct land use changes.

Since there are several seed oils available on the market, competition is high, thus, prices for rape seed oil might be insecure. Another difficulty is that compared to e.g. wood residues rape is harvested only once a year. Thus, either large storage facilities are needed or biorefineries are subject to strong price fluctuations if they want to enable a year-round processing.

Palm oil

For the provision of palm oil as feedstock the following SWOT arguments could be identified (Table 2-6):

Table 2-6 SWOT factors regarding palm oil provision

	Success factors	Failure factors
Internal factors	**Strengths** • Palm kernel cake can be used as feed • Long cultivation experience • At maturity the oil palm plantation provides income all over the year for the farmer • Year round harvest • High yield per hectare	**Weaknesses** • Bind farmers for many years • Direct competition to food production • Additional land use • Long transport distances → expensive, environmental burdens
External factors	**Opportunities** • Income opportunities	**Threats** • Encroachment of plantations on traditional cultivation land or on woodland • Often cultivated in countries with low environmental standards → high risk of deforestation and biodiversity loss • Often cultivated on peat soil → high CO_2 release • High competition → insecure prices • High risk of social conflicts due to banishment of local population

Oil palm plantations which are mainly established in tropical countries reach their maximum productivity only after 8-10 years, thus, an oil palm plantation bind farmers for many years. However, at a maturity stage of an oil palm plantation, farmers can harvest palm fruits all over the year. Thus, the income for the farmer is not dependent on the season and the feedstock can be provided the whole year round to the biorefinery. In addition, for oil palm plantations a much higher yield per hectare can be observed compared to e.g. rape. Furthermore, palm kernel cakes that occur during the conversion process can be used as feed and thus, constitute an additional income opportunity. Since oil palm plantations are often established in countries with less jobs, a higher demand for palm oil may lead to new jobs and thus, also to higher income opportunities. However, it needs to be kept in mind that the employment intensity per hectare in the palm oil sector is not as high as for other crop plants. If oil palm plantations replace plantations with higher employment intensity, the job balance is negative. If oil palm plantations replace natural ecosystems, the biodiversity and carbon balance is negative.

The key growing area of palms is not Europe; hence, longer transportation distances need to be covered. This causes higher costs and additional environmental burdens. Since palm oil can also be used as food, there is a direct competition between fuel and food production. If plants dedicated for bioenergy are cultivated on areas that are normally used for food production, additional land is needed to further guarantee food security. This can lead to indirect land use changes if the additional area is acquired e.g. by deforestation. The risk of direct or indirect land use changes is especially high in countries with less environmental standards compared to Europe as it is the case for palm oil producing countries such as Indonesia. A deforestation of rainforests also leads to a decrease in biodiversity since those ecosystems are considered as biodiversity hot spots. In Indonesia, the carbon impact of deforestation is particularly high because of large peat soil areas. If oil palm plantations are established on these soils a high amount of CO_2 is released from the soil, additionally contributing to global warming.

In addition, the set-up of new oil palm plantations in regions with population using land informally and traditionally might lead to a displacement of this local population and hence increases the risk of social conflicts.

Since there are several seed oils available on the market, competition is high, thus, prices might be insecure.

Soy oil

For the provision of soy oil as feedstock the following SWOT arguments could be identified (Table 2-7):

Table 2-7 SWOT factors regarding soy oil provision

	Success factors	Failure factors
Internal factors	**Strengths** • Soy cake can be used as high quality feed due to a high amount of essential amino acids • Long cultivation experience • High expertise regarding cultivation and breeding • Legume: symbiotic nitrogen fixation → less mineral fertiliser demand	**Weaknesses** • Direct competition to food production • Additional land use • Long transport distances → expensive, environmental burdens • Harvest only once a year • Low yields per hectare compared to palm oil
External factors	**Opportunities** • High demand for soy cakes	**Threats** • Encroachment of plantations on traditional cultivation land or on woodland • High competition → insecure prices • High risk of LUC especially in Southern America

Soy has been generally used as a food crop, thus, there is a huge expertise regarding cultivation practices and breeding in comparison with newly developed dedicated energy crops. Furthermore, soy is a legume that is characterised by a symbiosis with nitrogen fixating bacteria. Thus, compared to non-symbiotic seed oil crops, less mineral fertiliser is needed for the cultivation of soy. An issue of soy oil production is that in comparison e.g. to palm oil, yields per hectare are relatively low. Another difficulty is that soy is only harvested once a year, even though the time of harvest might differ between cultivation areas. Thus, either large storage facilities are needed or biorefineries are subject to strong price fluctuations if they want to enable a year round processing.

Soy oil cakes occur during the conversion process and are characterised by a high nutritional value since they contain a high amount of essential amino acids. Thus, soy bean cakes constitute the main source of income, especially since the demand for protein feed is high and rising.

However, due to the fact that soy oil can also be used as food, there is a direct competition between fuel and food production. If plants dedicated for bioenergy are cultivated on areas that normally are used for food production, additional land is needed to further guarantee food security. This can lead to indirect land use changes if the additional area is acquired e.g. by deforestation. In addition, it is also possible that the cultivation of soy by itself leads to direct land use changes.

Another issue is that the key growing area of soy is not Europe, thus, soy is mainly imported. This leads to longer transportation distances that cause higher costs and additional environmental burdens. Furthermore, since there are several seed oils available on the market, competition is high thus, prices for soy oil might be insecure.

Jatropha oil

For the provision of Jatropha oil as feedstock the following SWOT arguments could be identified (Table 2-8):

Since Jatropha can be grown on barren land, it can help to upgrade areas where a profitable agriculture is normally not possible. Thus, Jatropha plantations might provide higher income in those areas. Furthermore, Jatropha can also manage with little water, thus, it can be grown in areas with low precipitation. In addition, growing perennial plants such as Jatropha lowers the erosion risk of soils in comparison to annual plants since the ground is more or less permanently covered. Furthermore, since Jatropha is a dedicated energy crop there is no direct competition to food production, but at the same time only little cultivation experience exists, thus a higher risk of crop failures might occur. However, yield per hectare for Jatropha oil is relatively low in comparison to other oil crops. Another issue is that its maximum productivity is reached only after 5 years, thus, a Jatropha plantation bind farmers for many years.

The key growing area of Jatropha is not Europe, thus, longer transportation distances need to be covered. This causes higher costs and additional environmental burdens. However, Jatropha oil can be harvested the whole year round, thus, large storage facilities are not necessary in contrast to the use of rape seed or soy oil.

Table 2-8 SWOT factors regarding Jatropha oil provision

	Success factors	Failure factors
Internal factors	**Strengths** • Jatropha can be grown on barren land • Can manage with little water • No direct competition to food production • Control erosion and soil improvement • Year round harvest	**Weaknesses** • Bind farmers for many years • Dedicated energy crop • Long transport distances → expensive, environmental burdens • Jatropha cake is toxic • Relatively low cultivation experience • Low yields per hectare compared to palm oil
External factors	**Opportunities** • Income opportunities	**Threats** • Economic risk for farmers if another crop is preferred by the industry • Lacking in safe disposal methods for Jatropha cake • Encroachment of plantations on traditional cultivation land or on woodland • High competition → insecure prices

Another issue is that the Jatropha cake is toxic, thus it cannot be sold as an animal feed as it is the case for the other seed oils. As an alternative, however, the Jatropha cake can be used as a fertiliser.

Since there are several seed oils available on the market, competition is high, thus, prices might be insecure.

2.3 SWOT analysis on feedstock conversion and use

This section describes the results of the final SWOT analysis regarding feedstock conversion and use for the biochemical (sub-chapter 2.3.1) and the thermochemical (sub-chapter 2.3.2) route. The results of the add-on technologies are briefly described in sub-chapter 2.3.3.

2.3.1 Biochemical route

For the ethanol production pathways, a lot of SWOT arguments could be identified. The technologies are available at demo or pilot scale if wheat straw is used as feedstock. No show-stoppers were identified. Nevertheless, there is still a risk of failure in technological development with regard to the performance of this pathway, in particular with regard to the development of a simultaneous saccharification and co-fermentation (SScF) concept /Lervik Mejdell et al. 2014/. However, the SScF technology is less cost intensive compared to the separate hydrolysis and co-fermentation (SHcF) concept since less enzymes are needed.

In addition, the SScF process produces more energy that can be converted into electricity and exported to the grid compared to the SHcF process. Thus, net efficiency of pathways including the mature technology is better than of the early implementation. Furthermore, in total a higher net efficiency is reached for the biochemical pathway than for the thermochemical route /Lervik Mejdell et al. 2014/. However, it needs to keep in mind that a higher net efficiency not necessarily means that the process is also more environmentally friendly.

An important risk for failure lies in the high costs of enzymes. The reduction of enzyme quantities and costs should therefore be a focus of further research. Another risk is that other competing concepts for 2nd generation ethanol production such as the Proesa™ technology by Biochemtex (see http://www.biochemtex.com/proesa) could develop faster. An integrated sustainability assessment for this technology which is applied in a biorefinery in Cresentino, Italy was performed by /Kretschmer et al. 2014/. Furthermore, other transport fuels might gain momentum in future, so that there will not be any further interest in developing the present concept. In Europe for example, market penetration of ethanol might be at risk due to technical blending restrictions or a decreasing demand of gasoline due to a probable shift towards hybrid cars /Lervik Mejdell et al. 2014/.

Table 2-9 Most important SWOT factors regarding biomass processing along the biochemical route (ethanol as product)

	Success factors	Failure factors

Internal factors	**Strengths**
	Pre-treatment
	• Pre-treatment is demonstrated up to demo scale (for wheat straw)
	Production of ethanol
	• Enzymatic hydrolysis is demonstrated up to pilot scale (for wheat straw; basic configuration)
	• Mature technology for fermentation processes (basic configuration)
	• Mature technology for downstream processes
	• SScF (mature configuration)
	  - Compared to SHcF higher electricity export → better net efficiency
	Overall
	• Relatively high net efficiency
	• Based on non-food biomass (residues)
		Weaknesses
		Production of ethanol
		• High costs for enzymes
		• Use of GMOs (low acceptance, high requirements for process management)
		• SScF (mature configuration)
		  - Immature state
		  - Ethanol yield and productivity are unknown → possibly too low
		Wastewater
		• High water consumption; must rely on effective wastewater treatment technology for water recycling
		• Technologies for the gasification of the solids from wastewater treatment are still challenging

External factors	**Opportunities** Production of ethanol • Successful development of simultaneous saccharification and co-fermentation (SScF; mature configuration) → lower enzyme demand → lower OPEX/CAPEX costs	**Threats** Pre-treatment and enzymatic hydrolysis • Failure in efficient pre-treatment of other feedstocks Production of ethanol • Microorganisms cannot be recycled → might lead to additional costs • SScF fermentation unsuccessful (mature configuration) Overall • Competitors may succeed with superior alternative 2nd generation biofuel concepts • Other transportation fuels will gain momentum in the market

A further issue is the use of genetically modified organisms (GMOs) during feedstock conversion, which are associated with unclear safety risks and have a low acceptance in Europe. Due to that, GMOs cause high safety requirements and limited opportunities for use of fermentation residues. The research shall focus on at least non-pathogenic and thermophile organisms which are not likely to cause direct harm to human beings.

Compared to the thermochemical concept, the biochemical route has relatively high water demand which requires lots of efforts in terms of internal wastewater cleaning and recycling. Large biochemical conversion plants should therefore be limited to areas with sufficient water availability. Furthermore, technologies to gasify wastewater solids are still challenging, thus, further research is needed to improve this technology.

Another advantage of the SUPRABIO biochemical route is that it can run on residues, i.e. straw. Technologies that use residues are advantageous compared to technologies using dedicated crops (like e.g. poplar SRC) because of the reduced risk of land use change and biomass competition.

The most important SWOT arguments regarding biomass processing in the biochemical route are presented in Table 2-9. For more detailed SWOT factors see Annex, Table 4-4.

For the production of **mixed acids** SWOT arguments for pre-treatment, hydrolysis and wastewater as well as arguments regarding the overall performance, correspond to those of ethanol production. The process step of mixed acid production, however, is listed separately. Moreover, some additional arguments in the overall section are given that are only related to the overall performance of mixed acid production.

The production of mixed acids still relies on immature technologies with a high risk of failure. The available information about technology details is still very limited.

The advantage of mixed acid production is that they can be used in the feed industry where a higher price compared to fuels is very likely. It is expected that the market potential for mixed acids will further rise in future. Moreover, there is a potential that the fermentation platform can also be used for the production of other products. Since it is a young research field, improvements in breeding new microorganisms are expected. In addition, there is a high probability that new technologies are developed that can help to improve the production of mixed acids from lignocellulose.

An important difficulty is that a precise fermentation outcome is hard to predict due to inhibition effects, thus, the process might turn out to be too cost intensive. Especially, the separation process is very energy demanding and thus, causes high costs and additional environmental burdens.

Since this technology is still not fully demonstrated there is also the risk that other technologies might develop faster.

The most important SWOT arguments regarding the production of mixed acids are presented in Table 2-10. For more detailed SWOT factors see Annex, Table 4-5.

Table 2-10 Most important SWOT factors regarding mixed acid production

	Success factors	Failure factors
Internal factors	**Strengths** Production of mixed acids • Enzymatic hydrolysis is demonstrated up to pilot scale (for wheat straw; basic configuration) Overall • Slightly higher prices for mixed acids than for fuels • Rising market potential	**Weaknesses** Production of mixed acids • High costs for enzymes • Not fully demonstrated technology. Immature processes: bacterial fermentation and acid separation • Low yields because of product inhibition effects • Difficult to predict the precise fermentation outcome • Separation is very energy demanding → expensive, environmental burden
External factors	**Opportunities** Production of mixed acids • The developed fermentation platform can be used for other products (alcohols etc.) Overall • Young research field: Improvements in breeding of microorganisms and technological improvements likely	**Threats** • Failure to further develop immature technologies • Other technologies might develop faster and be more competitive • Eventually too cost intensive

2.3.2 Thermochemical route

For **FT liquid production** in the thermochemical route, many SWOT arguments were identified, mostly regarding technical concerns. The technologies are demonstrated. No show-stoppers were identified. Nevertheless, there is still a risk of failure in technological development regarding the performance of this pathway. That is in particular for the following technologies:

- Pressurised Entrained-flow Biomass Gasification (PEBG gasifier)
- Further development of efficient and robust reactors for synthesis

This failure might either be due to high costs, insuperable technological difficulties or problems while up scaling.

A general advantage of the thermochemical route is the low feedstock-sensitivity allowing the use of different kinds of residues, combined with the possibility to produce a broad variety of products from syngas. Furthermore, the possibility to combine reduced transportation expenditures with an efficient gasification by decentralised pyrolysis and centralised gasification is an important success factor (except for scenario VII). Compared to the biochemical route the production of FT liquids in SUPRABIO proves as a net water producer /Lervik Mejdell et al. 2014/.

Possible failure factors are high costs for sophisticated catalysts and technical risks (high temperatures and pressures, risks of explosions), which cause potentially high costs for safety measures.

Regarding the environmental sustainability of the system, recycling of ashes is an important issue. Further information is needed regarding the suitability of pyrolysis ashes as fertilisers.

Table 2-11 Most important SWOT factors regarding biomass processing along the thermo-chemical route (FT liquids as product)

	Success factors	Failure factors
Internal factors	**Strengths** Pyrolysis: • Fast pyrolysis technology: extra heat available for feedstock drying • Highly flexible towards feedstock: suitable for a large variety of biomass (residue) types Gasification • Demonstrated technology available FT diesel production • Enhanced economy at lower scale compared to conventional FT production Overall • Runs on residues (no direct competition to food) • Two-step-process (pyrolysis & gasification) allows a decentralised processing of biomass and hence lower transportation expenditures Wastewater • Compared to the biochemical route no additional water is needed	**Weaknesses** Gasification and syngas cleaning • PEBG gasifier not yet commercial technology • Steam is needed for syngas cleaning FT diesel production • Potentially low catalyst lifetime due to poisoning or carbon deposition → high catalyst demand, high costs • Micro reactors not yet commercial technology • Exothermic process → difficult temperature control • Large amount of light hydrocarbons and LPG are produced Overall • Low net efficiency compared to the biochemical pathway
External factors	**Opportunities** Gasification • Commercialisation of PEBG (pressurized entrained flow gasifier) → High gasifier temperature leads to relatively clean gas → facilitates FT diesel / DME production • Fuel flexible gasifier → many different biomass materials may be considered as feedstock • The produced syngas can be converted to many different chemicals, products or IGCC FT diesel production • Micro reactors increase process efficiency and stability of the process (by increased heat removal, high mass transfer rates and high pressure resistance) Overall • Route enables synthesis of a large variety of products from a large variety of feedstocks: flexibility advantageous in supply and demand market	**Threats** Pyrolysis • Failure to further develop immature technology to commercial technology FT diesel production • Failure in development of micro reactors Overall • Competitors may succeed with superior alternative 2^{nd} generation biofuel concepts • It is not clear if PEBG will provide a superior performance advantage compared to conventional gasifiers

The success of this technology depends on the achievement of high net-conversion efficiencies at low specific costs. For the latter, energy efficient pre-treatment (possibly achievable by running on larger particle sizes) and a long catalyst live-span seems to be determining for the success of this pathway.

Furthermore – as for all biomass based technologies – the availability of sustainable supplied biomass is crucial. Technologies that use residues (like wood residues, as in the standard scenario) are advantageous compared to technologies using dedicated crops (like e.g. poplar SRC) because of the reduced competition to other uses. Therefore from a sustainability point of view, the research focus should be to develop technologies suitable for inhomogeneous, low quality biomass like wood residues. A technology that can run on these feedstocks has clear advantages compared to technologies that require a homogenous high quality biomass, because homogenous high quality biomass can most likely be obtained only from dedicated crops or intensive forestry.

Another disadvantage is that a large amount of light hydrocarbons and LPG are produced that considerably reduce the production of FT liquid /Lervik Mejdell et al. 2014/. Furthermore, the production of FT liquids is an exothermic process that needs a temperature control to reduce the safety risk.

For the thermochemical pathway the net efficiency is lower compared to the biochemical route due to an additional steam demand for the syngas cleaning step in the thermochemical route /Lervik Mejdell et al. 2014/.

Another risk is that competing concepts such as the bioliq® concept (see http://www.bioliq.de/english/index.php) by Karlsruhe Institute of Technology could develop faster so that there will not be any further interest in developing the present concept.

The most important SWOT arguments regarding biomass processing along the thermochemical route are presented in Table 2-11. For more detailed SWOT factors see Annex, Table 4-6.

For **DME production,** SWOT arguments for pyrolysis, gasification, syngas cleaning, and wastewater treatment as well as arguments regarding the overall performance, correspond to those of FT liquid production. DME production, however, is listed separately. Moreover, some additional arguments are given that only relate to the overall performance of DME production.

Compared to FT diesel the production of DME is less cost-intensive and the energy efficiency is higher. However, as for FT liquid production micro reactors for DME production have also not been a commercial technology yet. Thus, as shown in the framework of this project there is still a long development process necessary in order to optimise the catalyst formulation, maximise DME selectivity and study the long term mechanical and chemical stability of the system /Lervik Mejdell et al. 2014/. Furthermore, the production of DME is an exothermic process that needs a temperature control to reduce the safety risk. Another issue for DME production is that slight vehicle adaptations are needed while FT diesel can be used in standard diesel engines (for details see also the BioDME Project, http://www.biodme.eu).

The most important SWOT arguments regarding DME production are presented in Table 2-12. For more detailed SWOT factors see Annex, Table 4-7.

Table 2-12 Most important SWOT factors regarding DME production

	Success factors	Failure factors
Internal factors	**Strengths** Overall • Lower production costs compared to FT diesel • Higher energy efficiency compared to FT diesel	**Weaknesses** DME production • Exothermic process → difficult temperature control • Micro reactors not yet commercial technology • Thin catalyst layers susceptible to poisoning, no catalyst reserve within reactor Overall • Vehicle adaptations are necessary
External factors	**Opportunities** DME production • Micro reactors increase process efficiency and stability of the process (by increased heat removal, high mass transfer rates and high pressure resistance) • Potential for downsizing process allied with reducing plant costs	**Threats** DME production • Failure in development of micro reactors • Not achieving desired conversion and yield of DME

2.3.3 Add-on technologies

For the "algae" and "seed oil to fuel" add-on technologies the following SWOT arguments could be identified. For detailed SWOT matrices see Annex, sub-chapter 4.4.

The big advantage of **algae production** is that non-fertile land can be used and at the same time high yields per hectare are expected. A big disadvantage is the high water and light demand as well as the seasonality of algae growth in comparison to a more or less constant output of wastewater in biorefineries. The biggest challenge is the product separation and the reduction of energy demand for lighting and pumping. Furthermore, the high water demand could be a big issue for fresh water algae in dry areas.

The hydrogenation of **seed oils** is already established as a commercial process, e.g. using Neste Oil's NExBTL technology (see /Neste Oil 2012/). One of the main success factors for the hydrogenation of seed oils is the quality of the derived final product: Hydrogenated oils have a high cetane number, low sulphur content and low exhaust emissions. Furthermore, the hydrogenation of seed oils leads to linear alkanes that in contrast to e.g. FAME (fatty acids methyl ester) can be blended with fossil diesel in any ratio without the need to modify the engines of the vehicles. Another advantage of this technology is that there is a wide range of feedstocks that can be used. Main disadvantage is the high costs for H_2 and catalysts. Besides technical aspects, the success or failure of hydrogenation depends on the costs of this technology since it might turn out that other technologies are cheaper and thus have a competitive advantage.

2.4 Conclusions and recommendations

The SUPRABIO project is much about basic research and immature technologies. As for the preliminary SWOT results in /Kretschmer et al. 2012/, also the final SWOT results are still very limited due to knowledge gaps especially regarding the advanced technology options (e.g. lignocellulose to mixed acids) and the add-on technologies (if integrated or as stand-alone concepts). Furthermore, immaturity itself is a main threat since there is always the risk of a failure in development. In particular for the alternative pathways, which are considered to be available in 2025, only very general specifications are available. Nevertheless, the SWOT analysis revealed some interesting ideas about successes and failure factors for the SUPRABIO concepts. Those ideas shall help stakeholders and politicians in decision making.

The following recommendations are given for policy makers, companies and farmers:

Recommendations for policy makers

- Generate **biomass allocation plans**: Biomass uses should be prioritised on reducing hunger ("food first") or conserving biodiversity.
- Generate suitable guidelines to **guarantee sustainability**:
  - Promote the introduction of a certification system for wood residues to enable a differentiation to stem wood.
  - Regulate and control the removal of wood residues.
  - Determine and control maximum straw extraction rates.
- Promote **feedstock flexible technologies**: Those technologies enable biorefineries to react easier on biomass shortages.
- Establish common European agriculture and forest policies:
  - Innovative biomass use policies and the common agricultural policies of the EU should be developed uniformly.
  - Subsidies for biorefineries should be bound to good agricultural practices (including also maximum straw extraction rates).
  - A common European forest policy can help to establish a sustainable woody biomass use in Europe. This policy should include harmonised sustainability criteria as well as a harmonised woody biomass allocation plan.
  - If a common agricultural or forest policy is not possible, **national legislation** combined with **voluntary certification** should be further developed to react on the new market opportunities.
- Further support the **research on the integration of add-on technologies**: The integration of add-on technologies can help to increase the efficiency of the biorefinery.

Recommendations for companies

- Involve **stakeholders** in the planning process: A participatory planning approach is considered essential for a successful realisation of a biorefining plant. Participation motivates farmers and raises the acceptance amongst the rural population. It helps to identify any hurdles as early as possible and hence give all parties the chance to react appropriately.

- Consider making **farmers shareholders:** Making farmer shareholders of the processing plant can stabilise the biomass supply of the factory. Another way to guarantee a stable biomass supply involves long term contracts with farmers. However, most farmers would not be willing to sign a long term contract for a by-product (straw) if they do not have a long term contract for the main product (grain).
- Select **factory location** carefully: Check the availability of sufficient sustainably provided biomass on a long term basis, before investing in a biorefinery.
- Look after a sustainable biomass supply:
  - Establish environmental and social sustainability criteria for biomass supply and control the compliance. This is relevant in particular in case of biomass imports from outside Europe, especially if countries with low environmental or social sustainability standards (or enforcement thereof) are involved.
  - Take care that a sustainable amount of straw and wood residues is left on the fields (or in the forests, respectively) since too high extraction rates can harm the environment and might lower future biomass availability due to reduced life support services of the soil.
- Focus on **energy efficiency**: Since energy is very cost intensive and often cause great environmental burdens, the reduction of energy demand per product unit should be a main focus of research. High potential in reducing the energy demand is particularly given for biomass pre-treatment and product separation.
- Support further research on **SScF technology**: The SScF process of the biochemical route is a promising technology that can help to increase the efficiency and decrease the costs per unit of product.

Recommendations for farmers

- Consider long term effects of straw extraction:
  - Extracting too high amounts of straw can lower soil fertility and hence negatively affect yields and income.
  - Local scientists or consulting agencies can help to define sustainable extraction rates.
- Plan a **shift to perennial crops** carefully: The establishment of SRC plantations can be an interesting income opportunity, but it binds the farmer for years. Thus, careful planning is needed. However, it is most likely that the demand for biomass will rise in the next years.

3 Biomass potential and competition

A sufficient and sustainable supply of biomass is a prerequisite for the successful implementation of biorefineries. The amount of biomass available for biorefining determines the number and capacities of biorefineries that could be established in a certain area as well as the price of biomass. Both influence the economic performance of the refineries.

To avoid environmental and social harms, social and environmental sustainability concerns have to be considered, forming containments for the biomass potential.

The analyses in /Keller et al. 2014/, /Schütz 2014/ and /Lervik Mejdell et al. 2014/ are based on the precondition that sufficient biomass and land is available, i.e. that there is no competition for biomass or land and thus no direct or indirect land use changes. Independent of how much unused biomass or agricultural land may be available in reality in 2015 or 2025, this precondition allows to only evaluate the impacts of the SUPRABIO concept and its optimisation options which would have been superposed by competition effects. Therefore separate analyses are needed that are described in the following sections of this report.

Although biomass is a renewable resource, it is not available unlimited, but restricted by its own time of regeneration or its usage rate. The growth is limited by the scarcity of land, water and nutrients (see Box 4–1). For socio-political decisions, it is important that the biomass availability within a geographical unit can be estimated for a certain point of time that is often settled in the future. For this purpose, usually so called biomass potential studies are compiled that identify the biomass potential with the help of scenario-based approaches (see sub-chapter 3.1). It should be noted that biomass potential studies are not to be confused with predictions or forecasts[1].

The use of biomass or land for industrial purposes, respectively, partially competes with the use of biomass for energy. In addition, both utilisation pathways compete with the use of biomass for food and feed as well as other land-demanding sustainability goals such as nature conservation, but also including the expansion of settlement area or golf courses. In particular, the highly ambitious renewable energy targets that were defined in recent years contribute to a worsening of the situation. If food and feed production is displaced, there are usually direct or indirect land use changes that are associated with undesirable effects (see sub-chapter 3.2).

Sub-chapter 3.3 finally provides conclusions and recommendations.

[1] Forecasts are statements about expectable future developments. Known developments and conceivable trends are extrapolated into the future (mostly linear) from which a specific image of the future is predicted with a certain probability (e.g. weather forecast). This approach is based on the assumption that the future world will be relatively similar to that of today. The scenario method differs in most definitions from the forecasting method. It describes several alternative developments in the future and accepts uncertainties, tries to understand them and to integrate them into the overall picture. Scenarios are no (linear) projections, predictions or preferences, but possible descriptions of the future (qualitative and / or quantitative) based on different pathways of development (e.g. climate scenarios based on the extrapolation of temperature models as a function of the concentration of greenhouse gases in the atmosphere) /IZT 2008/.

Box 4–1 Global human appropriation of net primary production (HANPP) in 2000

In an ecosystem, biomass is produced by photo- and chemosynthesis carried out by autotrophic microorganisms and plants (producers) as well as by animals and heterotrophic microorganisms (consumers). The most important measure of biomass production is the net primary production (NPP): it includes the total biomass production by photosynthesis (or chemosynthesis) less the share consumed by respiration. In perennial ecosystems (e.g. forest ecosystems) the NPP needs to be distinguished from accumulated biomass, also known as stock biomass. It is often a multiple of the NPP. For annual ecosystems (e.g. agro-ecosystems), however, both values are identical /Nentwig et al. 2004/.

In general, the NPP is specified for a given area and a certain period of time, for example, in grams of carbon (g C) per year. According to /Haberl et al. 2007/, the net primary production of the potential vegetation (NPP0, available in an ecosystem in the absence of human activities) amounted to 65.5 billion tonnes C in 2000, the net primary production of the actual vegetation (NPPact) to 59.2 billion tonnes C (Fig. 3-1 and Table 3-1).

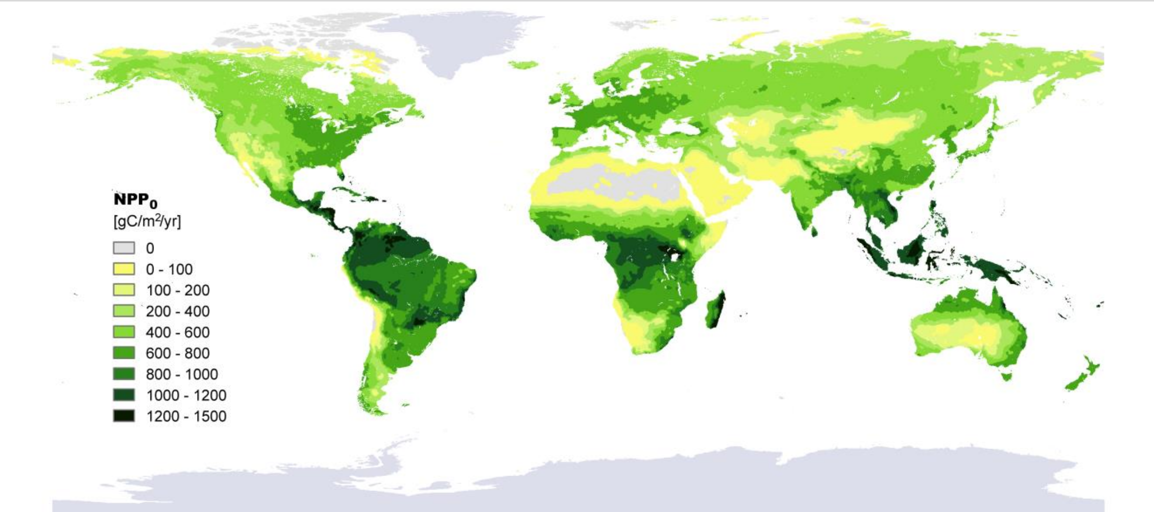

Fig. 3-1 Net primary production of the potential vegetation in [gC/m²/yr] /Haberl et al. 2007/

This biomass either remains in the ecosystem (NPP_t) or it is used by humans as a raw material for the food or material conversion industry or for energy production (NPP_h).

HANPP is defined here as the difference between the amount of net primary production that would be available in an ecosystem in the absence of human activities (NPP_0) and the amount of NPP which actually remains in the ecosystem, or in the ecosystem that replaced it under current management practices (NPP_t):

$HANPP = NPP_0 – NPP_t$ with $NPP_t = NPP_{act} – NPP_h$.

NPP_h includes primary crop harvest but also harvest losses, i.e. residues or biomass destroyed during harvest, grazing and human-induced fires.

In 2000, the global human appropriation of net primary production (HANPP[2]) amounted to 28.8 % of the above-ground NPP (5.2 % land use change [ΔNPPLC], 20.4 % harvest, 3.2 % human induced fire) or to 15.6 Pg C, respectively (Table 3-1). Thereof about a sixth (4.2 %) is returned to nature in the form of unused residues, crop losses, soil remaining roots or excreta of grazing animals /Haberl et al. 2007/.

Table 3-1 Global carbon flows related to the human appropriation of net primary production (HANPP) around the year 2000 /Haberl et al. 2007/

	Total NPP		Above-ground NPP	
NPP-related carbon flows	**Pg C/yr**	**%**	**Pg C/yr**	**%**
Potential vegetation (NPP_0)	65.51	100.0	35.38	100.0
Actual vegetation (NPP_{act})	59.22	90.4	33.54	94.8
Human-induced alteration of NPP (ΔNPP_{LC})	6.29	9.6	1.84	5.2
Human harvest (NPP_h)	**8.18**	**12.5**	**7.22**	**20.4**
Human-induced fires	1.14	1.7	1.14	3.2
Remaining in ecosystem (NPP_t)	49.90	76.2	25.18	71.2
$HANPP_{total}$	15.60	23.8	10.20	28.8
Backflows to nature*	2.46	3.7	1.50	4.2

* On-site backflows of harvested biomass to ecosystems, i.e., unused residues, harvest losses, feces of grazing animals, and roots killed during harvest.

In some countries, e.g. India, China and parts of Europe and the USA, HANPP is already close to or equal to NPP_0 (Fig. 3-2).

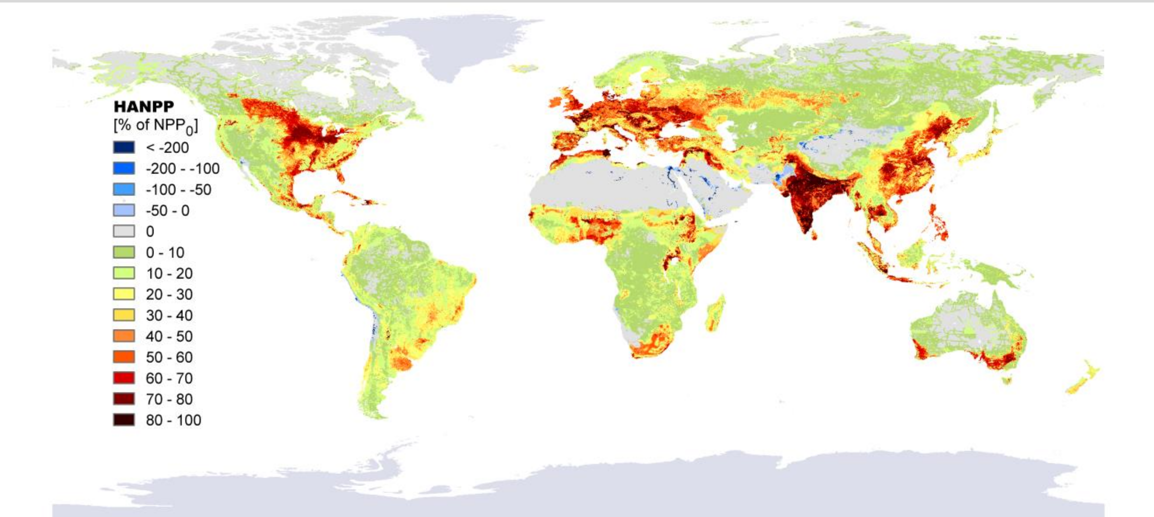

Fig. 3-2 Total HANPP as a percentage of NPP_0 /Haberl et al. 2007/

2 HANPP is a measure of the human dominance over terrestrial ecosystems and considers simultaneously (1) the extent to which the NPP is altered by land use (e.g. by replacement of natural ecosystems by agro-ecosystems, sealed area, etc.) and (2) the extent to which the availability of energy for natural ecosystem processes is reduced by harvest.

3.1 Biomass potentials

For the analysis of biomass potentials within SUPRABIO, a literature review was conducted, which considered the output relevant studies in this area, among others the outcomes of the EC-funded projects EUWood (Real potential for changes in growth and use of EU forests), BEE (Biomass Energy Europe) and BiomassFutures.

After some initial definitions (sub-chapters 3.1.1 and 3.1.2), exemplary results of biomass resource assessments for Europe are presented in sub-chapter 3.1.3. Sub-chapter 3.1.4 focuses on the feedstocks investigated in SUPRABIO and sub-chapter 3.1.5 summarises the findings.

3.1.1 Definition of biomass categories and types of biomass

Biomass can be divided into several **biomass categories**. This subdivision can be based on different parameters. For the BEE project, the following subdivision was used: (i) woody biomass from forestry, (ii) woody and herbaceous energy crops from agriculture, and (iii) organic waste. Each of these biomass categories comprises different **types of biomass**, the main ones being products (harvested biomass) and residues (by-products from cultivation, harvesting and processing).

Forestry and forestry residues

This biomass category is subdivided into woody biomass (harvested products) and residues from forestry.

Table 3-2 gives an overview of all subcategories and included types of biomass.

Table 3-2 Woody biomass and residues from forestry and trees outside forests: Biomass subcategories, origin and included types of biomass /Torén et al. 2010/

Biomass subcategory	Origin	Type of biomass
Woody biomass		
From forestry	Forests and other wooded land incl. tree plantations and short rotation forests (SRF)	Harvests from forests and other wooded land incl. tree plantations and SRF, excl. residues
From trees outside forests (landscape)	Trees outside forests incl. orchards and vineyards, public green spaces and private residential gardens	Harvests from trees outside forests incl. orchards and vineyards, excl. residues
Woody residues		
Primary residues	Cultivation and harvesting / logging activities in all of the above incl. landscape management	Cultivation and harvesting / logging residues (twigs, branches, thinning material), pruning from fruit trees and grapevines etc.
Secondary residues	Wood processing, e.g. industrial production	Wood processing by-products and residues (sawdust, bark, black liquor, etc.)

Woody biomass from forestry includes all biomass from forests (or other wooded land), tree plantations, and trees outside forests (TOF). All trees that are not part of a forest or plantation but rather grow in an orchard, meadow, garden and park or alongside roads and waterways are grouped under the general term ‘trees outside forests’.

Woody forestry residues include both primary residues, i.e. leftovers from cultivation and harvesting / logging activities (twigs, branches, thinning material etc.) and secondary residues, i.e. those resulting from all further industrial processing (sawdust, bark, black liquor etc.). Tertiary residues, i.e. used wood (wood in household waste, end-of-life wood from industrial and trade uses, waste paper, discarded furniture, demolition wood etc.) are considered organic waste and are included in the respective biomass category ‘organic waste’.

Energy crops and agricultural residues

This biomass category is subdivided into energy crops on agricultural and on marginal land.

Table 3-3 gives an overview of all subcategories and included types of biomass.

Energy crops on agricultural and on marginal land can be either herbaceous plants (cereals, oil seeds etc.) or woody plants (poplar or willow). The latter are mostly referred to as short rotation coppice (SRC) plantations. In contrast to short rotation forestry (SRF) they are classified as woody energy crops within the BEE project and therefore found under agriculture (and not forestry) due to the fact that the land on which the SRC plantation is established remains in agricultural use.

Table 3-3 Energy crops and residues from agricultural and marginal land: Biomass subcategories, origin and included types of biomass /Torén et al. 2010/

Biomass subcategory	Origin	Type of biomass
Woody and herbaceous energy crops		
Grown on arable land	Arable and permanent cropland incl. SRC	Harvest from arable and permanent cropland incl. annual energy crops and SRC, excl. residues
Grown on grassland	Permanent grassland (meadows and pastures)	Permanent or annual energy crops, excl. residues
Grown on marginal land	Other land (degraded lands, mine dumps...)	Permanent or annual energy crops, excl. residues
Woody and herbaceous agricultural residues		
Primary residues	Agr. cultivation and harvesting activities	Harvesting residues (straw, bagasse, husks, cobs etc.)
Secondary residues	Processing of agricultural products, e.g. for food	Processing residues (e.g. pits from olive pitting, shells/husks from seed/nut shelling and slaughter waste) as well as animal excrements

Following the FAO definition /FAOSTAT 2010/, agricultural land is seen as the sum of arable land, permanent crops and permanent meadows & pastures. Arable land in turn is the sum of temporary crops, temporary meadows & pastures and fallow land. Marginal land (or 'other land' according to the FAO definition), however, is much more difficult to define: it includes any other land not specifically listed under arable land and land under permanent crops, permanent pastures, forests and woodland, built on areas, roads, barren lands etc. Sometimes marginal land is also referred to as 'unproductive', 'low productive' or 'degraded' land, i.e. the terminology and the definitions lying behind them are rather vague.

Agricultural residues cover both primary residues, i.e. harvesting residues (straw, bagasse, husks, cobs etc.), and secondary residues, i.e. food processing residues and animal excrements. Tertiary residues, i.e. used agricultural materials and products thereof (e.g. food leftovers, flowers), are considered organic waste and included in the respective biomass category 'organic waste'.

Organic waste

This biomass category is made up of the tertiary residues and is subdivided into organic waste from households and from industry and trade. Table 3-4 gives an overview of all subcategories and included types of biomass.

Table 3-4 Organic waste (tertiary residues incl. woody and herbaceous biomass): Origin and included types of biomass /Torén et al. 2010/

Origin	Type of biomass
Households	Organic household waste incl. woody fractions, e.g. food leftovers, waste paper, discarded furniture, incl. sewage sludge
Industry	Organic waste from industry (excluding forestry industry) and trade incl. woody fractions: food waste, slaughter waste, used fats and oils, bulk transport packaging, recovered demolition wood (excluding wood that goes to non-energy uses)
Households and industry	Sewage sludge, sewage gas and landfill gas

Organic waste covers all organic food and non-food waste materials, including for example all non-eaten and discarded food, but also woody and other non-food organic waste from households (e.g. yard trimmings from private gardens) and industry (e.g. waste wood and demolition wood). Sewage sludge from sewage treatment plants is also included as a further type of recovered tertiary residue fraction.

3.1.2 Definitions of biomass potentials

There are different definitions of biomass potentials. In literature, it is usually distinguished between the theoretical, technical, economic and implementation potential (see e.g. /Kaltschmitt & Hartmann 2009/, /Rettenmaier et al. 2010a/, Fig. 3-3).

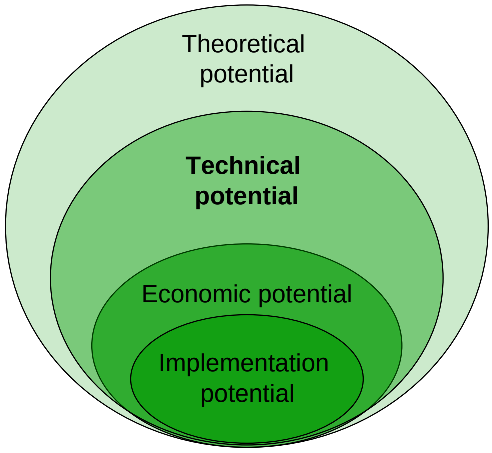

Fig. 3-3 **Illustration of the different biomass potentials**

Theoretical potential

The theoretical potential is the total amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits. Thus, it is equivalent to the net primary production (NPP) described in Box 3–1. In the case of biomass from crops and forests, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from soil, temperature, solar radiation and rainfall. In the case of residues and waste, the theoretical potentials equal the total amount that is produced.

However, the theoretical potential has no practical relevance since often only small parts of it can be developed due to certain technical, environmental and economic restrictions.

Technical potential

The technical potential is the fraction of the theoretical potential which is available under the regarded framework conditions with the current technological possibilities (such as harvesting techniques, infrastructure and accessibility, processing techniques). An assessment of the *sustainable* technical potential additionally takes into account confinements due to other land uses (food, feed and fibre production) as well as requirements in terms of environmental protection (e.g. nature reserves; soil conservation etc.).

Economic potential

The economic potential is the share of the technical potential which meets criteria of economic profitability within the given framework conditions.

Implementation potential

The implementation potential is the fraction of the economic potential that can be implemented within a certain time frame and under specific socio-political framework conditions, including institutional and social constraints and policy incentives.

The classification in types of biomass potentials helps the reader to understand what information is presented. For instance, some biomass types show high technical potentials while their economic potential is rather limited due to the high costs of extraction and transport. In existing biomass resource assessments, it is often difficult to distinguish between theoretical and technical potential and between economic and implementation potential. The technical and theoretical potential and the economic and implementation potential form two pairs of potential types. However, even more important than making this distinction in four types is the provision of insight into explicit conditions and assumptions made in the assessment.

Sustainable implementation potential

In theory, a fifth type of potential can be distinguished, which is the sustainable implementation potential. It is not a potential on its own but rather the result of integrating environmental, economic and social sustainability criteria in biomass resource assessments. This means that sustainability criteria act like a filter on the theoretical, technical, economic, and implementation potentials leading in the end to a sustainable implementation potential. Depending on the type of potential, sustainability criteria can be applied to different extents. For example, for deriving the technical potential, mainly environmental constraints and criteria are integrated that either limit the area available and/or the yield that can be achieved. Applying economic constraints and criteria leads to the economic potential and for the sustainable implementation potential, additional environmental, economic and social criteria may be integrated (see Fig. 3-4).

There is a strong demand for inclusion of sustainability aspects in bioenergy potential. Especially after bioenergy in general and biofuels in particular have lost some of their good reputation due to the food versus fuel debate and due to an increased awareness of land use competition and land use changes, both industry and politics strive for more sustainable practices. The concept of sustainable biomass contains multiple environmental, economic and social aspects, while integrating these aspects may be complex.

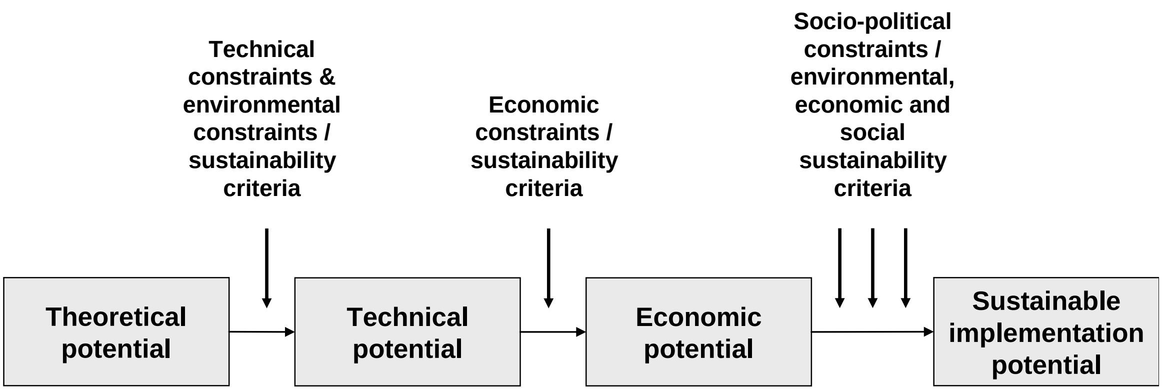

Fig. 3-4 Integration of sustainability criteria in biomass potential assessments /Rettenmaier et al. 2010a/

Although the sustainable implementation potential has of course a much greater importance for socio-political decisions, in most biomass potential studies, the technical potential is determined. This is understandable from the perspective of scientific robustness (economic conditions change rapidly and social conditions are difficult to be "translated" into scenario assumptions), but the use of such results involves the risk to ambitious political goals and regulations.

3.1.3 Exemplary results of biomass resource assessments for Europe

In literature, a variety of such biomass potential studies for different geographical reference systems (from global to the local level) can be found, however, the results might differ by a factor of 10 even if the same geographical and temporal reference is considered. In the following, exemplary results for biomass and land availability in Europe are presented.

Biomass availability

Several studies have estimated the current and future availability for biomass in Europe. For example, the EU funded **BEE** project analysed 55 European biomass resource assessment studies. The chosen studies differed largely with regard to the type of potential and types of biomass considered, the time frame and the geographical coverage of the analysis. The following types of biomass for bioenergy ('sectors') were considered: forestry biomass and forestry residues, energy crops, agricultural residues and organic waste.

Table 3-5 provides a summary of the reported biomass potentials at EU27 levels in the sector-focusing assessments. Fig 3-5 gives an overview of the span in potentials reported at EU27 level. The largest contribution to the total biomass potential for energy comes from dedicated energy crops on agricultural and marginal land. However, the range of results for energy crops is considerable.

Table 3-5 Summary of bioenergy potentials at EU27 levels in the sector-focusing assessments analysed [EJ/yr]

EU27	2000	2010	2020	2030	2040	>2050
Energy crops	0.1-1.6	0.3-9.6	0.5-14.7	2.0-18.4		15.4-19.9
Forestry and forestry residues	0.7-4.5	1.6-4.4	0.8-4.2	1.6-3.7		1.7-2.2
Agricultural residues and organic waste	0.5-3.9	1.0-3.9	1.5-4.4	1.1-3.1		0.7
TOTAL	1.3-10.0	2.8-17.9	2.8-23.3	4.8-25.2		17.8-22.8

Note that the geographical coverage and time frames are approximate: some of the reported data in the selected studies refer to geographical coverage and points of time that deviate somewhat from those stated in the table.

The range in estimated potentials is much greater for dedicated energy crops on agricultural land than that for residues from forestry and agriculture systems and organic waste. It is noteworthy to also mention that the span in potentials for dedicated crops increases substantially over time. In contrast, for the potentials from residues in forestry and agriculture there is no such clear trend over time. In particular for residues from forestry, the average of the reported potentials is relatively constant over time.

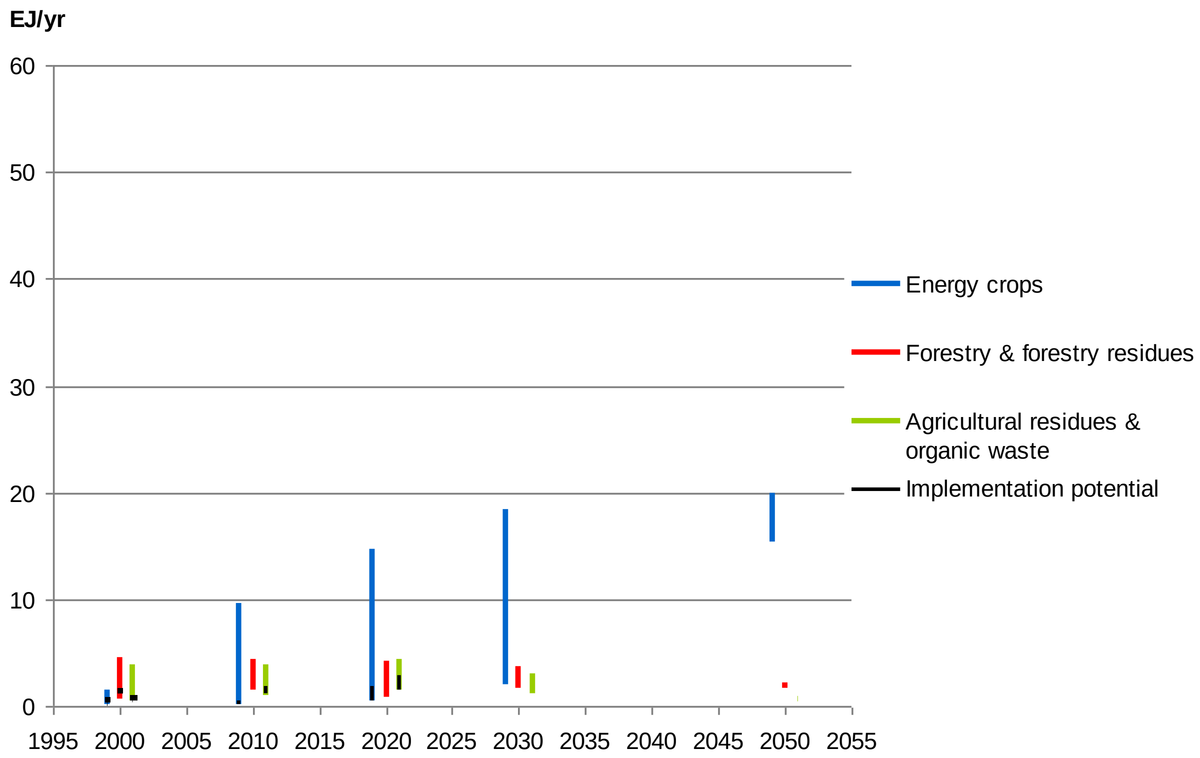

Fig 3-5 **Summary of biomass energy potentials at EU27 level in the sector-focusing assessments analysed. Thick lines indicate technical potential and thin black lines indicate implementation potential**

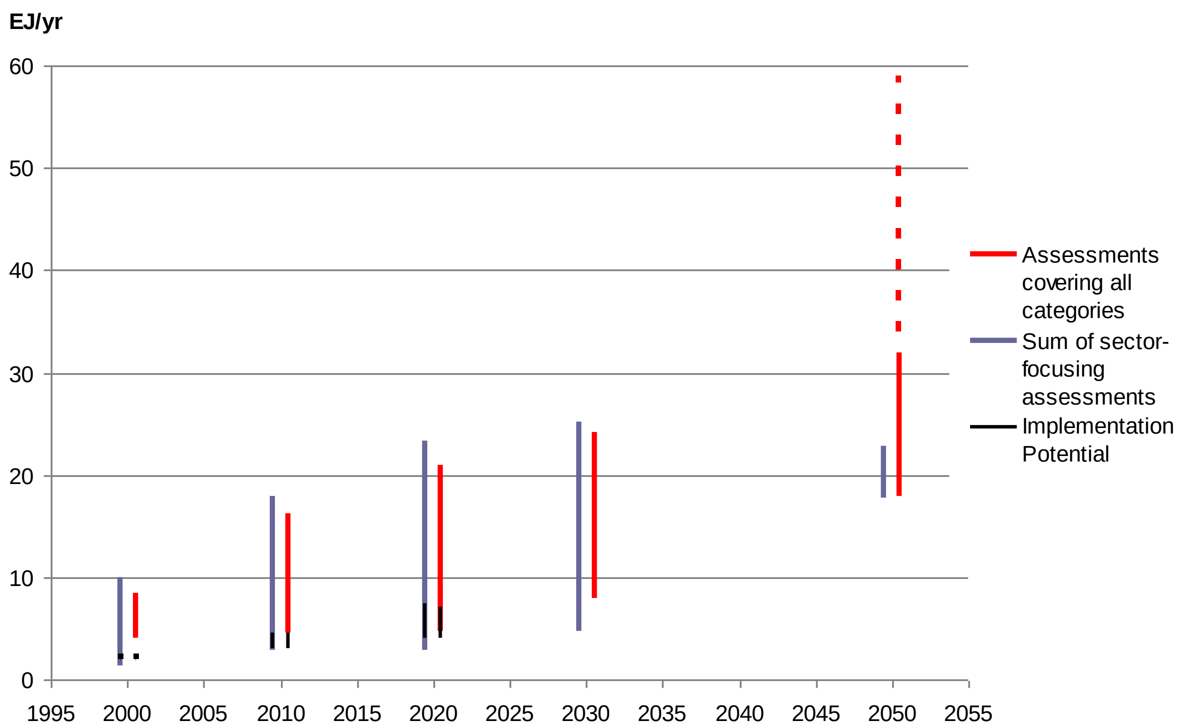

Fig 3-6 **Comparison of estimated total biomass energy potentials at European level in assessments covering all biomass categories and sector-focusing assessments. Thick lines indicate technical potential, black lines indicate implementation potential, dashed line represents range of System 3 & 4 in /Smeets et al. 2007/**

A numbers of studies which assess the total potential for biomass have also been analysed. Fig 3-6 gives a summary of the min-max values taking into account all scenarios in each of the studies. Besides the great deviations in potentials at each point of time, it can also be noted that deviations overall increases over time, as is clearly seen in Fig 3-6. The biomass category mainly responsible for the increased deviation is dedicated energy crops, whose upper-limit potential increases drastically in some of the studies.

The analysis of biomass resource assessments shows that the total biomass potential for energy in 2020 is estimated at 4 – 21 EJ/yr and increases to 18 – 59 EJ/yr in 2050. If only studies with a geographical coverage approximately matching the EU27 are taken into account, the estimates range from 4 – 21 EJ/yr and 18 – 23 EJ/yr in 2020 and 2050, respectively.

Moreover, the analysis shows that the reported total potentials differ to a considerable degree. The difference between the lowest and the highest estimate is three- to six fold for total potential. This difference is mainly due to the large uncertainties connected to the (dedicated) energy crops on agricultural and marginal land. These uncertainties can mainly be explained by ambiguous and varying methods of estimating (future) biomass production and availability as well as ambiguous and varying assumptions on system-external factors that influence potentials (such as land use and biomass production for food and fibre purposes). This aspect is further detailed in the section on land availability below. In contrast to energy crops, the potentials for forest biomass as well as agricultural residues and organic waste do not show a clear trend over time.

The estimates for the total biomass potential for energy in Europe are in the same order of magnitude as IEA's projections for the future total primary energy demand in EU27 (~70 – 75 EJ/yr), see Fig 3-7. It is not possible to meet the entire demand with biomass only, but biomass could contribute a substantial share. The fact that the biomass potential is smaller than the energy demand calls for a most efficient use of biomass and highlights that it is not an unlimited resource.

/Torén et al. 2010/ conclude that given the targets set in the RED and NREAPs it is clear that to reach the 2020 targets, there still needs to be a tremendous increase in RES production including bioenergy. To produce the remaining 10 % RES share, particularly for the biofuels targets set for 2020, large amounts of biomass are required. This will particularly lead to further increases in cropped biomass as with present state of technology most fuels will still be based on rotational arable crops providing sugar, starch and or oils as feedstock. Second generation biofuels based on lignocellulosic material cannot be expected to become economically viable at large scale within the next 10 years. This implies that large land areas are needed both inside and outside Europe for biofuel feedstock production but also, although to a lesser extent, for feedstock for renewable heat and electricity production. The demand in the latter category is however less land related as it can mostly be satisfied by waste and by-products from several sources.

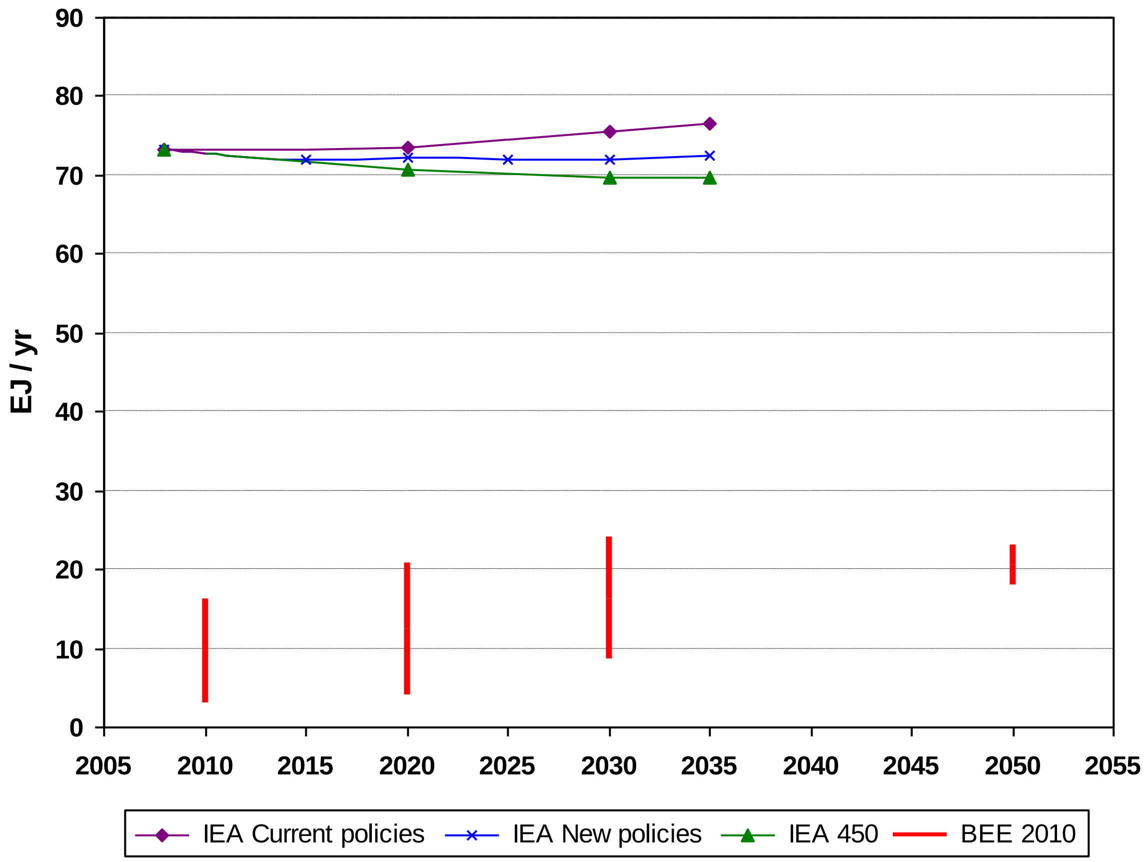

Fig 3-7 **Total primary energy demand in EU27 according to three IEA scenarios /IEA 2010/ versus total biomass potential for energy according to BEE.**

The **Biomass Futures** project /Elbersen et al. 2012/ shows that when a comparison is made with future potentials it becomes clear that potentials are expected to increase significantly, especially towards 2020 in the reference scenario. Between 2020 and 2030 the potentials will stabilise (Table 3-6). An important contribution to the growth in potential comes from the expectation that bioenergy cropping will increase significantly both for biofuels on existing agricultural land and on released agricultural land with perennials crops. This growth is however expected to be much larger in the reference scenario then in the sustainability scenario where biofuel cropping on existing agricultural lands is not going to happen and also the perennial cropping potential is more limited because of constraints on access to land. Towards 2030 the overall cropping potential will be smaller than in 2020 while the agricultural residues potential remains stable. Similar levels of agricultural residues are purely a coincidence as the contribution of the separate residues categories to these totals ranges between 2020 and 2030. In 2020 the contribution by manure is lower than in 2030 while there is a larger contribution of straw and prunings.

Another reason for growth in biomass potentials is caused by increases in the primary and tertiary forestry residues. This is however only expected in the reference scenarios, while in the sustainability scenarios this will be lower as primary forestry residues are expected to remain at the same level as for the current situation. Waste potentials are expected to decline towards the future and landscape care wood potential is expected to increase. In summary it becomes clear that the contribution of the waste sector will further decline to the total potential, the forest sector contribution currently contributing with 52 % will also decline to a 47 % contribution. The growth in contribution to the overall potential is expected to come from agriculture. Currently it contributes with 31 % tot the total potential, but this is expected to increase to above 40 % in both reference and sustainability scenario in 2020 and 2030. Within the agricultural group the largest contribution may come from manure, straw and dedicated cropping. Countries with the largest potential are not only the biggest countries, e.g. Germany, UK, France, Poland, but also the ones with a large forest area, population and/or agricultural sector.

However towards the future the contribution of countries to the potential may shift. Overall there will be a decline in the contribution of big countries like Germany and Italy to the EU potential, while increase can be expected in France, Spain, Poland and Romania. Particularly in the sustainability scenario the contribution of Poland could increase significantly. Overall there are however very small changes expected in relative country contribution between the scenarios.

Table 3-6 Potentials (PJ) per aggregate class compared over period and scenario /Elbersen et al. 2012/

PJ	Current	2020 reference	2020 sustainability	2030 reference	2030 sustainability
Wastes	1758	1507	1507	1382	1382
Agricultural residues	3726	4438	4438	4438	4438
Rotational crops	377	712	0	837	0
Perennial crops	0	2428	2177	2052	1549
Landscape care wood	377	628	461	502	461
Roundwood production	2386	2345	2345	2345	2345
Additional harvestable roundwood	1717	1591	1465	1633	1507
Primary forestry residues	837	1717	795	1758	795
Secondary forestry residues	586	628	628	712	712
Tertiary forestry residues	1340	1884	1884	1591	1591
Total	13147	17961	15701	17208	14779

Land availability

Even though estimates of the size might vary strongly, the European Commission /EC 2007/ calculated that 17.5 million hectares (Mha) of land are needed if the target of the EU (RED) should be achieved that in 2020 at least 10 % of each Member State's transport fuel use must come from renewable sources (including biofuels). This means that about 10 % of the total Utilised Agricultural Area (UAA) in EU27 has to be used.

Their starting point was that 50 % of the production would come from cultivation of rotational biomass crops for 1st generation biofuels. The other 50 % would come from ligno-cellulosic by-products and perennial biomass crops or imports from outside the EU. For conversion of these ligno-biomass feedstock they assumed 2nd generation biofuel technology to become commercially available before 2020.

The studies analysed in the **BEE** project show that land availability in the EU 27 for energy crop production is up to 100 Mha between 2030 and 2039 (Fig 3-8). However, results deviate strongly between studies depending on the underlying assumptions.

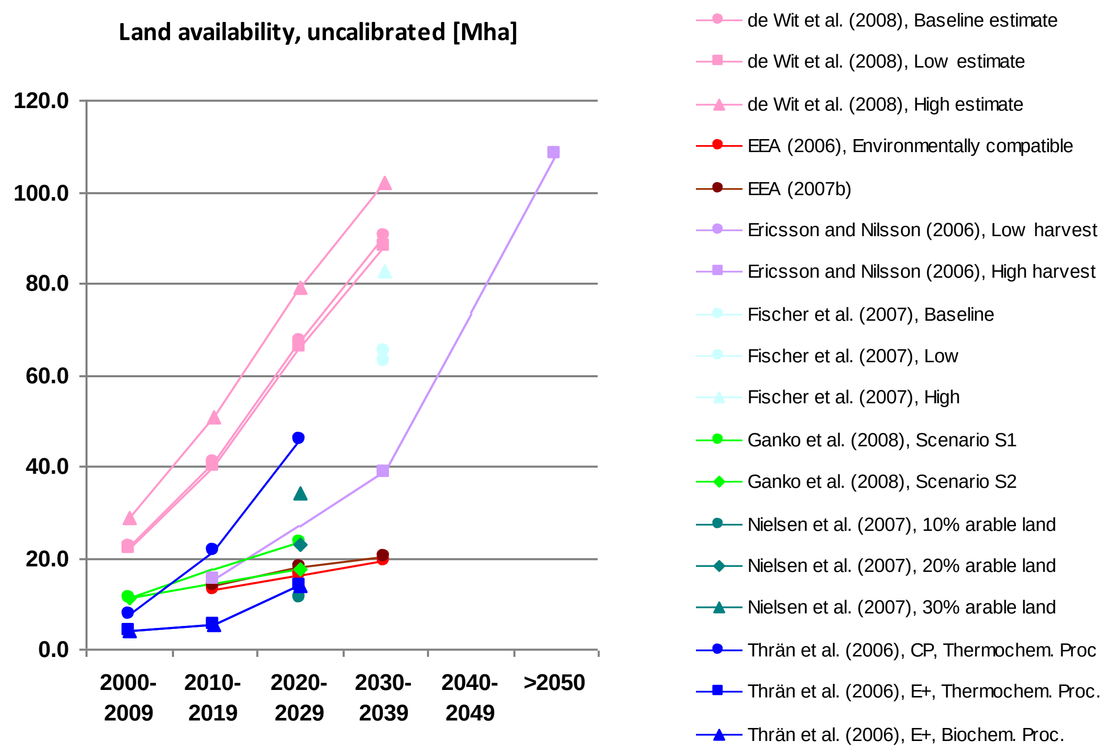

Fig 3-8 **Land availability for energy crop production [Mha]**

In the **BiomassFutures** project /Elbersen et al. 2012/, it is expected that dedicated perennials for bioenergy production are most likely cultivated on land that is not needed for the production of food, feed or bioenergy crops. Thus, in order to estimate the amount of land that can be released from agricultural production between 2004 and 2020 and 2004 and 2030, a post model analysis was conducted that also determine the quality type of the released land. As “good quality”, land is considered that is normally used for arable cropping. As “low quality”, land is considered that is used for perennial crop cultivation (e.g. vineyards or olive tree plantations). Furthermore, fallow land was also considered as low quality land. Table 3-7 shows that in total about 22 Mio hectares land will be released between 2004 and 2020 and about 18 Mio hectares between 2004 and 2030 (reference scenarios). Thus, between 2004 and 2020 slightly more land is released then between 2004 and 2030. This is mainly due to a larger arable land demand in 2030 compared to 2020. In the sustainability scenarios 2020 and 2030 less land will be released compared to the reference scenarios due to constraints on the use of land that is biodiversity rich or contains a high carbon stock. Thus, it is expected that in total about 19 Mio hectares of land are released between 2004 and 2020 and about 16 Mio hectares between 2004 and 2030. Regarding the quality of land less “good quality” land is released than land with low quality in all investigated scenarios.

Besides the land released from agricultural production, there is also a category of land only occurring in the sustainability scenarios: “Good quality land not fit for sustainable biofuel production”. In the sustainability scenarios 2020 and 2030, rotational arable biofuel crops cannot be produced sustainably in the EU as they do not reach the GHG emission mitigation target of 70 % and 80 %, respectively, including a compensation for indirect land use change (iLUC). However, in a post-model assessment, it turned out that by cultivating dedicated perennial crops (instead of rotational arable crops) on this category of land, the GHG emission mitigation target could be reached on more than half of this area, declining from 2020 to 2030. This decline is a result of a 10 % higher mitigation target in 2030. /Elbersen et al. 2012/.

Table 3-7 **Land released from agricultural production (*1000 ha) between 2004 and 2020 and 2004 and 2030 in the EU-27 /Elbersen et al. 2012/**

Land released between 2004 and:	Good quality released	Good quality land not fit for sustainable biofuel production	Low quality land	total
2020 reference	8,200	0	13,526	21,726
2020 sustainability	6,003	3,039	9,315	18,357
2030 reference	5,093	0	13,700	18,793
2030 sustainability	4,016	2,590	9,499	16,105

The above described studies show that the pressure on land might increase strongly under a growing biomass demand. This may cause adverse effects on biodiversity as it may lead to the further intensification of existing land uses, both in agricultural and forest lands, but also the conversion of non-cropped biodiversity-rich land into cropped or forest area (for further details see sub-chapter 3.2).

3.1.4 SUPRABIO feedstocks and biomass potentials in Europe

The biorefining pathways assessed in SUPRABIO use different feedstocks, the main ones being straw, forest residues and poplar short rotation coppice (SRC).

Forest residues

The **BiomassFutures** project /Elbersen et al. 2012/ shows a total potential of wood residues (primary, secondary and tertiary) ranging from 3,300 to 4,230 PJ in 2020 and 3,100 to 4,060 in 2030, compared to current level of 2,760 PJ. Primary forest residues correspond to 800 PJ and ~1,750 PJ in the sustainability and reference scenario, respectively. There is not much change between 2020 and 2030. These results are based on the EUWood project.

The regions with a relatively large contribution to the primary forest residues are concentrated in Scandinavia, France, Italy, Germany and Austria (Fig. 3-9). This potential is generally much smaller than the additional harvestable potential although still a significant contribution in absolute terms. In general, there is a relationship between present stem wood production and additionally harvestable stem wood and primary forestry residues. If the round wood production is already highly efficient i.e. removing a large part of the total potential, the additional harvestable potential is relatively smaller. From a bioenergy perspective, the largest potential should then be searched in the primary and secondary residues categories.

The additional harvestable and the primary residues categories are the main sources for feedstock for bioenergy. Presently these resources are practically not harvested, but they could become mobilised if enough economic and other stimulation measures become applied.

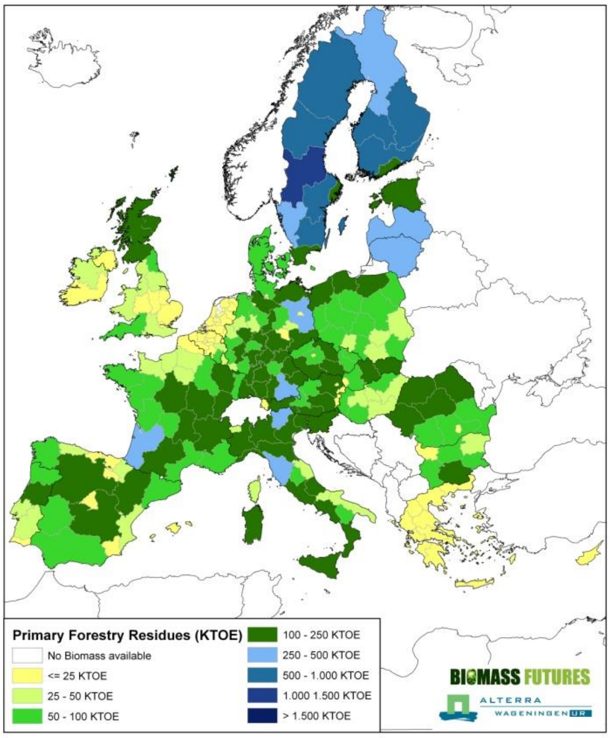

Fig. 3-9 **Current round wood, additional harvestable round wood and primary forestry residues potential (kTOE) for the current situation /Elbersen et al. 2012/**

Within SUPRABIO, /Pedersen 2011/ looked into the logistics of lignocellulosic biomass. Apart from biomass availability and potential, distance from supplier to refinery, competing interests and scale of possible refinery are of interest. In the case of forest residues, the author suggests that considering the above mentioned factors, the best locations for a forest residues-based biorefinery would be Scandinavia or central Germany.

Straw

The results from the **BiomassFutures** project /Elbersen et al. 2012/ presented in the maps (Fig. 3-10) show that the total straw potential remains relatively stable between 2020 and 2030. The straw potential is well spread over practically the entire EU, but countries like France, Germany, Poland, Italy, Hungary and in the future UK have the largest potentials. In Denmark there is the largest concentration of straw although the potential remains limited compared to the larger EU countries. Countries which show particularly large increases towards 2020 and 2030 are France, Poland, Hungary, Romania, UK and Denmark.

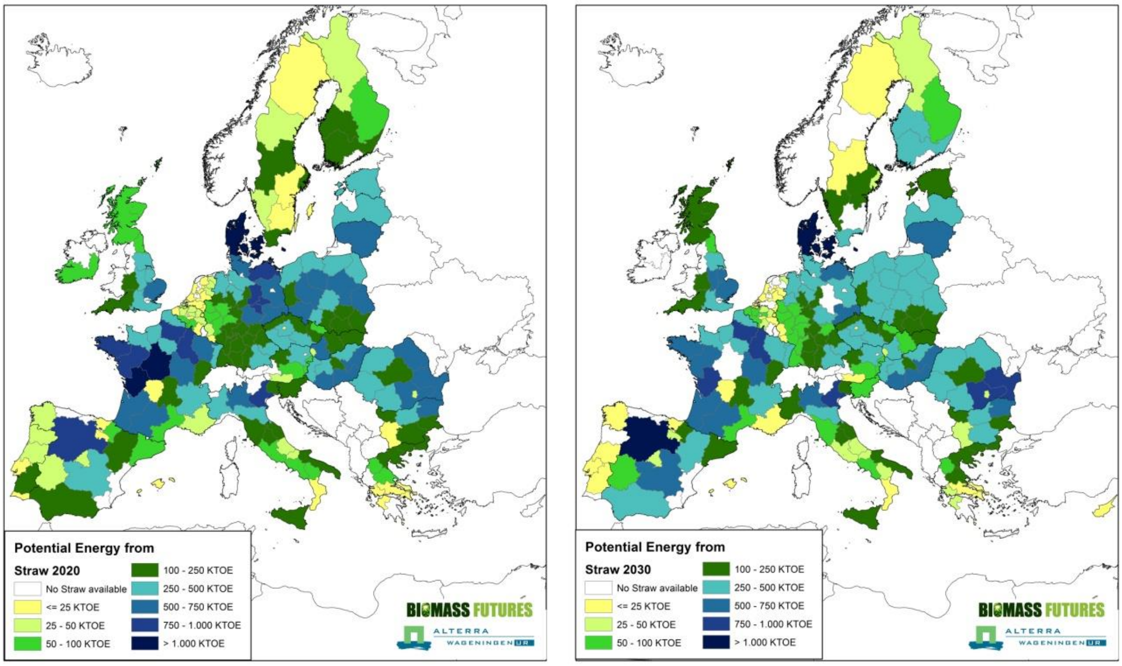

Fig. 3-10 **Economic and environmentally sustainable straw potentials (KTOE) in 2020 and 2030 /Elbersen et al. 2012/**

A study on straw potential in Germany shows that in total, 29.8 million tonnes of straw (fresh matter) are produced there annually (1999–2007) /Zeller et al. 2012/. Approximately, 4.8 million tonnes of the total straw occurrence are annually required by animal husbandry. Between 8 and 13 million tonnes of straw can be classified as sustainable straw. The reason for this rather large bandwidth is that there are several methods for calculating soil organic carbon stocks (VDLUFA lower and higher value as well as HE). There is no scientific consensus on the two competing methods and more research is needed.

The highest straw potential (3.99 tonnes ha^{-1}) can be found in parts of Schleswig-Holstein, Mecklenburg–West Pomerania, North Rhine-Westphalia and Lower Saxony, i.e. in northern-central Germany. But there are also regions that show a net deficit /Weiser et al. 2014/.

Within SUPRABIO, /Pedersen 2011/ looked into the logistics of lignocellulosic biomass. Apart from biomass availability and potential, distance from supplier to refinery, competing interests and scale of possible refinery are of interest. In the case of straw, the author suggests that considering the above mentioned factors, the best locations for a straw-based biorefinery would be northern France or central-northern Germany.

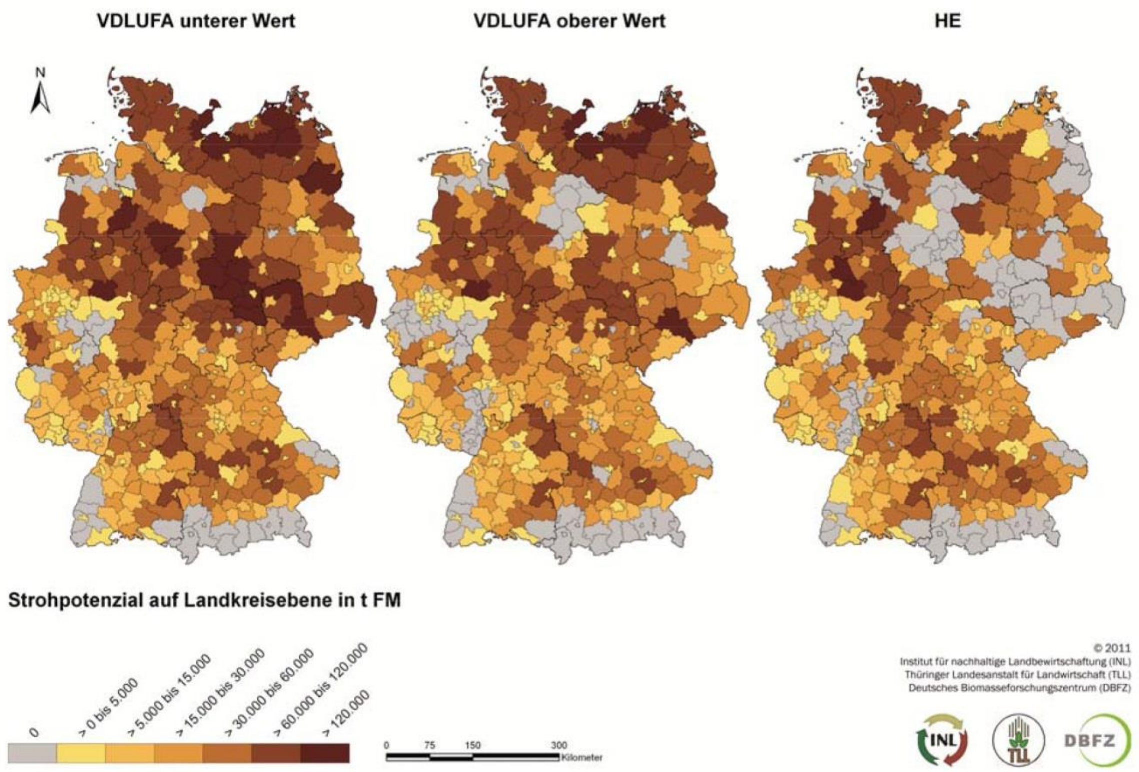

Fig. 3-11 **Sustainable straw potential according to different methods of calculating soil organic carbon stocks (average 1999-2007) /Zeller et al. 2012/**

Poplar SRC

The results from the **BiomassFutures** project /Elbersen et al. 2012/ show total potentials for dedicated crops of 2,160 to 2,930 PJ in 2020 (thereof 27 % and 42 %, respectively, for dedicated woody perennial crops) and 1,540 to 2,550 PJ in 2030 (thereof 18 % and 25 %, respectively for dedicated woody perennial crops). The lower values are given for the sustainability scenario (Fig. 3-12 and Table 3-8). The largest potentials are found in Romania, France, Germany and Bulgaria (2020) as well as in Poland (2030).

Differences between the final dedicated crops potential for the reference and the sustainability scenarios occur because of the stricter sustainability criteria. Thus, in the sustainability scenario there is less land available to use for dedicated cropping and/or there are more regions where the mitigation requirement is not reached. This is the case for example in Ireland and Scotland where in the reference scenario in 2030 there is still ample potential, but in the sustainability scenario this potential disappears because there is no single perennial energy pathway in which an 80 % mitigation can be reached. At the same time it can also be seen that in 2020 in the sustainability scenario there is still potential in Northern Ireland and Scotland, while towards 2030, when the mitigation requirement shifts from 70 % to 80 % of fossil alternative, the dedicated crop potential disappears /Elbersen et al. 2012/.

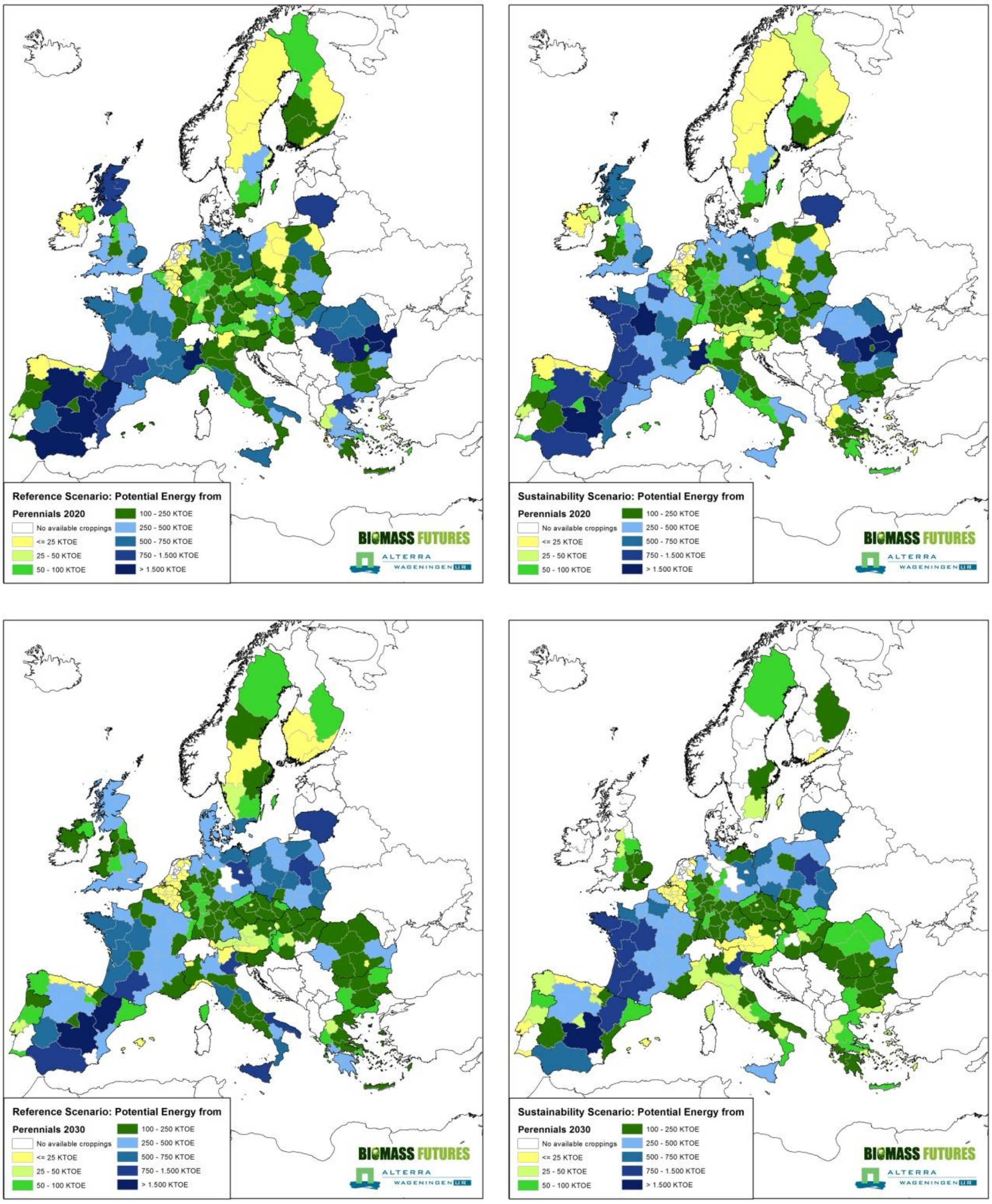

Fig. 3-12 **Dedicated cropping potential with perennials on released agricultural land in 2020 and 2030 in the reference and sustainability scenario /Elbersen et al. 2012/**

Table 3-8 Summary of cropping potential (PJ) in 2020 and 2030 /Elbersen et al. 2012/

PJ	Biofuel potential	Energy maize (biogas)	Dedicated woody perenn. crops	Dedicated grassy perenn. crops	Total
2020 reference	495	231	780	1,657	2,932
2020 sustainability	-	-	910	1,251	2,161
2030 reference	488	332	453	1,609	2,549
2030 sustainability	-	-	379	1,163	1,541

Within SUPRABIO, /Pedersen 2011/ looked into the logistics of lignocellulosic biomass. Apart from biomass availability and potential, distance from supplier to refinery, competing interests and scale of possible refinery are of interest. In the case of poplar, the author suggests that considering the above mentioned factors as well as the fact that poplar mainly is produced central and southern Europe, the best locations for a poplar-based biorefinery would be southern Germany. However, agro-climatic suitability for poplar might be even better in France (see Fig. 3-13) /Seyfried et al. 2008/.

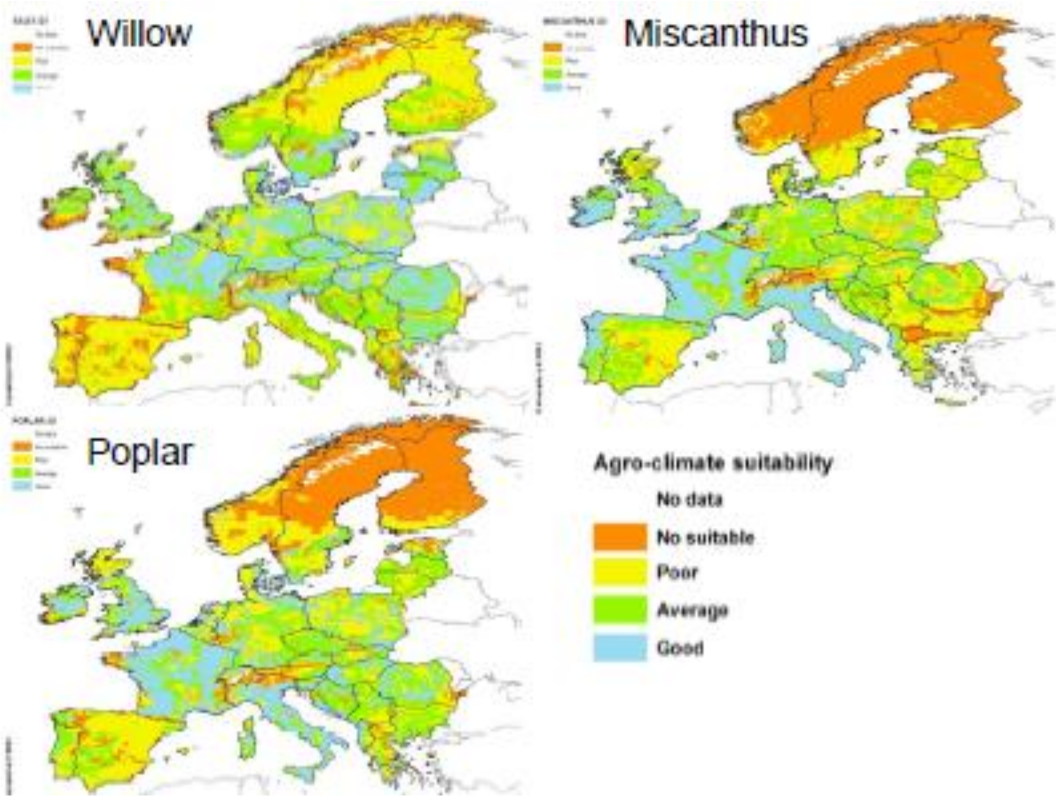

Fig. 3-13 Suitability map for willow, poplar and Miscanthus. Source: RENEW final report /Seyfried et al. 2008/

3.1.5 Summary

As stated in the introduction to chapter 3, biomass potential studies are providing important background information for socio-political decisions. In literature, a variety of such biomass potential studies for different geographical reference systems (from global to the local level) can be found, however, the results might differ by a factor of 10 even if the same geographical and temporal reference is considered.

This discrepancy is mainly due to the different underlying scenario assumptions such as the demographic development, the demand for food and feed, the demand of biomass for material use or the development of the energy demand. In addition, several other aspects such as the differences in potential definitions and biomass categorisation, different methodological approaches as well as the used data base play an important role /Rettenmaier et al. 2010a/.

The EC-funded projects EUWood (Real potential for changes in growth and use of EU forests), BEE (Biomass Energy Europe) and BiomassFutures have laid an important foundation for a better understanding of the biomass potential in Europe. This work will be continued within the FP7-funded S2BIOM project, launched in September 2013.

Having a bioenergy focus (results are expressed in unit energy rather than in unit [bio-]-mass), these studies suggest that the availability of land and biomass is limited, i.e. that various land and biomass uses are competing with each other. The European biomass potential is significantly lower than the energy demand in the EU. Europe will therefore be dependent on the import of biomass, especially from tropical countries. In the most existing studies on biomass potentials, however, land-demanding sustainability goals (e.g. biotope networks) and competing uses (particularly future material use of biomass) are only insufficiently addressed.

Therefore, for operators of biorefinery plants, scenario-based biomass potential studies are only helpful for a certain degree. Even though with an appropriate spatial resolution, areas with a high potential of biomass availability can be identified, this can in no case replace a detailed analysis of biomass availability at the site of the planned biorefinery. Biorefinery operators definitely need reliable forecasts.

In terms of the main SUPRABIO feedstocks (straw, forest residues and poplar short rotation coppice (SRC)), possible sites for biorefineries include northern France or central-northern Germany (in case of straw), Scandinavia or central Germany (in case of forest residues) and southern Germany or France (in case of poplar). Taking the example of sustainable straw potentials in Germany (between 8 and 13 million tonnes, depending on calculation method for soil organic carbon stocks), it becomes clear that the potentials are mainly located in central-northern Germany. High straw density is only found in a few administrative districts which limits the potential number of straw-based biorefineries in Germany. Since the capacity of a mature straw-based SUPRABIO biorefinery in 2025 was set to 400 kt dry biomass input, the potential number of units is probably in the range of 5-10 (rather than 20, which is the theoretical maximum).

3.2 Biomass competition

In many parts of the world, climate change and concerns of security of supply are the main drivers for the promotion of the use of renewable resources. One of the main pillars of most strategies to mitigate climate change and save non-renewable resources is the use of biomass for energy. Strong incentives have been put in place to increase the use of biomass for energy both in the transport as well as in the energy supply sector (heat and/or power generation), mainly in the form of mandatory targets (/U.S. Congress 2007/, /EP & CEU 2009/). Many countries have successfully implemented policies to foster biofuels and bioenergy, including tax exemptions or relief, feed-in tariffs or quotas. On the contrary, much less attention has been paid to the use of biomass for bio-based products, despite considerable potentials to mitigate climate change and save non-renewable resources /Rettenmaier et al. 2010b,c/. Nevertheless, the demand for industrial crops for biochemicals and biomaterials is expected to increase in the future since biomass is the only renewable source of carbon.

However, the use of biomass, and especially the use of dedicated crops for bioenergy and bio-based products, will put pressure on global agricultural land use /Bringezu et al. 2009/. At the same time, world population growth (projected to reach 9.3 billion people by 2050 according to /UN 2011/) and changing diets due to economic development, lead to an additional demand for land for food and feed production. As a consequence, the already existing competition for land for the production of food, feed, fibre (bio-based products), fuel (bioenergy) and ecosystem services[3] might even aggravate over the next decades. Concerns have been raised both in terms of social and environmental impacts since land use competition might jeopardise food security and give rise to social conflicts, and lead to an expansion of agricultural land through conversion of (semi–)natural ecosystems such as grasslands or forests (land use changes).

As already mentioned in the introduction to chapter 3, competition effects were deliberately disregarded in the previous analyses (or studied at most in form of sensitivity analysis), although - particularly in LCA - it is of great importance, what the agricultural land would be used for if the energy crop under investigation was not cultivated or what the biomass residue would be used for if it was not used as a biorefinery feedstock. These so-called reference systems for land use and biomass use are an essential part of LCAs for biomass-based systems /Jungk et al. 2002/. By definition, the agricultural reference system also comprises any change in land use or land cover induced by the cultivation of the energy crop.

In the following, details on LUC (sub-chapter 3.2.1) are described as well as its consequences for the environment (sub-chapter 3.2.2) and human beings (sub-chapter 3.2.3).

3 Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services /Millennium Ecosystem Assessment 2003/.

3.2.1 Land-use changes

Land-use changes involve both direct and indirect effects /Fehrenbach et al. 2008/. Direct land-use changes (dLUC) comprise any change in land use or land cover which is directly induced by the cultivation of the energy crop under investigation. This can either be a change in land use of existing agricultural land (replacing fallow / set-aside land or grassland) or a conversion of (semi)natural ecosystems such as grassland, forest land or wetland into new cropland. Indirect land-use changes (iLUC) occur if agricultural land so far used for food and feed production is now used for energy crop cultivation. Provided that the global demand for food and feed is constant, food and feed production is crowded out and displaced to another area where again unfavourable land-use changes, i.e. the conversion of (semi-)natural ecosystems, might occur. This phenomenon is also called leakage effect, crowding-out or displacement and is illustrated in Fig. 3-14.

Not only the production of energy crops in Europe leads to indirect land-use changes elsewhere in the world. Also the import of biomass or biofuel into Europe has such effects. This mechanism is shown in Fig. 3-15. In the producing country good agricultural practice and the absence of direct land-use change may be certified. However, the required area now being used by the new crop is no longer available for the previous food or feed production. As a result, food or feed production is displaced to other areas where in turn land-use changes may occur.

Scientific challenge: Quantification of indirect land use change (iLUC)

Indirect land-use (iLUC) change effects are difficult to verify empirically: they occur at global level and they are linked to the cultivation of energy crops (e.g. in Europe) via economic market mechanisms. These markets are very complex and the following dampening factors have to be taken into account:

- The use of by-products from the production of 1st generation biofuels plays an important role. If these by-products can be used as animal feed (e.g. rapeseed meal), they substitute conventional feed (e.g. soybean meal) and thus reduce the overall pressure on land.
- An increased demand for energy crops may trigger plant breeding and lead to increased yields, i.e. the use of one hectare of land for bioenergy does not necessarily mean that exactly one hectare of new land will be developed for the displaced food/feed/fibre crops. This **intensified production on existing agricultural** land might take place at the cost of agro-environmental programs.
- **Re-utilisation of set-aside land**, which had been taken out of use to control supply. As a side-effect, benefits for nature were obtained which are lost if this land is ploughed up again.
- **Reclamation of “idle”, “marginal” or “degraded” land**, which possibly needs high input and is associated with negative environmental impacts. Moreover, the extent of these types of land is unclear /Rettenmaier et al. 2012/.

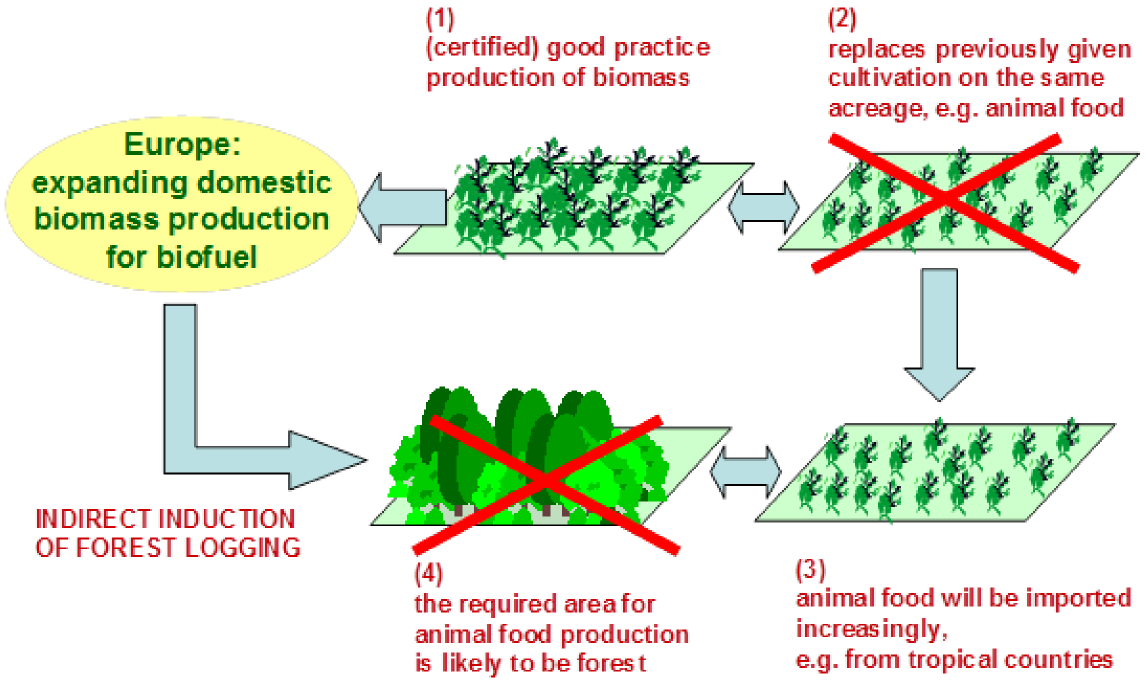

Fig. 3-14 **Exemplary mechanism of indirect land-use change due to biomass for bioenergy production in Europe /Fehrenbach et al. 2008/**

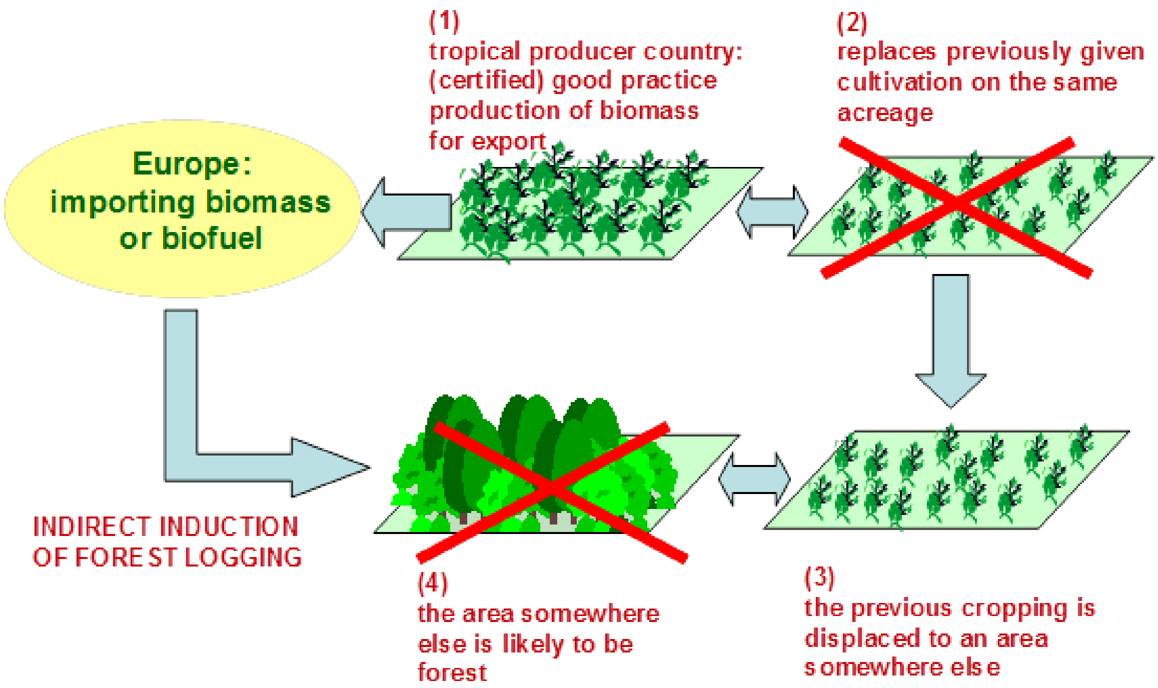

Fig. 3-15 **Exemplary mechanism of indirect land-use change due to biomass for bioenergy import to Europe /Fehrenbach et al. 2008/**

In contrast to direct land-use changes, indirect effects cannot be exactly allocated to the cultivation of a specific energy crop. In addition, they are closely linked to the increase of global food and feed production which results from global population growth and changing human diets due to economic development (increasing purchasing power). Therefore, several studies use partial and / or general equilibrium models (sometimes even linked to biophysical models) to quantify the iLUC effect of different non-food biomass expansion scenarios (/Melillo et al. 2009/, /Havlík et al. 2010/, /Britz & Hertel 2010/). Despite all efforts, up to date there is no commonly accepted method on how to quantify iLUC effects (/Banse et al. 2008/, /Kim et al 2009/, /Fehrenbach et al. 2009/).

Quantification of indirect land-use change (iLUC) is currently debated among scientist. The difficulties of quantifying the emissions from iLUC are:

- ILUC cannot be attributed individually to a specific biofuel production process, but depend upon the complex mechanisms of agricultural markets and prices of possible substitutes.
- Using one additional hectare for bioenergy production does not imply that one additional hectare of natural area needs to be converted to cropland.
- In some cases, bioenergy production has positive effects on land availability. For example, if by-products of bioenergy production are used as feed (soybean or rapeseed meal, sugar beet pulp etc.) they are substituting feed that would have to be produced otherwise.

Using historical date to empirically test iLUC approaches, /Kim & Dale 2011/ state that crop intensification may have absorbed the effects of expanding US biofuel production. However, /O'Hare et al. 2011/ argue that Kim and Dale have used statistical methods inappropriately and drawn incorrect conclusions. It is quite obvious that additional efforts are required to develop methodologies to observe indirect land-use change from historical data. Such efforts might reduce uncertainties in indirect land-use change estimates or perhaps form the basis for better policies or standards for biofuels.

With /Sheehan 2009/ it can be concluded that research on the quantification of iLUC still has a long way to go despite the already complex approaches of econometric modelling. He stresses at the same time that the uncertainties in the quantification of iLUC must not be a reason for disregarding them. This conclusion is shared by policy makers in Europe and the US: as iLUC may significantly influence GHG emissions it cannot be ignored when setting up policy support for biofuels that aim at reducing GHG.

Scientific challenge: Indirect land use change (iLUC) within LCA

At the same time, there is no consensus how to integrate indirect land-use changes into life cycle assessments (/Kløverpris et al. 2008/, /Liska & Perrin 2009/, /Finkbeiner 2013/). However, if iLUC is not considered in LCAs, the informative value of a LCA is very low since its results for greenhouse effect may not at all reflect reality.

Political challenge: Incorporation of iLUC into political framework

It still is an open question how to address iLUC in policy making. In the US, the Environmental Protection Agency (EPA) issued a proposal regarding the inclusion of iLUC. After receiving criticism from different national and international actors, the implementation of this proposal was put on hold by a five-year moratorium agreed on in the House of Representatives on 24 June 2009. The proposal will be subject to a scientific review in the meantime.

The European Commission stated in their report of 22 December 2010 /EC 2010a/ that there were still a number of deficiencies and uncertainties associated with the examined modelling approaches and that no action would be taken for the time being – the problem was postponed to the future. Finally, in 2012, the EC issued a proposal for a directive amending the RED /EC 2012/ which aimed at

- limiting the contribution that conventional biofuels (with a risk of ILUC emissions) make towards attainment of the targets in the Renewable Energy Directive;
- improving the greenhouse gas performance of biofuel production processes (reducing associated emissions) by raising the greenhouse gas saving threshold for new installations subject to protecting installations already in operation on 1st July 2014;
- encouraging a greater market penetration of advanced (low-ILUC) biofuels by allowing such fuels to contribute more to the targets in the Renewable Energy Directive than conventional biofuels;
- improving the reporting of greenhouse gas emissions by obliging Member States and fuel suppliers to report the estimated indirect land-use change emissions of biofuels.

In December 2013, the Energy Council examined a presidency compromise text of this proposed directive. However, since there were still some outstanding issues, no compromise could be achieved. Only on 13 June 2014, a political agreement was reached.

However, from a scientific point of view, this proposal is not fully convincing because i) limiting the share of biofuels from food crops to 7 % doesn't help solving the food insecurity problem (since the amount of land used is crucial and not the fact that some crops are edible and others aren't), ii) non-food crops (e.g. lignocellulosic crops) also cause indirect effects and iii) the strong push towards the use of biomass residues (through multiple counting) will probably cause undesired indirect effects ("indirect residue use change", iRUC) and market distortions.

3.2.2 Environmental impacts of competition-induced land-use changes

Both direct and indirect land-use changes ultimately lead to changes in the carbon stock of above- and below-ground biomass, soil organic carbon, litter and dead wood /Brandão et al. 2010/. Depending on the previous vegetation, the crop to be established and the agronomic practices, these changes can be neutral, positive or negative. For example, if fallow / set-aside land is transformed the carbon stock does not change significantly since it remains agricultural land (not subject to natural succession). The carbon stock change is therefore often set at zero. However, if (semi-)natural ecosystems such as grassland, forest land or wetland are converted, high carbon emissions can be caused. In contrast, the use of degraded land may even lead to carbon sequestration.

In addition to changes in carbon stocks, land use changes are having an impact on biodiversity as the conversion of (semi-)natural ecosystems into agricultural land most often results in a loss of biodiversity. Intensification of production on existing agricultural land (high inputs, monocultures etc.) and expansion of agricultural land (i.e. land use changes) at the cost of (semi-)natural ecosystems may lead to biodiversity loss. As these impacts are strongly depending on location, agricultural practices and previous land use, efforts towards a regionalization of LCA are needed. Methodological developments on how to address this impact category in LCAs are still ongoing (e.g. /Koellner & Scholz 2008/, /Koellner et al. 2013/).

3.2.3 Socio-economic impacts of competition-induced land-use changes

Impacts on food security: In terms of socio-economic impacts, LUC often has an impact on food security issues: diverting land away from food and feed production makes the affected people more vulnerable to rising food prices. In-depth insights into socio-economic impacts of biofuels and bio-based materials are provided by the GLOBAL-BIO-PACT project /Rutz & Janssen 2013/.

Further research is necessary to assess if biofuel production causes food insecurity and in how far biofuel mandates in developed countries and / or globally rising energy prices contribute to that (see recent FAO report produced within the “Bioenergy and Food Security Criteria and Indicators” (BEFSCI) project /FAO 2012a/). FAO’s BEFSCI framework /FAO 2012b/ provides some important findings and suggestions. For instance, it has identified a range of policy instruments that can be used to require or promote – either directly or indirectly – good environmental and socio-economic practices in bioenergy feedstock production, and to discourage bad practices.

3.2.4 Certification as a silver bullet?

In the light of a controversial discussion on the net benefit of biofuels and bioenergy, the European Renewable Energy Directive (2009/28/EC, RED) – which sets out a mandatory target for the share of renewable energy in the transport sector (10 % by 2020) – has established a number of mandatory sustainability criteria as well as reporting obligations (see Box 4–2).

Box 4–2 Mandatory sustainability criteria and reporting obligations in the RED

The European Renewable Energy Directive (2009/28/EC, RED) has established a number of mandatory sustainability criteria, which biofuels and bioliquids have to meet to be able to be counted towards the target (Articles 17(2) to 17(6)):

- Climate change-related criteria: The greenhouse gas emission (GHG) saving from the use of biofuels and bioliquids – including emission from direct land-use changes (dLUC) – shall be at least 35 % compared to the fossil fuel comparator (Article 17(2)). From 2017 and 2018, the GHG emission saving shall be at least 50 % and 60 %, respectively. Further details are found in Article 19 and Annex V (rules for calculating the GHG impact).
- Land cover-related criteria: Biofuels and bioliquids shall not be made from raw material obtained from land that in or after January 2008 had the status of i) land with high biodiversity value such as primary forest, protected areas or highly biodiverse grassland[4] (Article 17(3)), ii) land with high carbon stock such as wetlands or continuously forested areas (Article 17 (4)) or iii) peatland (Article 17(5)).
- Cultivation-related criteria: Agricultural raw materials cultivated in the Community shall be obtained in accordance with the common rules for direct support schemes for farmers (Cross Compliance) under the common agricultural policy and in accordance with the minimum requirements for good agricultural and environmental condition (Article 17(6)).

In addition, the RED sets out a number of so-called reporting obligations (not to be confused with mandatory criteria) by the European Commission (Article 17(7)):

- on national measures taken to respect the sustainability criteria set out in paragraphs 2 to 5 and for soil, water and air protection;
- on the impact on social sustainability in the Community and in third countries;
- on the impact on the availability of foodstuffs at affordable prices, in particular for people living in developing countries;
- on the respect of land-use rights;
- whether the countries that are a significant source of raw material have ratified and implemented the core Conventions of the International Labour Organisation (ILO);
- whether these countries have ratified and implemented the Cartagena Protocol on Biosafety and the Convention on International Trade in Endangered Species (CITES).

[4] Protected areas and *non-natural* highly biodiverse grassland may be used provided that the raw material production does not interfere with nature protection purposes and that the harvesting of the raw material is necessary to preserve its grassland status, respectively. Primary forests and *natural* highly biodiverse grassland, however, may not be used at all.

The mandatory sustainability criteria listed above so far only have to be met by liquid and gaseous biofuels for transport and bioliquids for heat and power generation, but not by solid and gaseous biofuels for heat and power generation nor by bio-based products. Although repeatedly demanded by many stakeholders, EC's report on sustainability requirements for the use of solid and gaseous biomass sources /EC 2010b/ so far hasn't been turned into a 'RED 2' directive. Instead, the EC proposed that the criteria could be voluntarily adopted by the member states. Mandatory sustainability requirements for bio-based products do not exist yet, however, voluntary criteria are increasingly discussed, e.g. in CEN/TC 411/WG 4 or within the German 'Initiative for the Sustainable Supply of Raw Materials for the Industrial Use of Biomass' (INRO). From an acceptance point of view, these should be considered when planning the raw material supply of a biorefinery.

Secondly, the mandatory sustainability criteria only address selected environmental impacts (GHG emissions and biodiversity) and omit impacts on soil, water and air as well as GHG emissions due to indirect land-use change (iLUC). But also the existing criteria regarding biodiversity insufficient, in particular with regard to the protection of forests with high biodiversity and to sustainability requirements for forestry (see below). There is an urgent need to include (and define) "highly biodiverse forests" under land cover-related criteria (Article 17) as well as "minimum requirements for good silvicultural and environmental condition" under cultivation-related criteria (Article 17(6)).

Thirdly, social / socio-economic impacts were excluded from the list of mandatory sustainability criteria due to their likely non-conformity with WTO standards. This should be verified once again. If it turns out that mandatory social sustainability criteria regarding working conditions and rights, land use conflicts and land tenure (see for example recent FAO guidelines /FAO 2012a/), health and safety as well as gender are incompatible with WTO standards, it could be an idea to set new mandatory environmental sustainability criteria regarding soil, water and air protection, i.e. criteria that have a strong link to ecosystem services (e.g. /UNEP et al. 2011/). This way, some social impacts affecting the constituents of well-being 'security', 'basic material for good life' and 'health' could possibly be covered indirectly.

Following the release of RED, the European standard EN 16214 was developed (Sustainable produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids) on the European scale, which further specifies the requirements of the RED in areas such as greenhouse gas balancing. At the same time, efforts are made to further promote the ISO standard 13065 at international scale (Sustainability criteria for bioenergy).

Sustainability criteria and certification are definitely steps in the right direction, however, they are not a silver bullet since the problem of displacement and indirect effects is not resolved. As long as only biomass used for liquid biofuels is certified 'green' instead of all biomass independent of its use, undesired land use changes will continue to occur.

3.3 Conclusions and recommendations

Conclusions

The analysis of biomass potential studies has shown that the availability of land and biomass is limited, i.e. that various land and biomass uses are competing with each other. Having a bioenergy focus (results are expressed in unit energy rather than in unit [bio-]-mass), land-demanding sustainability goals (e.g. biotope networks) and competing uses (particularly future material use of biomass) are only insufficiently addressed in most existing studies. Even without considering these aspects, it could be shown that the European biomass potential is significantly lower than the energy demand in the EU. Europe will therefore be dependent on the import of biomass, especially from tropical countries. This immediately raises questions in terms of security of supply (e.g. number of suppliers, quality of biomass feedstock, extreme weather events) and sustainability (especially in case of weak law enforcement and governance).

Sustainability criteria and certification are definitely steps in the right direction; however, they are not a silver bullet since the problem of displacement and indirect effects are not resolved. Indirect effects have to be taken into account - not only in terms of greenhouse gas emissions, but also with regard to biodiversity and food security - until all biomass across all sectors is covered and the global land use is effectively limited.

This is because the impacts associated with the production of biomass are fairly independent of its use, i.e. whether the feedstock is used for biofuels, bio-based products or for other purposes. Therefore it is important to apply the same rules for all agricultural products irrespective of their use for food, feed, fibre or fuel. As long as only biomass used for liquid biofuels is certified ‘green’, undesired land use changes will continue to occur. Therefore, mandatory sustainability criteria should urgently be expanded to solid and gaseous biofuels for heat and power generation as well as by bio-based products.

Recommendations

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

- In the mid- to long-term, national and European biomass allocation and land use plans should be compiled in a participatory manner. Because environmental burdens and social impacts of resource scarcity in particular do not possess an adequate price, market mechanisms cannot replace these plans.
- Regional planning, which comprises project planning guidelines, should be based on this premise. This framework should also rule out the cultivation of cultures that are unsuited to the local conditions. For example, the quantity of agricultural or forest residues that can be extracted without impairing soil fertility, depends on the location. Moreover, regional planning is also important because market partic-

ipants with individual high biomass demand and large market power are created with the aid of public funding, and may be additionally created by establishing bio-refineries. Distortions in the biomass market can and must be mitigated by appropriate planning.

- As long as this is not the case, binding area- and cultivation-specific sustainability criteria should be uniformly defined as preventive measures for all applications, that is for bio-based materials, chemicals, fuels and energy, as well as for food and feed.

4 Annex: SWOT matrices

4.1 Feedstock provision

Table 4-1 Wheat straw

	Success factors	Failure factors
Internal factors	**Strengths** • Farmers have an additional benefit since the straw is used as a high value product • No direct competition to food production • Cheap biomass for biorefineries because of low competition (residues) • Straw is an agricultural by-product → No additional land use • High cultivation experience since straw is a by-product of an established crop	**Weaknesses** • High competition with other use options: - Biomass based power plants - Animal bedding - Forage production • Balled straw has only a low density (ca. 150 kg / m^3) → Logistics can be costly • Straw is harvested only once a year • High storage requirements (low density, rain protection) • Trend: The higher the grain yield the shorter the length of the straw • Straw availability depends on grain harvest → Risk for harvest failures • Soil organic content decreases if straw is harvested regularly • Thermochemical route: Higher production costs compared to wood residues
External factors	**Opportunities** • Straw requires only little water (so far) • Long stem varieties are again used by the farmer	**Threats** • Soil fertility (soil biodiversity and soil carbon content) may be harmed if straw is extracted from fields excessively → may increase the erosion risk • Straw extraction from fields means also nutrient removal →need for more mineral fertilisers • Competition of other energetic uses (biomass heating plants etc.) may become important • Climate change can induce several threats, e.g.: - Droughts can decrease straw availability and increase competition with forage and bedding production - Additional water demand may be required

Table 4-2 Wood residues

	Success factors	Failure factors

Internal factors	**Strengths**
	• Income opportunity for the forestry sector
	• No direct competition to food production
	• Feedstock potential is high - Example: ca. 48 Mt wood could be cut annually in Germany
	• Higher density compared to straw → less expenditures for logistics
	• For forest trees less external inputs are needed (no fertiliser or pesticides)
	• A sustainable use of forests plays an important role for climate protection, since forests are carbon sinks
	• Thermochemical route: Lower production costs compared to straw and poplar
		Weaknesses
		• Compared to straw and SRC poplar, forest trees generate only low yields per hectare
		• Specific needs for the biorefinery by special breeding or cultivation efforts cannot be fulfilled
		• High competition with other use options:
		  - Competition to direct energetic use (combustion)
		  - Competition to direct material use (timber work etc.)
		  - Example: Wood deficit of 12 Mt in Germany expected by 2020 without taking biorefineries into account
		• Traditional domestic log-wood heating also competes with a use in biorefineries and is hard to change
		• Forest ownership structure in Europe hinders wood mobilisation for centralised processing (many private owners of small forests; villages want to become energy independent)
		• Chipping into small particles could be energy demanding
		• Large transport distances → high expenditures for logistics

External factors	**Opportunities**
	• Saw dust can be pelletized and used as by-product
	• There is a tendency in European bioenergy policy towards lower support for dedicated bioenergy crops. Use of forest wood in biorefineries could benefit from this tendency and generate higher added value from wood
	• European bioenergy policy could stronger support wood by arguing with better environmental performance than agricultural crops
		Threats
		• A more sustainable use could prevented
		• An increased demand could be an incentive for unsustainable forest management practices
		• Climate change can induce several threats, e.g.:
		  - Extreme weather events such as storms
		  - New pest infestations can cause heavy damages
		• Increased nature conservation strategies can cause use restrictions in forests
		• Risk of mixing-up stem wood and residues after chipping→ certification system necessary

Table 4-3 **SRC poplar**

	Success factors	Failure factors
Internal factors	**Strengths** • Income opportunity for forestry sector / farmers • Increased feedstock availability by using SRC poplar and low risks for shortcoming • Produced widespread over Europe (especially in Central and Southern Europe) • Fast growing crop • Promising energy crop • Non-food crop → no direct competition for use as food • Low input crop (grows in difficult soil conditions) • Big phytoremediation potential • High content of cellulose, hemicelluloses and lignin • Easier storage compared to straw • Genome (DNA) is entirely unravelled → great potential for breeding dedicated characteristics • Carbon sink (young forests store a great amount of CO_2) • High product yields when using clean poplar wood • Dedicated feedstock allows optimisation of pyrolysis oil production process (thermochemical route) • Net efficiency similar to those of straw (biochemical route)	**Weaknesses** • Resprouting (coppicing) is limited • Susceptibility to rust disease • Requires land for cultivation → direct and indirect land use change effects possible • Establishing short rotation coppice on rich agricultural soils can be cost intensive • Little knowledge on SRC cultivation and its market opportunities amongst farmers • Bind farmers for many years → low flexibility for the farmer, thus, eventually low acceptance • Competition issues: more attractive use alternatives compared to wood residues • Will compete with e.g. wheat for food / feed production • Dedicated crop • Not as available as wood residues • Probably higher price for cultivated feedstock compared to use of residues • Extra handling of biomass prior to pre-treatment may be needed → could be energy demanding • Processing only partially tested on lab scale • Higher production costs than wood residues (thermochemical route) • At the end of the cultivation period high efforts are needed to restore arable land • Long transport distances → high expenditures for logistics • Biochemical route: results only modelled for batch processes
External factors	**Opportunities** • Utilisation of a substrate that is normally burned • Low utilisation rate so far • High breeding potential • May positively affect the use of farmland for alternative productions • Higher availability allows bigger plant capacities and hence a more efficient conversion • SRCs can be established on industrial waste or other marginal lands • Environmental impacts are lower compared to most annual crops	**Threats** • Economic risk for farmers if another crop is preferred by the industry • No governmental support • Utilisation may affect the value of the crop • Fellings often restricted to certain times of year • Competition with other biomass crops and for land with food production

	(positive impacts on soil, water resources and biodiversity) • Since there are successful trials, the knowledge on performance and best cultivation practices could now be spread amongst farmers • Long term contracts can have positive effects for both, farmers and processors • Wood supply can be enlarged that eases pressure on forests	

4.2 Biochemical route

Table 4-4 Standard configuration (ethanol as final product)

	Success factors	Failure factors

Internal factors	**Strengths**
	<u>Pre-treatment</u>
	• Pre-treatment is demonstrated up to demo scale (for wheat straw)
	<u>Production of Ethanol</u>
	• Enzymatic hydrolysis is demonstrated up to pilot scale (for wheat straw; basic configuration)
	• Mature technology for fermentation processes (basic configuration)
	• Mature technology for downstream processes
	• SScF (mature configuration)
	  • Compared to SHcF higher electricity export → better net efficiency
	<u>Overall</u>
	• Relatively high net efficiency
	• Based on non-food biomass
	• Huge market potential
	  - Rising energy demand worldwide
	  - Limited resources for fossil fuels and 1st generation biofuels
	  - Ethanol can be used as substitute of gasoline in existing engines
		Weaknesses
		<u>Pre-treatment and enzymatic hydrolysis</u>
		• Device construction: Wear and corrosion by acids
		• High capital expense (CAPEX) for pre-treatment unit, high operating costs (OPEX) for steam and enzymes
		<u>Production of ethanol</u>
		• High costs for enzymes
		• Cooling needed (100°C out of pre-treatment to 55°C → but heat can be used for heating in other processes)
		• Use of GMOs (low acceptance, high requirements for process management, restrictions for use of residues)
		• High capital expense (CAPEX) for distillation unit and bioreactor
		• High operating costs (OPEX) for fermentation nutrients
		• SScF (mature configuration)
		  - Immature state
		  - Ethanol yield and productivity are unknown → possibly too low
		<u>Wastewater</u>
		• High water consumption; must rely on effective wastewater treatment technology for water recycling
		• Technologies for the gasification of the solids from wastewater treatment are still challenging
		<u>Gas turbine sub scenarios</u>
		• High investment costs for compressors and turbines

External factors	**Opportunities** Pre-treatment and enzymatic hydrolysis • Development of continuous pre-treatment → advantages to continuous downstream processes Production of ethanol • SScF (mature technology) Successful development of simultaneous saccharification and co-fermentation (SScF) → lower enzyme demand → lower OPEX/CAPEX costs Overall • Subsidies to be expected • Licensing of intellectual property • Increase in amount of flex fuel vehicles • Increase in crude oil prices • Integration in cellulosic ethanol plants in the future Waste treatment • Waste treatment process BTG is developing could improve heat & power integration in biorefinery but is still far from market	**Threats** Pre-treatment and enzymatic hydrolysis • Failure in efficient pre-treatment of other feedstocks Production of ethanol • Microorganisms cannot be recycled → might lead to additional costs • SScF fermentation unsuccessful (mature configuration) Overall • Competitors may succeed with superior alternative 2^{nd} generation biofuel concepts • Loss of interest by policy makers and loss of subsidies • Other transportation fuels will gain momentum in the market • Government regulations in agriculture • Decline in crude oil prices • Acceptance of shale gas may reduce support for biofuels

Table 4-5 Alternative route: Production of mixed acids

	Success factors	Failure factors
Internal factors	**Strengths** Production of mixed acids • Enzymatic hydrolysis is demonstrated up to pilot scale (for wheat straw; basic configuration) Overall • Slightly higher prices for mixed acids than for fuels • Rising market potential • Hydrogen could be a valuable by-product	**Weaknesses** Production of mixed acids • High costs for enzymes • Not fully demonstrated technology. Immature processes: bacterial fermentation and acid separation • Low yields because of product inhibition effects • Difficult to predict the precise fermentation outcome • Unwanted side products: acetate, lactate • Separation is very energy demanding → expensive, environmental burden Overall • Long production time (days) compared to chemical production
External factors	**Opportunities** Production of mixed acids • The developed fermentation platform can be used for other products (alcohols etc.) Overall • Young research field: Improvements in breeding of microorganisms and technological improvements likely	**Threats** Overall • Failure to further develop immature technologies • Other technologies might develop faster and be more competitive • Eventually too cost intensive

4.3 Thermochemical route

Table 4-6 Standard configuration (FT diesel as final product)

	Success factors	Failure factors

Internal factors	**Strengths**
	Pyrolysis
	• Fast pyrolysis technology: No carrier gas needed, robust and compact process, extra heat available from burning charcoal to dry feedstocks
	• Plant is self-sufficient in energy → electricity export
	• Highly flexible towards feedstock: suitable for a large variety of biomass (residue) types
	• Hydrogen could be a valuable by-product
	Gasification
	• Demonstrated technology available
	• High pressure oxygen blown entrained flow gasifier (PEBG)
	• High temperature gasifier→ low tar content in syngas
	• Continuous flow of oil
	• Fuel flexible technology
	FT diesel production
	• Enhanced economy at lower scale compared to convent. FT production
	  • Increased heat and mass transfer by plated reactors
	  • Reduced downtime (exchange of single modules possible)
	Overall
	• Runs on residues (no direct competition to food)
	• Two-step-process (pyrolysis & gasification) allows a decentralised processing of biomass and hence lower transportation expenditures
	• Processing of oil can be de-coupled from bio-oil production in time, scale and place → makes on demand processing easy
	• Huge market potential: Rising energy demand world-wide, limited resources for fossil fuels and 1st generation biofuels
	• High conversion rates & product yields compared to biochem. proc.
	Wastewater
	• Compared to the biochemical route no additional water is needed
	High pressure sub scenario
	• Calculations show higher efficiencies and lower CAPEX costs
		Weaknesses
		Pyrolysis
		• Biomass has to be sized in small particles → energy demanding
		• Toxic risk of CO for personnel
		• No fixed specifications for handling and transportation available for pyrolysis oil (REACH)
		Gasification and syngas cleaning
		• PEBG gasifier not yet commercial technology
		• Synthesis gas is poisonous and explosive
		• Steam is needed for syngas cleaning
		• Containment / ceramic must withstand the temperature and ash
		FT diesel production
		• Potentially low catalyst lifetime due to poisoning or carbon deposition →high catalyst demand, high costs
		• Exothermic process → difficult temperature control
		• Micro reactors not yet commercial technology
		• Large amount of light hydrocarbons and LPG are produced
		Wastewater:
		• No strategy for managing the brine stream
		Overall
		• The significance of ash management is not clearly understood, e.g. if nutrients could not be recycled and how that would impact on sustainability
		• Low net efficiency compared to the biochemical pathway

<table>
<tr><th>External factors</th><th>Opportunities</th><th>Threats</th></tr>
<tr><td></td><td><u>Pyrolysis</u>
• Ash could be used as fertilizer for agriculture
<u>Gasification</u>
• Commercialisation of PEBG (pressurized entrained flow gasifier) → High gasifier temperature leads to relatively clean gas → facilitates FT diesel / DME production
• Fuel flexible gasifier → many different biomass materials may be considered as feedstock
• The produced syngas can be converted to many different chemicals, products or IGCC
• Policies regarding gasifier technology, subsidies
<u>FT diesel production</u>
• Potential for downsizing process allied with reducing plant costs
• Micro reactors increase process efficiency and stability of the process (by increased heat removal, high mass transfer rates and high pressure resistance)
<u>Overall</u>
• Subsidies to be expected
• Licensing of intellectual property
• Route enables synthesis of a large variety of products from a large variety of feedstocks: flexibility advantageous in supply and demand market</td><td><u>Pyrolysis</u>
• Failure to further develop immature technology to commercial technology
<u>Gasifier</u>
• Restrictions for implementation because of explosion risks
• Impurities from bio feedstock may require special gas clean up compared to fossil fuel gasifier
• Competition of biomass
• Sustainable outtake of biomass
• High gas purity cannot be achieved → lowering lifetime and efficiency of catalysts
<u>FT diesel production</u>
• Failure in development of micro reactors
<u>Overall</u>
• Competitors may succeed with superior alternative 2nd generation biofuel concepts
• Loss of interest by policy makers and loss of subsidies
• Decline in crude oil prices
• It is not clear if PEBG will provide a superior performance advantage compared to conventional gasifiers
• Acceptance of shale gas may reduce support for biofuels</td></tr>
</table>

Table 4-7 Alternative route: Production of DME

<table>
<tr><th></th><th>Success factors</th><th>Failure factors</th></tr>
<tr><td>Internal factors</td><td>Strengths
<u>Overall</u>
• Technology already demonstrated
• If used as fuel → high market potential
• Lower production costs compared to FT diesel
• Higher energy efficiency compared to FT diesel</td><td>Weaknesses
<u>DME production</u>
• Exothermic process → difficult temperature control
• Micro reactors not yet commercial technology
• Thin catalyst layers susceptible to poisoning, no catalyst reserve within reactor
<u>Overall</u>
• Vehicle adaptations are necessary</td></tr>
</table>

External factors	Opportunities DME production • Micro reactors increase process efficiency and stability of the process (by increased heat removal, high mass transfer rates and high pressure resistance) • Potential for downsizing process allied with reducing plant costs	Threats DME production • Failure in development of micro reactors • Not achieving desired conversion and yield of DME

4.4 Add-on technologies

Table 4-8 Algae production

	Success factors	Failure factors
Internal factors	**Strengths** • No need for agricultural land • High biomass productivity • Can be used to produce high value products: Omega-3-fatty acids, β-glucans	**Weaknesses** • Algae for waste valorisation is immature technology • Lipid extractions are immature technologies • Lighting: sunlight not continuous, artificial light energy demanding • Not yet commercial technology → further research needed • High water demand • Seasonality of algae → demand is varies but output from the biorefineries are constant • Optimising biorefineries in respect to water and heat, algae add-on might be needless • It is not clear to what extent waste water needs to be cleared to be fed into the photobioreactor
External factors	**Opportunities** • Capturing of CO_2 emissions from industrial processes (challenge: if toxicity caused by flue gas impurities can be handled) • O_2 emissions can possibly be used in biochemical processes • Energy costs might be reduced by using sun light (challenge: irregularity in solar radiation) • Can be used to clean waste water streams (challenge: composition of waste water stream has to be known, to select algae accordingly and to add missing nutrients)	**Threats** • Might turn out to be too energy demanding (lighting, pumping) • Product separation and use might turn out to be too energy demanding / too costly • Value of products produced from algae grown on components from waste streams unknown. Must pass an End-of-Waste control

Table 4-9 Hydrogenation of seed oils

	Success factors	Failure factors
Internal factors	**Strengths** • High product quality compared to fossil diesel: high cetane number, low sulphur content, low exhaust emissions • Product (linear alkanes) that can be mixed with fossil diesel without modifying the engines • Demonstrated technology → low risks of R&D failure • Almost unlimited market for fuels • Wide variety of feedstocks	**Weaknesses** • Exothermic process → can harm catalyst and hence cause high costs, safety risks • H_2 needed → high costs for H_2 supply
External factors	**Opportunities** • Development of improved heat and mass transfer in SUPRABIO →increased catalyst life span by avoiding rapid temperature increase • Might become cheaper than esterification • Staged hydrogen addition may improve selectivity of product	**Threats** • Not yet commercial → other technologies might turn out to be cheaper

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6 Abbreviations

BTG

Biomass Technology Group

D

Deliverable

DME

Dimethylether

DHA

Docosahexaenacid

EPA

Eicosapentaenacid

EtOH

Ethanol

FAME

Fatty Acids Methyl Ester

FT

Fischer Tropsch

GHG

Greenhouse gases

GMO

Genetically modified organism

IGCC

Integrated gasification combined cycle

IUS

Institut fuer Umweltstudien Weibel und Ness GmbH

kt

Kilo tonne

LC

Life cycle

LPG

Liquefied petroleum gas

MEK

Methyl ethyl ketone

PEBG

Pressurised entrained-flow biomass gasification

SHcF

Separate hydrolysis and co-fermentation

SRC

Short rotation coppice

SScF

Simultaneous saccharification and co-fermentation

SWOT

Strengths, weaknesses, opportunities, threats

WP

Work package

Yr

Year