This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691874

Sustainable exploitation of biomass for bioenergy from marginal lands in Europe

SEEMLA

Sustainable exploitation of biomass for bioenergy

from marginal lands in Europe

SEEMLA Project Grant Agreement no. 691874

Final report on environmental assessment covering LCA & LC-EIA

Heidelberg, October 31st, 2018

INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH HEIDELBERG

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I. About the SEEMLA project

The aim of the Horizon 2020-funded 'Sustainable exploitation of biomass for bioenergy from marginal lands in Europe' (SEEMLA) project is the reliable and sustainable exploitation of biomass from marginal lands (MagL), which are used neither for food nor feed production and are not posing an environmental threat. The project will focus on three main objectives: (i) the promotion of re-conversion of MagLs for the production of bioenergy through the direct involvement of farmers and forester, (ii) the strengthening of local small scale supply chains, and (iii) the promotion of plantations of bioenergy plants on MagLs. The expected impacts are: Increasing the production of bioenergy, famers' incomes, investments in new technologies and the design of new policy measures. FNR will coordinate the project with its eight partners from Ukraine, Greece, Italy and others from Germany.

Project coordinator

Agency for Renewable Resources		
Fachagentur Nachwachsende Rohstoffe e.V.	FNR	Germany

Project partners

Salix Energy Ltd.	SALIX	Ukraine
Institute for Bioenergy Crops & Sugar Beet of the National Academy of Agricultural Science	IBC&SB	Ukraine
Legambiente	LEGABT	Italy
Democritus University of Thrace	DUTH	Greece
Decentralized Administration of Macedonia and Thrace	DAMT	Greece
Brandenburg Technical University Cottbus-Senftenberg	BTU CS	Germany
ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH	IFEU	Germany

II. About this document

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III. Background

This 'Final report on environmental assessment covering LCA & LC-EIA' (Deliverable D4.3) presents the final results, conclusions and recommendations of the environmental assessment within the SEEMLA project. It corresponds to the work description of tasks 4.2 (Life cycle assessment, LCA) and 4.3 (Life cycle environmental impact assessment, LC-EIA) in the Grant Agreement Annex I of the Horizon 2020 project SEEMLA (GA no. 691874).

- Task T4.2 *Short description* (Lead: IFEU)

Task 4.2 will evaluate the environmental impacts associated with the general SEEMLA value chains identified in WP2 and the value chains in the specific pilot cases established in WP5, each of them in comparison to their reference systems. This will be done by means of life cycle assessment (LCA), which addresses the environmental aspects and potential environmental impacts (e. g. use of resources, environmental consequences of emissions) of a product throughout its life cycle. With this, all inputs and outputs along the full life cycles of all systems under investigation will be considered and concluded upon in terms of their environmental implications such as greenhouse gas savings (carbon footprint) and energy savings. Which further environmental impacts are to be analysed (e. g. acidification, eutrophication, stratospheric ozone depletion and ozone creation) will be agreed in the internal workshop in month 10 (see task 4.1).

In general, IFEU will carry out screening LCAs taking into account the guidelines of ISO 14040/14044 [ISO 2006a; b] on product life cycle assessment. Prior to executing the LCA, its methodology is adjusted to the needs and specifications of the SEEMLA approach: For instance, if biofuels for transportation are involved, the biofuel performance will be analysed also according to the Renewable Energy Directive [European Parliament & Council of the European Union 2009] and if biomass is used to produce green electricity and / or heat / cooling, the respective EC Directive may be applied [European Commission 2014a]. Another example is the reference unit used for the analysis: In general, the environmental implications will be analysed on area basis – however, sensitivity analyses necessary for a thorough understanding of the results may require an analysis on raw material or usage basis.

Overall, weak points and optimisation potentials will be identified and the best (or optimised) SEEMLA value chains will be determined through the analysis of different scenarios. Life cycle improvements with especially high environmental potentials will be depicted.

On the basis of the findings during the course of the analyses, this task updates all necessary changes to definitions, settings, system boundaries and methodology in an iterative way and feeds back changes relevant to the WP or the project to task 4.1. The calculations are then performed on this new basis.

Results consist in both quantitative data and qualitative information. All of them regarding the pilot cases will be transferred to WP5. General results from this task will be transferred to WP6 according to the specifications established in that WP. This includes also conclusions and recommendations towards strategies to exploit sustainable MagL use for bioenergy provision with respect to LCA aspects such as greenhouse gas savings.

- Task T4.3 *Short description* (Lead: IFEU)

In task 4.3, a life cycle environmental impact assessment (LC-EIA) is performed addressing site-specific environmental impacts with a generic (life-cycle) approach, which are not considered in LCAs but are important especially with biomass provision systems. It covers impacts such as biodiversity, fauna and flora, on soil and on water. The methodological approach is used to cover the full life cycles and uses elements from the so-called environmental impact assessment (EIA), a standardised methodology for analysing proposed projects regarding their potential impact on the environment.

Like the LCA, the LC-EIA is executed on the general SEEMLA value chains from WP2 as well as those identified in WP5 in the specific pilot cases. Also here, a comparison is made versus the respective reference systems. For this, the LC-EIA methodology must be adapted to the specific needs of the SEEMLA approach by choosing the most suitable reference system or systems as well as relevant impacts to be considered. Many of the qualitative information concerning the environmental impact as far as possible will be transferred into a matrix of semi-quantitative data. Concluding, the task will identify possible optimisation options and the best SEEMLA value chains.

During the progress of the work, updates to definitions and settings might be necessary. Once this happens, the new characteristics will be returned back to task 4.1 and used for the further analysis. This task will transfer its results to WP5 and WP6, respectively, following the system boundaries and needs determined there. Also, conclusions and recommendations with respect to site-specific environmental impacts will be supplied to WP 5 and WP6 according to their requests and needs.

IV Acknowledgements

The authors would like to thank all SEEMLA partners sincerely for the close and successful collaboration as well as fruitful and stimulating discussions within the SEEMLA project. We are very grateful to Werner Gerwin, Frank Repmann (BTU CS), Fotios Kiourtsis, Dimitrios Keramitzis (DAMT), Vadym Ivanina, Oleksandr Hanzhenko (IBC&SB), Iryna Gnap, Maksym Zibtsev and Karine Podolian (SALIX) who kindly provided data and information on their respective pilot cases and / or country-specific data and took us on interesting field trips. The provided data and information as well as the observations from the field trips formed an important basis of the environmental and socio-economic assessment, respectively. We would also like to thank Diego Piedra-Garcia (FNR), Frank Repmann (BTU CS) and Despoina Vlachaki (DUTH) for reviewing the final draft of this document. Last but not least, we would also like to thank our IFEU colleagues Heiko Keller, Tobias Wagner and Marie Hemmen for their support, including internal reviews and valuable suggestions.

V Executive Summary

The aim of the Horizon 2020-funded 'Sustainable exploitation of biomass for bioenergy from marginal lands in Europe' (SEEMLA) project is the reliable and sustainable exploitation of biomass from marginal lands, which are used neither for food nor feed production and are not posing an environmental threat. The expected impacts are: Increasing the production of bioenergy, famers' incomes, investments in new technologies and the design of new policy measures. For details see www.seemla.eu.

This study analyses the environmental impacts of different options for cultivation and use of perennial energy crops (grasses and woody biomass with up to 20 years rotation time) on marginal land. In order to cover the spectrum of all potential environmental impacts as completely as possible, the environmental assessment was carried out using a combination of two methods: screening Life Cycle Assessment (LCA) and Life Cycle Environmental Impact Assessment (LC-EIA).

The most important results of our environmental assessment are as follows:

- **The well-known pattern of environmental impacts is confirmed**: with regard to standard environmental impacts, there are no significant differences between bioenergy from standard agricultural land and bioenergy from marginal land (compared to conventional energy in each case): Environmental benefits through the reduction of greenhouse gas emissions and non-renewable energy use tend to be offset by disadvantages with regard to other environmental impacts, including acidification, eutrophication and ozone depletion.

- **The range of results is wider than usual**: The results for bioenergy production on marginal land show an exceptionally wide range, which is due to the many energy crops and use options available for selection as well as to the very different site qualities.

- **Woody biomass is sometimes better than herbaceous biomass**: although perennial grasses have greater advantages in terms of energy and greenhouse gas (GHG) emission savings, they also have greater disadvantages in terms of other environmental impacts. Woody biomass, on the other hand, has hardly any disadvantages. On sensitive sites, trees with a 20 year rotation period are particularly recommended.

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- **The central challenge is the conservation of biodiversity**: the greatest environmental shortcoming in the future use of marginal land is the high risk of biodiversity loss. This has to be counteracted by support programmes that support cultivation only on marginal land that has not been used at all for at least 5 years (i.e. not even extensively) and at the same time exclude land with a high carbon stock and / or high biodiversity value. Since marginal land is often a sensitive site, ambitious requirements should be met for the cultivation of energy crops that are compatible with nature conservation, such

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as greater distances from surface waters, greater field margins, staged transitions between open land and forests, etc. Dedicated guidelines would be helpful in this respect.

- **Bioenergy from marginal land competes with alternative land uses**: Bioenergy not only competes with biodiversity conservation, but also with other alternative uses of the marginal land, some of which have greater environmental benefits (e.g. higher GHG savings) and fewer disadvantages, such as ground-mounted photovoltaic (PV) systems.

- **Land use and land allocation plans are necessary**: In the sense of a sustainable use of marginal land, it is necessary to address and resolve trade-offs between nature conservation objectives, bioenergy production and other alternative uses. A suitable means for this would be the preparation of national or supranational land use and land allocation plans.


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In addition to the main results listed, many other detailed results were derived within the framework of this study, which are explained in this report; see in particular chapters 4 and 5.

Overall, the cultivation of perennial energy crops on marginal areas and their use as bioenergy carriers can be associated with environmental benefits in terms of saving non-renewable energy and GHG emissions. For these advantages to be effective, however, a number of boundary conditions must also be met in order to minimise negative impacts, in particular on biodiversity. This must be taken into account when designing financial incentives so that public money is actually used for the benefit of the environment and society.

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1 Introduction

This chapter explains the background of the EC-funded SEEMLA project (Sustainable exploitation of biomass for bioenergy from marginal lands in Europe, GA No. 691874). Furthermore the objective of this study and the concept of the environmental assessment are described.

The SEEMLA project

Focussing on perennial, lignocellulosic crops, the main objective of the SEEMLA project is the establishment of suitable innovative land-use strategies for a sustainable production of plant-based energy on marginal lands while improving general ecosystem services. The use of marginal lands could contribute to the mitigation of the fast growing competition between traditional food production and production of renewable biomass resources on arable lands.

The project will focus on three main objectives:

- the promotion of re-conversion of marginal lands for the production of bioenergy through the direct involvement of farmers and foresters,
- the strengthening of local small-scale supply chains, and
- the promotion of plantations of bioenergy plants on marginal lands.

An essential part of the project is to ensure the environmental and socio-economic sustainability of the foreseen actions, which is the aim of work package 4 (WP 4).

Objective of this environmental assessment

The objective of this environmental assessment is to analyse all environmental implications associated with bioenergy from perennial, lignocellulosic crops cultivated on marginal land in Europe and to highlight optimisation potentials. The environmental assessment provides answers to the goal questions which were defined in Deliverable D 4.2 [Gärtner et al. 2018]:

- Which implications on environment are associated with the proposed SEEMLA concepts, i.e. with
    - the use of marginal land as defined in WP 2,
    - the pilot cases carried out in WP 5, and
    - the general SEEMLA exploitation scenarios defined in WP 6?
- Do some crops show a better environmental performance than others?
- Do some use options show a better environmental performance than others?
- Which life cycle steps and unit processes determine the results significantly and which optimisation potentials can be identified?
- Are there sites or types of land that should be prioritised for bioenergy production?
- Which boundary conditions have to be met in order to advocate bioenergy production from marginal land in Europe?

General scientific approach

Environmental assessment within this project includes two methodological approaches: the life cycle assessment (LCA) and the life cycle environmental impact assessment (LC-EIA). Both methodologies are described in detail in the corresponding sections 4.1 and 5.1.

Comparative screening life cycle assessments quantify the potential environmental impacts of the SEEMLA product chains along their entire life cycle (i.e. from cradle to grave) and compare these to the environmental impacts associated with the conventional reference products that are providing the same utility. LCA allows a quite comprehensive consideration of relevant environmental problems. Nonetheless, especially those environmental impact categories capturing local and site-specific impacts (e.g. biodiversity and water use), are still under development.

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

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

Table 1-1 Overview of environmental impact categories covered in this study.

Environmental impact category	Covered by LCA	Covered by LC-EIA
Climate change	X	–
Ozone depletion	X	–
Human toxicity	–	–
Ecotoxicity	–	(X)
Particulate matter formation	X	–
Ionising radiation	–	–
Photochemical oxidant formation	X	–
Terrestrial acidification	X	–
Freshwater eutrophication	X	(X)
Marine eutrophication	X	–
Land use	(X)	X
Resource depletion: water	–	X
Resource depletion: phosphate rock	X	–
NREU: Non-renewable energy use	X	–

2 Common definitions and settings

All elements of an environmental and socio-economic sustainability assessment should be based on the same common definitions and settings in order to ensure consistency. These common definitions and settings are used both in this environmental assessment and in the socio-economic assessment [Keller et al. 2018]. For an extensive description of the overall definitions and settings see the Deliverable D 4.2 [Gärtner et al. 2018]. In the following sections, these definitions and settings are summarised.

For additional specific definitions, settings and methodological aspects of the two approaches of the environmental assessment please refer to sections 4.1 for LCA and 5.1 for LC-EIA, respectively.

2.1 Goal definition

The comprehensiveness and depth of the environmental assessment can differ considerably depending on its goal. This is similar to LCA studies, in which the scope of the study, including the system boundary and level of detail, depends on the goal and the intended application of the study. In addition, the goal definition covers among others the reasons for carrying out the study, the decision context and the target audience(s).

Intended applications and goal questions

The environmental assessment within the SEEMLA project aims at several separate applications. The subject of the first group of applications is the project-internal support of ongoing production systems development:

- Comparisons of specific cultivation systems, which are potential results of ongoing production systems development, and biomass use options.
- Identification of key factors for sustainable cultivation systems and product chains to support further optimisation.

This makes this study a scenario-based, ex-ante assessment because the investigated systems are not yet implemented, neither on a relevant scale nor for a sufficiently long time. Due to this nature, the results of the analysis are unsuitable for (ex-post) accounting purposes, in particular for entries in relevant life cycle inventory (LCI) databases.

The second group of applications provides a basis to communicate findings of the SEEMLA project to external stakeholders, i.e. science and policy makers.

- Policy information: Which product chains have the potential to show a low environmental impact?
- Policy development: Which raw material production strategies and biomass use technologies may emerge, what are their potential environmental impacts, and how could policies guide this development?

In this context, a number of goal questions have been agreed upon. They are listed in chapter 1. Their purpose is to guide the environmental assessment in WP 4.

Target audience
The definition of the target audience helps identifying the appropriate form and technical level of reporting. In the case of the SEEMLA project, the target audience can be divided into project partners and external stakeholders (EC staff, political decision makers, interested laypersons).

Reasons for carrying out the study and commissioner
The environmental assessment is carried out because the SEEMLA consortium has decided to supplement the establishment of suitable innovative land use strategies for a sustainable production of plant-based energy on marginal lands with a corresponding analysis. The study is financially supported by the EU Commission, which signed a grant agreement with the SEEMLA consortium.

2.2 Scope definition
With the scope definition, the object of the environmental assessment (i.e. the exact product or system(s) to be analysed) is identified and described. The scope should be sufficiently well defined to ensure that the comprehensiveness, depth and detail of the study are compatible and sufficient to address the stated goal.

The analysis of the life cycles within the SEEMLA project is taking into account international standards such as ISO standards on product life cycle assessment [ISO 2006a; b]. For more details, please refer to section 4.1.

For the analysis of the SEEMLA scenarios, definitions and settings are necessary. They are used in the subsequent analyses (tasks) to guarantee the consistency between the different assessments of the environmental implications. The definitions and settings are described and explained below.

2.2.1 Investigated systems
The SEEMLA project investigates various perennial lignocellulosic crops suitable for the cultivation on marginal lands under various growing conditions. Annual crops such as oil, starch and sugar rich crops as well as biomass residues are not in the focus of the SEEMLA project. Also, several biomass use options are involved. For these reasons, there is not just one single SEEMLA system to be analysed. Instead, there is a wide spectrum of potential implementations combining several of the developed elements. Within the SEEMLA project, these systems are considered in the form of scenarios which reflect the most important of all possible implementations. These SEEMLA scenarios are described in chapter 3.

Within the environmental assessment, a distinction is made between

- a set of so called *'generic scenarios'* which aim at representing typical conditions that can be found across Europe (see section 3.1) and
- *'case study scenarios'* which are related (but not identical) to the pilot cases carried out by the SEEMLA partners in WP 5 and which are characterised by the boundary conditions defined in WP 5 (see section 3.2)

It is the goal of the environmental assessment WP 4 to derive reliable *general* statements and recommendations concerning the cultivation of biomass on marginal land for bioenergy

production in Europe. From the case study scenarios which are related to very specific framework conditions, such general recommendations cannot be reliably derived. Therefore, they are supplemented by the generic scenarios.

2.2.1.1 Geographical coverage

Geography can play a crucial role in many sustainability assessments, determining e.g. agricultural conditions, transport systems and electricity generation. Geographically, the environmental assessment within the SEEMLA project covers Europe. LCA case studies are conducted for Germany, Greece and Ukraine since the WP 5 pilot cases are situated in those countries. In order to allow for more general statements and recommendations that can be derived from the assessments in WP 4, other growing conditions and cultivation practices in Europe are taken into account as well.

This is achieved by categorising the various conditions and yield potentials that can be found in Europe based on the climatic zones identified by [Metzger et al. 2005]. For the SEEMLA project, these climatic zones – excluding the Alpine North and Alpine South zones – are aggregated into four large zones as specified in the following and shown in Fig. 2-1:

- 'Boreal zone' comprising the Boreal (BOR) zone,
- 'Atlantic zone' (ATL) comprising the Atlantic North (ATN), Atlantic Central (ATC) and Lusitanian (LUS) zone,
- 'Continental zone' (CON) comprising the Pannonian (PAN), Continental (CON) and Nemoral (NEM) zone, and
- 'Mediterranean zone' (MED) comprising Mediterranean mountains (MDM), Mediterranean North (MDN) and Mediterranean South (MDS).

The 'Boreal zone', however, is not covered in the environmental and socio-economic sustainability assessment since none of the SEEMLA partners was located in this zone and able to provide data for crops cultivated in this zone. Even for the generic scenarios, expert knowledge of the SEEMLA partners was essential for the environmental and socio-economic sustainability assessment.

With respect to the provision of conventional reference products, the geographical coverage is broadened in order to represent the generic (e.g. European or global) production of each replaced commodity. In some cases, country-specific conditions are chosen for the estimation of a single parameter's influence on the overall results, e.g. related to labour costs or land rent.

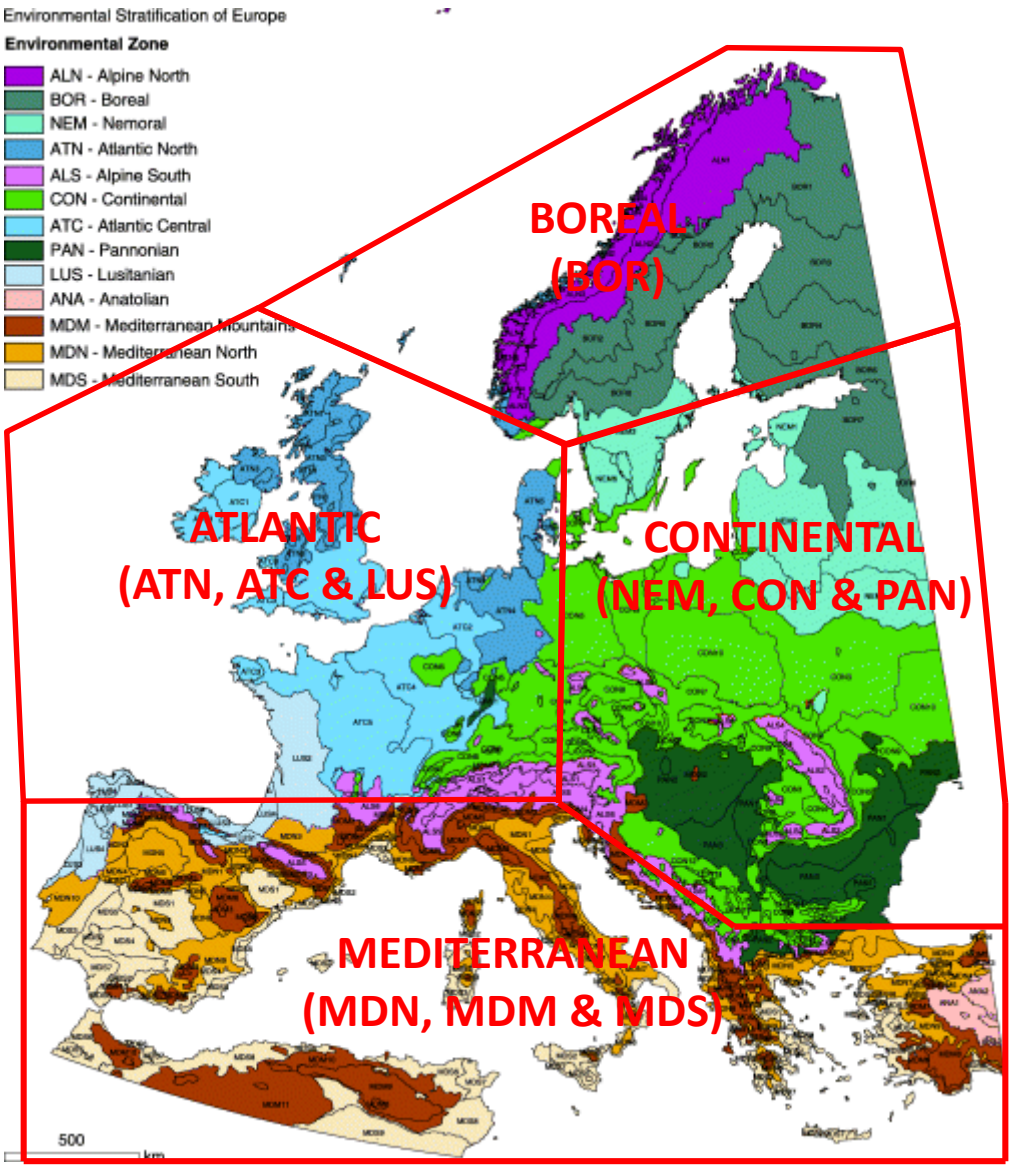

Fig. 2-1 Aggregated zones used for the environmental assessment within the SEEMLA project based on climatic zones of Metzger et al. [2005].

2.2.1.2 Technical reference

The technical reference describes the agricultural practice and the conversion technology to be assessed in terms of development status and maturity.

In order to evaluate whether the cultivation of energy crops on marginal lands is worth being further developed or supported, it is essential to obtain information how future implementations will perform compared to established energy provision pathways which are operated at industrial scale. Therefore, mature, commercial-scale technology is set as technical reference for agricultural practice and conversion technology.

2.2.1.3 Time frame

Typically, the time frame has a strong influence on the assessment of products because it takes several years to ramp up production volumes in order to benefit from economies of scale and to optimise production with respect to resource efficiency.

Cultivation of energy crops on marginal lands is still in an immature state and thus cannot compete with conventional energy provision systems. By setting 2030 as a reference year, unbiased comparisons can be achieved and results benefit from a more representative picture of the investigated system's potential to achieve its goals.

2.2.2 System boundaries

System boundaries specify which unit processes are part of the production system and thus included into the assessment as well as the processes excluded based on cut-off criteria.

The environmental assessment of the SEEMLA system follows the concept of life cycle thinking and takes into account the products' entire value chain (life cycle) 'from cradle to grave', i.e. from resource extraction for fertilisers applied during cultivation to the combustion of energy carriers (see Fig. 2-2). The system boundary also covers the so-called agricultural reference system (see sections 2.2.3 and 3.3.1), including land use change effects and associated changes in carbon stocks. Also, for the equivalent conventional reference products (see section 3.3.2), the entire life cycle is taken into account.

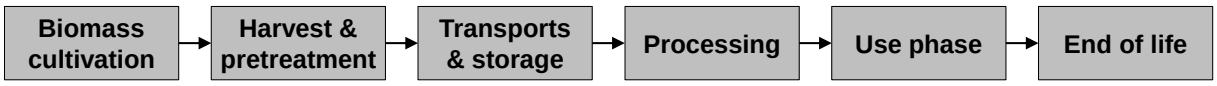

Fig. 2-2 System boundaries applied within the SEEMLA project. © IFEU 2018

Infrastructure, i.e. the production and processing equipment, vehicles, buildings and streets connected with the crop's production and use is not included in the inventory, except for background data (generic LCI databases such as ecoinvent may include infrastructure with no possibility of its exclusion with reasonable efforts). In many LCAs assessing bioenergy systems it was shown that infrastructure accounts for less than 10% of the overall results (see [Fritsche et al. 2004; Gärtner 2008; Nitsch et al. 2004]).

2.2.3 Alternative land use

For the assessment of biomass production systems, the agricultural reference system is a crucial parameter for the outcome of the investigation. It describes the alternative land use, i.e. what the cultivation area would be used for if the crop under investigation was not cultivated [Jungk et al. 2002; Koponen et al. 2018]. The assessment is carried out by comparing the proposed energy crop cultivation with the alternative land use (see Fig. 3-1) in terms of associated environmental impacts. For a more detailed description see section 3.3.1.

2.2.4 Functional unit and reference unit

The key elements of any environmental assessment are the system's function and functional unit. It is a reference to which the environmental impacts of the studied system are related, and is typically a measure for the function of the studied system. Consequently, it is the basis for the comparison of different systems.

All life cycle comparisons between bioenergy and conventional energy systems are based on equal function of both life cycles. This utility is measured and expressed in units specific for each product, e.g. 1 MJ of heat, 1 kWh of electricity or 1 MJ of fuel.

In order to make the different systems comparable, the results are displayed related to

- the occupation of ten hectares of agricultural land for one year (10 ha · year) or
- one tonne of dry biomass (1 t DM).

Depending on the question to be answered, results are also displayed related to other reference units where appropriate. For example, for analyses related to the Renewable Energy Directive (RED), the reference unit is 1 MJ fuel and for analyses related to heat or electricity, the reference unit is 1 MWh generated energy.

2.2.5 Data sources

The environmental assessment of the SEEMLA systems requires a multitude of data. Primary data is obtained from the following sources:

- Case study scenarios: Data on biomass cultivation, yields etc. stem from SEEMLA partners.
- Generic scenarios: All data on biomass cultivation, e.g. the amount of fertiliser input stem from IFEU's internal database [IFEU 2018] and are partially based on expert judgments by SEEMLA partners and external experts (see Table 9-1 to Table 9-3 in the annex).
- Data on all other biomass conversion processes were taken from IFEU's internal database [IFEU 2018] and supplemented with literature data and judgements by external experts.

All processing steps analysed are based on estimates for commercial agricultural systems and industrial processing units. Sources for secondary data such as prices of or emissions related to process inputs are specific for each used assessment methodology.

3 System description

It is one goal of the SEEMLA project to evaluate and to improve the biomass production on marginal land for bioenergy. The project focuses on perennial, lignocellulosic biomass, i.e. annual crops such as oil, starch and sugar rich crops as well as biomass residues are excluded. The environmental assessment is based on a number of defined systems. In the following, these SEEMLA systems are qualitatively described. As indicated in [Gärtner et al. 2018], the SEEMLA systems follow the principle of so-called life cycle comparisons (see also section 2.2.1). A schematic overview of a life cycle comparison scheme is shown in Fig. 3-1. The entire life cycles of the SEEMLA system and the obtained products are assessed – starting from cultivation through production, use and end-of-life ('cradle-to-grave approach'). All material and energy inputs into and outputs from the system are taken into account. All products and co-products replace conventional reference products that provide the same function. For the reference products, the entire life cycle is taken into account as well.

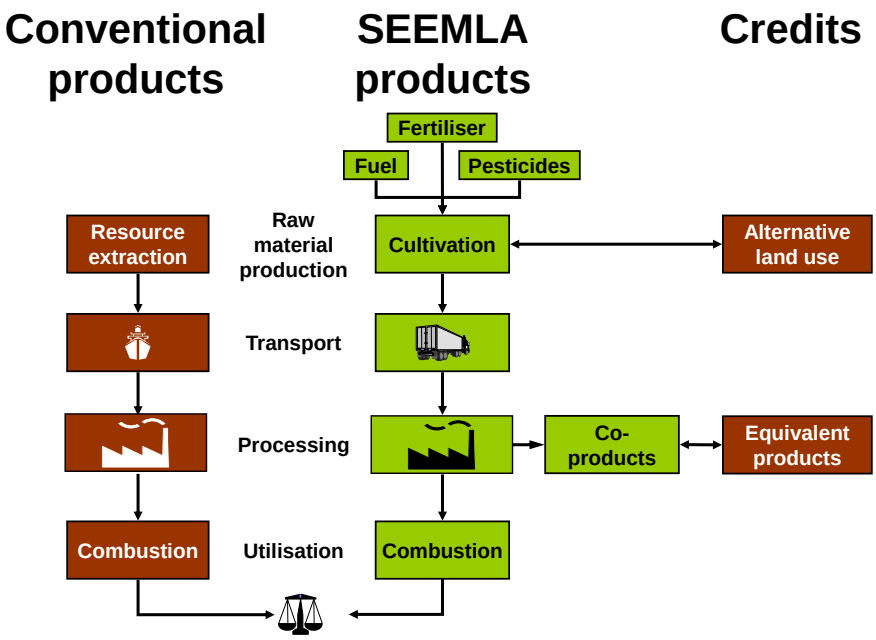

Fig. 3-1 Basic principle of life cycle comparison applied in WP 4. © IFEU 2018

As introduced in section 2.2.1, WP 4 considers the SEEMLA systems in the form of scenarios and follows a 'dual approach' involving both *case study scenarios* and *generic scenarios*. Field trials are carried out by the SEEMLA project partners based on which insights and data on biomass cultivation for their respective boundary conditions can be gained. The *case study scenarios* which are related (but not identical) to the pilot cases carried out by the SEEMLA partners in WP 5 are thus an important part of the assessments in WP 4 and summarised accordingly in section 3.2. However, it is the goal of the environmental assessment carried out in WP 4 to derive reliable *general* statements and (policy) recommendations concerning the cultivation of biomass on marginal land for bioenergy production in Europe. The case study scenarios are thus supplemented by a set of *generic scenarios* in section 3.1 which shall represent generic average conditions for biomass production on marginal land in Europe.

3.1 The SEEMLA generic scenarios

A set of generic scenarios is defined for investigation in WP 4 which shall represent generic average conditions for biomass production on marginal land in Europe. These conditions are described in the following sections 3.1.1 to 3.1.3.

3.1.1 Biomass production

Biomass production within the SEEMLA project consists of the cultivation of lignocellulosic crops including removal of the plantation after the end of its economic life time. The cultivation of crops includes the required demand of fertiliser, diesel and pesticides and is compared to other use options for the same land (section 3.3.1). Harvesting of the biomass including chopping or baling and transportation to a conditioning facility is treated in section 3.1.2. This study assesses several perennial lignocellulosic crops (section 3.1.1.1) which can be grown in different climatic zones (section 3.1.1.2) and on soils of different quality (section 3.1.1.3).

3.1.1.1 Crops investigated

Table 3-1 lists all perennial lignocellulosic crops investigated within the SEEMLA project. Paulownia, for which a pilot case was established in Ukraine, was not included into the WP 4 assessment due to insufficient data. On the other hand, the WP 4 assessment also covers switchgrass and giant reed, for which no pilot cases were established, in order to achieve a better balance between woody and herbaceous crops.

Table 3-1 List of crops investigated in the WP 5 pilot cases and in the WP 4 scenarios.

Crop category	Common name	Scientific name	WP 5 pilot cases	WP 4 scenarios
Woody	Black locust (tree)[1]	*Robinia pseudoacacia* L.	X	X
	Black pine	*Pinus nigra* J.F.Arnold	X	X
	Calabrian pine[2] (aka Turkish pine)	*Pinus brutia* Ten.	X	X
	Basket willow	*Salix viminalis* L.	X	X
	Poplar	*Populus spp.*	X	X
	Black locust (SRC)[1]	*Robinia pseudoacacia* L.	X	X
	Paulownia	*P. elongata x fortunei*	X	–
Herba-ceous	Miscanthus	*Miscanthus × giganteus*	X	X
	Switchgrass	*Panicum virgatum* L.	–	X
	Giant reed	*Arundo donax* L.	–	X

[1] Black locust can be cultivated as a short rotation (tree) plantation or as short rotation coppice (SRC).

[2] The results for Calabrian pine also apply to Aleppo pine (*Pinus halepensis* Miller) which is a closely related (vicariant) species: Calabrian pine is located mainly on the eastern coasts of the Mediterranean basin, while Aleppo pine is concentrated in its western coasts.

More information on the crops can be found in Deliverable D 2.2 'Catalogue for bioenergy crops' [Hanzhenko et al. 2016]. Regarding forest tree species (black locust and the two pine species), the reader is referred to the European Atlas of Forest Tree Species [San-Miguel-Ayanz et al. 2016].

3.1.1.2 Climatic zones

As detailed in section 2.2.1.1, the climatic zones of Europe identified by Metzger et al. [2005] were aggregated into four larger zones, of which three are covered by the sustainability assessment within the SEEMLA project:

- 'Continental',
- 'Mediterranean' and
- 'Atlantic'.

The 'Boreal zone', however, is not covered in the environmental and socio-economic assessment since none of the SEEMLA partners was located in this zone (see also section 2.2.1.1).

Due to differences in climatic suitability, not all of the perennial lignocellulosic crops listed in Table 3-2 can be cultivated in all climatic zones. Table 3-2 gives an overview of which crops can be cultivated where.

Table 3-2 Matrix of crops investigated in the three climatic zones.

Crop category	Common name	Scientific name	Medi-terranean	Conti-nental	Atlantic
Woody	Black locust (tree)	*Robinia pseudoacacia* L.	X	X	X
	Black pine	*Pinus nigra* J.F.Arnold	X	X	X
	Calabrian pine (aka Turkish pine)	*Pinus brutia* Ten.	X	–	–
	Basket willow	*Salix viminalis* L.	–	X	X
	Poplar	*Populus spp.*	X	X	X
	Black locust (SRC)	*Robinia pseudoacacia* L.	X	X	X
Herba-ceous	Miscanthus	*Miscanthus × giganteus*	X	X	X
	Switchgrass	*Panicum virgatum* L.	X	X	X
	Giant reed	*Arundo donax* L.	X	–	–

3.1.1.3 Soil quality / marginality classes

In Europe, a huge spectrum of marginal land can be found, characterised by different biophysical constraints regarding soil, climate and terrain, which according to van Orshoven et al. [2014] are the major determinants of land suitability for agricultural use.

Within the SEEMLA project, a definition of the term 'marginal land' was elaborated in Deliverable D 2.1 'Report of general understanding of MagL' [Ivanina & Hanzhenko 2016]. Based on the Müncheberg Soil Quality Rating (SQR) [Mueller et al. 2007], the definition classifies land as being 'marginal' if its SQR score is below 40. For the purpose of the assessments in WP 4, this class was further subdivided into very marginal land (marginal 2, SQR score < 20) and moderately marginal land (marginal 1, 20 < SQR score < 40). In order to enable comparisons between marginal and non-marginal conditions and since some of the pilot cases showed a SQR score close to 40 (upper threshold for marginal land), 'standard land' (40 < SQR score < 80) is included in the assessment, too (Fig. 3-2 and Table 3-3). The forth class 'high' is left out since it is definitely too far from marginal conditions.

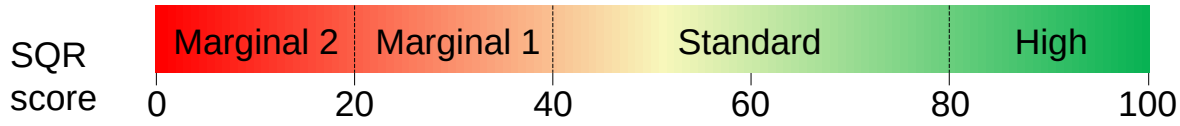

Fig. 3-2 Soil marginality classes defined within the SEEMLA project, adapted and modified based on [Mueller et al. 2007]. © IFEU 2018

Main characteristic of these biomass production settings is the possible yield under the respective conditions, which is assumed to be targeted by cultivation practice. In order to reach the respective yields throughout the plantation's life time, cultivation intensity must be adjusted accordingly. This determines e.g. the amount of fertilisers applied and the amount of diesel needed. The yield in turn determines the magnitude of a conversion plant's radius for biomass acquisition. Table 3-3 gives an overview of the three yield levels defined for biomass production. In the following, due to the focus on marginal biomass production sites, the yield level 'high' is not displayed.

Table 3-3 Yield levels for biomass production.

Name	Abbreviation	Explanation
Marginal 2 / very marginal	Marg. 2 / M2	Marginal conditions which lead to a considerable yield reduction, caused by different factors such as pronounced water stress, pronounced salt stress or high inclination; very low yield, very low nutrient demand
Marginal 1 / (moderately) marginal	Marg. 1 / M1	Moderately marginal conditions can be caused by different factors such as moderate water stress, moderate salt stress or moderate inclination; low yield, low nutrient demand
Standard	Std.	Typical climate and soil conditions in the respective climatic zone; standard yield, standard nutrient demand

3.1.2 Harvesting, logistics and conditioning

In the following, typical concepts for harvesting, logistics and conditioning of perennial lignocellulosic crops for bioenergy production are described which can be found across Europe. The key parameter determining the harvesting strategy is the water content of the biomass (Table 3-4). The general idea behind the concepts is to avoid technical drying of the harvested biomass wherever possible.

Table 3-4 Harvesting strategies and water contents for the different types of crops in the generic scenarios.

	Harvest, logistics and conditioning	Water content ($\%_{FM}$) at harvest	Water content ($\%_{FM}$) after air-drying
Trees	Motor-manual; drying at forest road	50%	30%
SRC	Cutting and chipping, technical drying	50%	n.a.
Perennial grasses	Cutting, air drying on swath, baling, chipping at conditioning facility	Miscanthus: 40%	15 / 25%*
		Switchgrass: 15%	15%
		Giant reed: 50%	15%

* 15% in the Continental and Mediterranean zone; 25% in the Atlantic zone

As depicted in Fig. 3-3, trees (black locust, black pine, Calabrian pine) are harvested motor-manually and air-dried at forest roads, decreasing water content from 50% (of fresh matter, FM) to 30%$_{FM}$. Short rotation coppice (SRC) like poplar, willow and black locust are harvested with a self-propelled harvester (cut and chipped) and technically dried. Perennial grasses are cut, air-dried on swath (with switchgrass and giant reed reaching 15%$_{FM}$ in all climatic zones) and baled. In case air drying is not feasible (e.g. Miscanthus in the Atlantic zone), perennial grasses are harvested with a self-propelled harvester and technically dried.

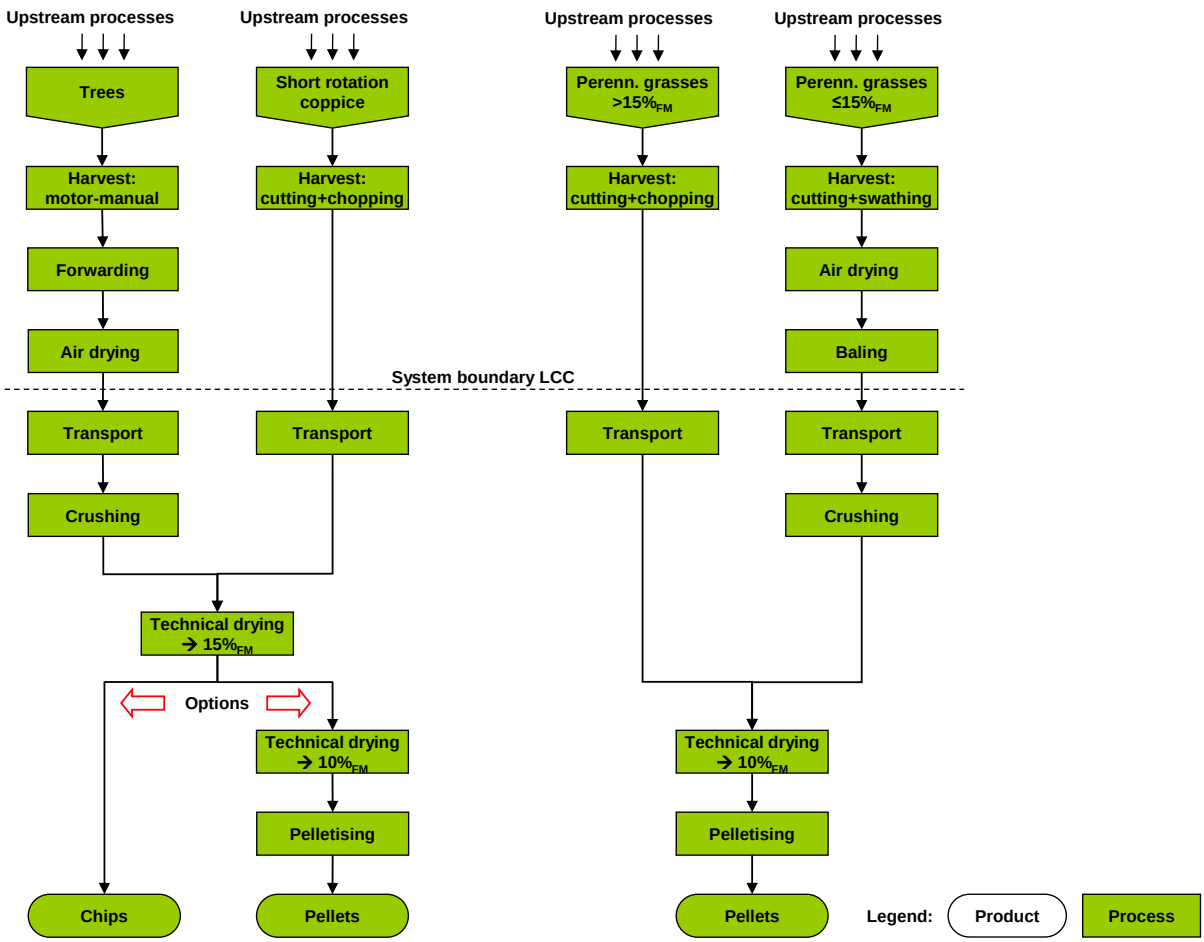

Fig. 3-3 Biomass harvesting, logistics and conditioning options investigated in within the SEEMLA project. © IFEU 2018

Most woody biomass requires technical drying depending on the later use. The generic scenarios are based on technical drying from 50%$_{FM}$ (SRC) and 30%$_{FM}$ (trees), respectively, to a water content of 15%$_{FM}$. Whether further conditioning (drying and pelleting) of the harvested biomass is necessary, depends on the selected biomass conversion and use option (Table 3-5). Drying is set to take place in central facilities e.g. at the pelleting plant. Pelleting of woody biomass is applied only if required by the later use, e.g. in the case of domestic heating. For larger district heating plants, power plants and CHP plants, wood chips are acceptable. Herbaceous biomass, however, is set to be dried to a water content of 10%$_{FM}$ and pelletised in any case, i.e. irrespective of the later use.

Table 3-5 Types of fuel and corresponding water content compatible with biomass conversion and use options.

Biomass conversion and use	Wood chips	Wood pellets	Grass pellets
Direct combustion (pellet boiler) → Domestic heat from biomass	-	X $10\%_{FM}$	X $10\%_{FM}$
Direct combustion (heat plant) → District heat from biomass	X $15\%_{FM}$	(X) $10\%_{FM}$	X $10\%_{FM}$
Direct combustion (power plant) → Power from biomass	X $15\%_{FM}$	(X) $10\%_{FM}$	X $10\%_{FM}$
Direct combustion (combined heat and power plant, CHP plant) → Heat & power from biomass	X $15\%_{FM}$	(X) $10\%_{FM}$	X $10\%_{FM}$
1. Hydrolysis & fermentation → 2nd generation ethanol (biofuel) 2. Use in passenger car	X $15\%_{FM}$	(X) $10\%_{FM}$	X $10\%_{FM}$

Important note:
For most use options, biomass from perennial grasses will very likely have to be mixed with other biomass such as wood (e.g. combustion) or straw (e.g. ethanol) to fulfil technical specifications. The assessed scenarios depict only the share of biomass from perennial grasses in the value chains. Since major synergies beyond fulfilment of specifications are not expected, total sustainability effects of mixed fuel pathways can be assigned to the individual feedstock shares. Under these preconditions, this is identical to assessing additional effects of the introduction of biomass into mixed pathways while increasing the total production volume. The approach entails that additional measures necessary for using grass pellets only are not assessed. This includes the addition of limestone to pellets for neutralisation or the installation of additional flue gas treatment equipment that may become necessary if technical specifications are not met by the grass pellets.

3.1.3 Biomass conversion and use

A wide variety of biomass conversion and use options exists for lignocellulosic biomass. This variety is reflected by the set of bioenergy options defined for the SEEMLA project which include heat, power and transportation fuels. Both advanced conversion technologies like production of 2nd generation ethanol as well as established conversion technologies like combustion in a pellet boiler to produce heat for domestic use are included.

Due to the project partners' focus on the agricultural production phase, the potentially even longer list of biomass conversion and use options was limited to the following ones (which are depicted in Fig. 3-4). Detailed life cycles of the considered use options are illustrated in section 9.1 in the annex.

- Direct combustion of biomass pellets in a pellet boiler for production of domestic heat.
- Direct combustion of biomass chips or pellets in a boiler for production of district heat.
- Direct combustion of biomass chips or pellets in a boiler for power generation.
- Direct combustion of biomass chips or pellets in a combined heat and power (CHP) plant.
- Production of 2nd generation ethanol for use in a passenger car.

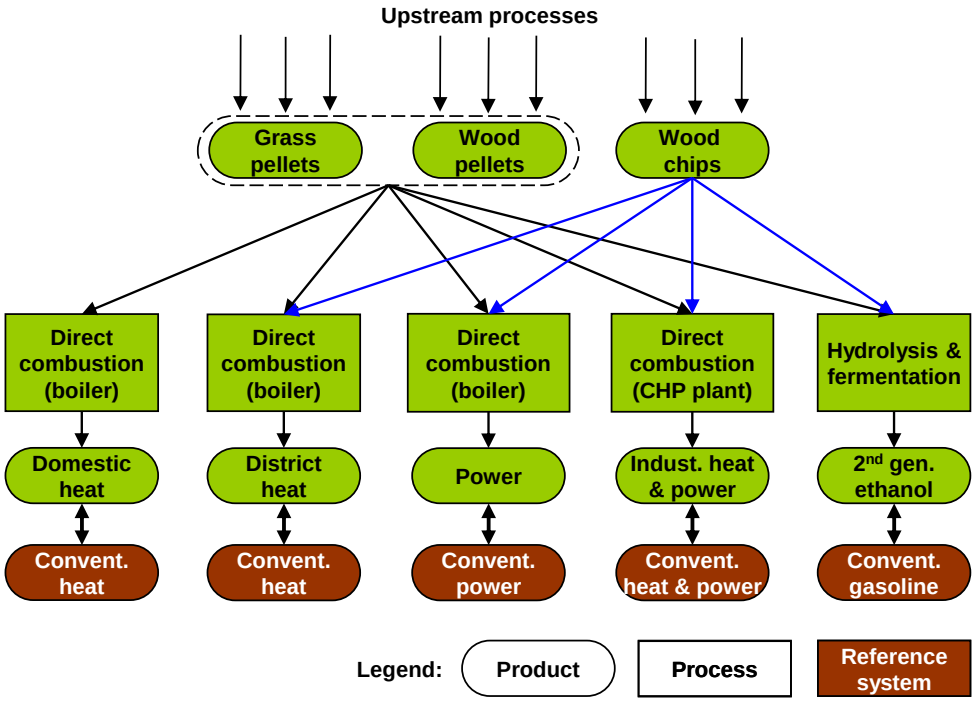

Fig. 3-4 Biomass conversion and use options investigated within the SEEMLA project. © IFEU 2018

In order to show the bandwidth of possible results of the environmental assessment, three conversion efficiencies for all use options were defined, similar to the yield levels for biomass production. While the SEEMLA project focusses on studying a wide spectrum of agricultural production sites, only generic configurations of industrial conversion pathways are analysed.

For this reason, a common bandwidth for industrial conversion processes is defined ranging from 'low' to 'high' efficiency. A summary and a definition of the conversion efficiencies are given in Table 3-6. Further varied parameters are summarised in Table 3-7. The scenarios reflect potential implementations of conversion technology in 2030. Innovative industrial conversion technologies such as 2nd generation ethanol are modelled as mature technology implementations on industrial scale.

Transport distances from the pelleting facility to the conversion plant are set to the same generic values independent of the use option. However, transport distances depend on the conversion efficiency.

Table 3-6 Conversion efficiencies for biomass use options.

Name	Definition
Low	Low conversion efficiency, high transport distance (30 km), low output of co-products, high resource demand
Standard	Standard conversion efficiency, standard transport distance (20 km), standard output of co-products, standard resource demand
High	High conversion efficiency, low transport distance (15 km), high output of co-products, low resource demand

Table 3-7 Overview of possible settings that can be varied in the scenarios.

	Varied parameters	Possible settings (default in bold)
Conversion	Conversion efficiency	Low | **standard (std.)** | high
Use	Replaced energy carrier for direct combustion	See Table 3-11 (p. 35)
	Replaced power mix	**Power mix** (from grid) | coal | natural gas

3.2 The SEEMLA case study scenarios

Within the SEEMLA project, pilot cases were established in Germany, Greece and Ukraine. More detailed information on the pilot cases can be found in Deliverables D 5.1 'Report on site selection for case studies' [Kiourtsis & Keramitzis 2016] and D 5.2 'Report on characteristics of MagL in pilot areas' [Gerwin & Repmann 2016]. Based on these pilot cases, eight *case study scenarios* at country-level related (but not identical) to these pilot cases were defined for the assessment in WP 4 (Table 3-8).

Table 3-8 Case study scenarios investigated in WP 4.

Country	Cultivated crops
Germany	Poplar
Germany	Black locust (SRC)
Greece	Black pine
Greece	Calabrian pine
Greece	Black locust (tree)
Ukraine	Willow
Ukraine	Poplar
Ukraine	Miscanthus

3.2.1 Biomass production

Major characteristics of biomass production in the pilot cases are listed in Table 3-9. These include the vegetation that would be in place if the biomass production was not implemented and the alternative use of the land if it was not used for biomass production (see section 2.2.3).

The cultivation sites on which field trials are carried out represent a large variety of growing conditions. Also, multiple crops – seven in total – are cultivated, mainly woody crops but also Miscanthus as a perennial grass. The woody crops can be divided into those which are cultivated as short rotation coppice with rotation periods from three to seven years and those which are cultivated as short rotation (tree) plantations and are harvested after twenty years. Against this background, it is important to carefully distinguish between all case study sites.

For the outcome of the environmental assessment, the alternative land use is usually a major factor which determines the results significantly (see section 2.2.3). For instance, carbon emissions due to initial clearing and plantation establishment are linked to the alternative vegetation. Also, impacts on biodiversity caused by biomass cultivation are determined by alternative land use. For these reasons, alternative vegetation and alternative land use are included in the overview of pilot cases in Table 3-9.

Table 3-9 Overview on biomass production in the pilot cases established in WP 5 [Ivanina & Hanzhenko 2016].

No	Country	Pilot case name	Cultivated crops	Alternative vegetation	Alternative land use
1	Germany	German Railways	Poplar, Black locust (SRC)	Woody vegetation	No use
2	Germany	Welzow	Black locust (SRC)	Woody vegetation	No use
3	Greece	Fillyra / Drosia	Black pine, Black locust (tree)	Sparse grassy vegetation	No use / periodically extensive pasture
4	Greece	Ismaros / Pelagia	Calabrian pine	Mixed vegetation (forests, bushes, grassland)	No use
5	Greece	Kalhantas / Sarakini	Black locust (tree)	Sparse grassy vegetation	Periodically extensive pasture
6	Ukraine	Poltava	Willow, Miscanthus	Woody vegetation	No use
7	Ukraine	Vinnitsa	Willow, Miscanthus	Sparse grassy vegetation	No use
8	Ukraine	Volyn A	Poplar*, Paulownia	Grassland / shrubland	No use
9	Ukraine	Volyn B	Willow	Grassland / shrubland	No use
10	Ukraine	Volyn C	Willow	Grassland / shrubland	No use
11	Ukraine	Lviv A	Poplar*, Paulownia	Grassland / shrubland	No use
12	Ukraine	Lviv B	Poplar*	Grassland / shrubland	No use
13	Ukraine	Lviv C	Willow	Grassland	No use
14	Ukraine	Lviv D	Poplar*	Grassland	No use

* In Ukraine, poplar cuttings and rods are cultivated. The latter are not part of this study.

3.2.2 Harvesting, logistics and conditioning

Before the energy use, the produced biomass has to be processed and transported to the conversion unit. The necessary process steps are mainly determined by the quality of biomass and the local conditions.

The following process steps were suggested for the respective case studies:

- Germany (pilot case names: German Railways, Welzow):
  - Cutting, crushing, transportation to storage and conditioning unit, technical drying, pelleting and transportation to the conversion unit (option 1)
  - Cutting, crushing, transportation to the conversion (option 2)
- Greece (pilot case names: Fillyra, Ismaros, Kalhantas): Cutting, trimming, transportation to storage and conditioning unit, final crushing and transportation to the conversion unit.
- Ukraine (pilot case names: Poltava, Vinnitsa, Volyn A–C, Lviv A–D):
  - Cutting, baling and transport to the conversion unit (Miscanthus)
  - Cutting, crushing, transportation to the conversion unit (all others)

In the case study scenarios, information on harvesting strategies and water contents are provided by the project partners and are summarised in Table 3-10. However, due to the project partners' focus on the agricultural production phase, no case study-specific data on logistics and conditioning (including mass and energy flow data) could be obtained. Therefore, it was decided to link the case study-specific biomass production to the generic harvesting, logistics and conditioning options described in section 3.1.2.

Table 3-10 Harvesting strategies and water contents for the different types of crops in the case study scenarios.

	Country	Harvest and logistics	Water content ($\%_{FM}$) after air-drying
Trees	Greece	Motor-manual; drying at forest road	20%
SRC	Germany, Ukraine	Cutting and chipping, technical drying	50%
Miscanthus	Ukraine	Cutting, air drying on swath, baling, chipping at conditioning facility	17%

3.2.3 Biomass conversion and use

Biomass can be used for bioenergy in various ways. The following use options were suggested for the respective case studies:

- Germany (pilot case names: German Railways, Welzow):
  - local heating (option 1)
  - combined heat and power (CHP) plant (option 2)
- Greece (pilot case names: Fillyra, Ismaros, Kalhantas): local heating

- Ukraine (pilot case names: Poltava, Vinnitsa, Volyn A–C, Lviv A–D):
    - Local heating (option 1)
    - District heating network (option 2)
    - CHP (option 3)

Due to the focus of the project partners on the agricultural production phase, however, no case study specific data on biomass conversion and use (including mass and energy flow data) could be collected. Therefore, it was decided to link the case study specific biomass conversion with the generic biomass conversion and utilisation possibilities described in section 3.1.3.

3.3 Reference systems

The bioenergy options are compared to so-called reference systems which include both the agricultural reference system (section 3.3.1) and the reference products (section 3.3.2). The reference systems would alternatively provide the same function as the bioenergy systems (heat, electricity or fuel) and are required for statements regarding environmental advantages or disadvantages of the analysed bioenergy systems.

3.3.1 Agricultural reference system

For the assessment of biomass production systems, the agricultural reference system is a crucial parameter for the outcome of the investigation. It describes the alternative land use, i.e. what the cultivation area would be used for if the crop under investigation was not cultivated [Jungk et al. 2002; Koponen et al. 2018]. Since the SEEMLA approach promotes the use of *unused* marginal land for bioenergy purposes, 'idle land' is defined as the main alternative land use (agricultural reference system). This means that no indirect land use changes (iLUC) are induced and that only direct land use changes (dLUC) have to be taken into account (see box below). According to the SEEMLA definition, marginal land mainly includes sites which were affected by degradation processes, in most cases triggered by anthropogenic impact. Apart from degraded land, overlaps exist with abandoned land, reclaimed land and brownfields [Ivanina & Hanzhenko 2016]. In all cases, even if the land once had been used as cropland (e.g. in Soviet times), a grassy vegetation cover has developed over the idling time which can be characterised as either

- grassland or
- shrubland / woody grassland.

If land use changes are considered, they often are the most influential contribution to the greenhouse gas balance of the investigated agricultural system. In order to guarantee undistorted conclusions from the drawn comparisons between the investigated scenarios, direct and indirect land use changes (i.e. carbon stock changes) are not part of the main scenarios. Instead, the applied methodological approach follows the so-called attributed LUC (aLUC). According to [Fehrenbach et al. 2016], the average actual situation for land use change in a particular country is taken as a basis and allocated to the corresponding agricultural products. The basic data is obtained from the annual inventory submissions to the United Nations Framework Convention on Climate Change (UNFCCC) which regularly

document LUC emissions at national level. The resulting aLUC emissions are 0.19 t CO_2 eq / (ha · year) for Europe and 0.21 t CO_2 eq / (ha · year) for Germany, respectively [Fehrenbach et al. 2018]. In addition, dLUC is assessed in a sensitivity analysis.

Land use and land use changes not only affect the greenhouse gas balance but also the impact category 'land use' which focusses on changes in land quality. Here, the hemeroby concept by Fehrenbach et al. [2015] is applied for the impact assessment (see section 4.1.3).

Excursus on land use change (LUC)

By definition, the agricultural reference system comprises any change in land use or land cover induced by the cultivation of the investigated crop. 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 industrial crop under investigation. This can either be a change in land use of existing agricultural land (replacing idle / set-aside land) 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 industrial crop cultivation. Assuming that the demand for food and feed remains constant, then food and feed production is displaced to another area, which once again provokes unfavourable land-use changes, i.e. the conversion of (semi-)natural ecosystems might occur. 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. 2011]. Depending on the previous vegetation and on the crop to be established, these changes can be neutral, positive or negative. In many cases, land use changes also have remarkable effects on other environmental issues as well as social and economic concerns.

Carbon stock changes in the soil

In the main scenarios, carbon stock changes in the soil are addressed via the aLUC approach. Still, in order to assess the potential impacts of a direct land use change, carbon stock changes are subject of a sensitivity analysis on dLUC.

It is widely held that during cultivation on cropland (previously used for annual crops), perennial crops accumulate soil organic carbon [Nocentini et al. 2015]. This effect improves soil fertility and may add to climate change mitigation by delaying and / or mitigating carbon dioxide emissions. However, the potential to sequester carbon in soils is very site-specific and highly dependent on former, current and future agronomic practices, climate and soil properties [Larson 2006] and large uncertainties are related to the long-term effects of this process. For instance, clearing the planation after its life time (e.g. in order to cultivate annual crops again) significantly reduces long-term effects. For that reason, the relevance of such soil organic carbon sequestration for climate change mitigation is still subject to debate.

Moreover, since within the SEEMLA project, land currently used as cropland is excluded from the definition of marginal land, potential *changes* in soil organic carbon stocks (i.e. the

SOC differences between the respective land covers) are expected to be rather small, since both grassland (77.43 t C ha^{-1}) and shrubland / woody grassland (73.18 t C ha^{-1}) show carbon stocks in the soil which are similar to cropland with perennial crops (72.64 t C ha^{-1}) [German Environment Agency 2018].

Carbon stock changes in the vegetation

Carbon stock changes in the vegetation are considered in the main scenarios via the aLUC approach. In addition, they are subject of a sensitivity analysis on dLUC.

Average biomass carbon stocks for grassland and shrubland / woody grassland in Germany are reported to be 6.81 t C ha^{-1} and 43.16 t C ha^{-1}, respectively [German Environment Agency 2018]. If these types of vegetation are cleared and converted into a plantation of perennial lignocellulosic crops, both positive and negative carbon stock changes can occur, depending on the carbon stocks of these plantations. Yield-dependent carbon stocks were calculated by IFEU [2018] based on the equation of Mokany et al. [2006] and are in the range of 9–24 t C ha^{-1} for short rotation plantations (trees), 3.5–9 t C ha^{-1} for short rotation coppice and 2–6 t C ha^{-1} for perennial grasses.

3.3.2 Reference products

The conventional reference product represents the product that is replaced by the proposed bioenergy chain. The appropriate definition of conventional reference products is an essential part of the life cycle comparison approach illustrated in Fig. 3-1. It highly affects the sustainability results of a given system to be investigated.

The general approach in WP 4 is to investigate the impacts that an introduction of the proposed production chains would have in the future if they were implemented. With respect to life cycle assessment, the approach is called 'consequential modelling'. Against this background it is the aim to identify reference systems that would most likely be replaced in case the bio-based products were produced, i.e. the 'marginal' conventional reference products that are closest to displacement due to economic and political boundary conditions. Since these boundary conditions vary strongly across Europe the reference systems listed in Table 3-11 are default options, which aim at representing average conditions in Europe and from which robust statements in terms of sustainability impacts can be derived.

For each biomass use option expressed in section 3.1.3, Table 3-11 lists appropriate conventional reference systems to which the bioenergy systems are compared. In general, the conventional reference systems shall represent the technology that would most likely be replaced first (the so-called 'marginal' technology) if additional bioenergy as suggested by the SEEMLA approach was used.

However, adaptations to the defined reference systems that are specifically suitable for the assessment of the case study scenarios can be reasonable e.g. in order to highlight the significance of a single parameter's influence such as the power grid mix.

Table 3-11 List of investigated biomass conversion and use options including conventional reference systems.

Biomass conversion and use	Conventional reference system (default in bold)
Direct combustion (pellet boiler) → Domestic heat from biomass	Direct combustion (boiler) → Domestic heat from natural gas | **light fuel oil**
Direct combustion (heat plant) → District heat from biomass	Direct combustion (boiler) → District heat from **natural gas** | light fuel oil | heat mix
Direct combustion (power plant) → Power from biomass	**Power mix** (from the grid) | natural gas | coal
Direct combustion (combined heat and power plant, CHP plant) → Heat & power from biomass	Direct combustion (boiler) → Heat from **natural gas** | light fuel oil | heat mix + **Power mix** (from the grid)
1. Hydrolysis & fermentation → 2nd generation ethanol (biofuel) 2. Use in passenger car	1. Conventional gasoline 2. Use in passenger car

4 Screening life cycle assessment (LCA)

This chapter on screening life cycle assessment comprises a comprehensive section on the main methodological issues (section 4.1), the presentation of the results for the SEEMLA value chains (sections 4.2 – 4.5) and the concluding summary (section 4.6).

4.1 Methodology

In this section on methodology, a comprehensive overview on the methodology of LCA is given. The cited literature can be consulted for a more detailed description of the methodology. In addition to the common definitions and settings in chapter 2, further definitions and settings necessary for the environmental assessment of the SEEMLA value chains are described in the sections 4.1.2 – 4.1.4.

4.1.1 Introduction to LCA methodology

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

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

Life cycle assessment (LCA) is structured, comprehensive and internationally standardised through ISO standards 14040:2006 and 14044:2006 [ISO 2006b; a]. The LCA within the SEEMLA project is carried out largely following these ISO standards on product life cycle assessment. According to the ISO standards, a LCA consists of four iterative phases:

- Goal and scope definition (see chapter 2),
- Inventory analysis (see section 4.1.2),
- Impact assessment (see section 4.1.3), and
- Interpretation (see sections 4.2 to 4.6).

The ISO standards 14040 and 14044 provide the indispensable framework for life cycle assessment. This framework, however, leaves the individual LCA analysts with a range of choices, which can affect the legitimacy of the results of a LCA study. While flexibility is essential in responding to the large variety of questions addressed, further guidance is needed to support consistency and quality assurance. The International Reference Life Cycle Data System (ILCD) Handbook [JRC-IES 2012] has therefore been developed to provide guidance and specifications that go beyond the ISO standards 14040 and 14044, aiming at consistent and quality-assured life cycle assessment data and studies. The screening LCA study carried out within the SEEMLA project takes into account the major requirements of the ILCD Handbook following these considerations of flexibility and strictness. The analyses in this study are so-called screening LCAs which follow the above mentioned ISO standards except for a) the level of detail of documentation, b) the quantity of sensitivity analyses and c) the mandatory critical review. Nevertheless, the results of these screening LCAs are quite reliable due to the close conformity with the ISO standards.

Compared to a full LCA, a screening LCA is not fully compliant to the ISO standards 14040 and 14044. For example, this study includes comparisons of the overall environmental impact of two or more systems and is planned to be disclosed to the public. Usually, this aspect entails a number of additional mandatory requirements under ISO standards 14040 and 14044 on the execution, documentation, review and reporting of the LCA study due to the potential consequences the results may have for e.g. external companies, institutions, consumers, etc. However, since these comparisons are made on a generic level and only for scenarios on potential future implementations, we think that statements regarding superiority, inferiority or equality of alternatives do not directly affect specific companies, institutions and stakeholders. Thus, these comparative assertions can be disclosed to the public even without entirely fulfilling the requirements for LCA studies to be disclosed to the public. But for the avoidance of doubt, the analyses in this study are termed screening LCAs.

4.1.2 Settings for Life Cycle Inventory Analysis (LCI)

For the life cycle inventory analysis (LCI), specifications need to be defined regarding the modelling principle, the solving of multifunctionality and the accounting approach for biogenic carbon and carbon storage. Further relevant aspects on technical reference, time frame, geographical coverage and data sources are already specified in section 2.2.1.

Modelling principle

The decision-context is one key criterion for determining the most appropriate methods for the LCI model, i.e. the LCI modelling principle which can be differed between the attributional and the consequential approach.

The ILCD Handbook differentiates three decision-context situations (see Table 4-1). These situations differ regarding the question whether the LCA study is to be used to support a decision on the analysed system (e.g. product or strategy), and,

- if so: by the extent of changes that the decision implies in the background system and in other systems because of market mechanism. These can be 'small' (small-scale, non-structural) or 'big' (large-scale, structural).
- if not so: whether the study is interested in interactions of the depicted systems with other systems (e.g. recycling credits) or not.

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

Situation B is considered to apply for the value chains of SEEMLA, since its main application is policy information and development. It is assumed that the implementation of biomass production and use chains developed within the SEEMLA project could have consequences that are so extensive that they overcome threshold – via market mechanism – result in additionally installed or additionally decommissioned equipment / capacity (e.g. production infrastructure) somewhere else.

As a consequence of this classification, the consequential approach is applied in this study.

Table 4-1 Combination of two main aspects of the decision-context: decision orientation and kind of consequences in background system or other systems [JRC-IES 2010].

Decision support?		Kind of process-changes in background system / other systems	
		None or small-scale	Large-scale
	Yes	Situation A 'Micro-level decision support'	Situation B 'Meso / macro-level decision support'
	No	Situation C 'Accounting'	

Solving multifunctionality

If a process provides more than one function, i.e. delivering several goods and / or services, it is a multifunctional process. Agricultural production systems and biomass processing, like those within the SEEMLA project, often include multifunctional processes, producing (co-) products with different functions. For solving this problem of multifunctionality within the LCI, two approaches exist: system expansion (substitution) and allocation. The decision between these two approaches is closely related to the choice of appropriate LCI modelling framework. Since the aim of the SEEMLA project is the meso / macro-level decision support, the substitution approach is applied.

Biogenic carbon and carbon storage

There are two possible sources for carbon dioxide (CO_2) emissions: (recent) biogenic or fossil carbon stocks. For biofuels, the amount of CO_2 released into the atmosphere from direct biofuel combustion equals the amount of CO_2 that has been taken up by the crops recently (short carbon cycle). This release of biogenic CO_2 is considered carbon neutral, i.e. it does not promote climate change. Therefore, the standard approach among LCA practitioners is to only report CO_2 emissions from fossil carbon. In contrast, the ILCD Handbook stipulates to additionally inventory and evaluate both biogenic carbon emissions and uptake of atmospheric carbon by crops to avoid errors due to inconsistencies (provision 7.4.3.7 in [JRC-IES 2010]). Within the SEEMLA project, the consistency of biogenic carbon accounting is verified but results are only reported if they are not zero, e.g. in the case of soil organic matter accumulation (see explanations on direct land use change in section 2.2.3).

Carbon storage time is expected to be much less than 100 years for all SEEMLA products. Delayed emissions are not taken into account in this study.

4.1.3 Settings for Life Cycle Impact Assessment (LCIA)

According to ISO standard 14040 [ISO 2006a], life cycle impact assessment (LCIA) includes the mandatory steps of classification and characterisation as well as the optional steps of normalisation and weighting. Classification and characterisation depend on the chosen impact categories and LCIA methods. Regarding the optional elements, only the normalisation step is applied within the SEEMA project. The corresponding specifications of these LCIA elements are described in the following sections.

Impact categories and LCIA methods

All main environmental issues related to the SEEMLA value systems should be covered within the impact categories of the screening life cycle assessment in a comprehensive way. Furthermore, the impact categories must be consistent with the goal of the study and the intended applications of the results. Table 1-1 on page 15 lists the impact categories that are being considered within the SEEMLA project. In the following, the selection process of the impact categories and the LCIA methods are summarised.

Potential environmental impacts can be analysed at midpoint or at endpoint level. For the environmental assessment within the SEEMLA project, the midpoint level is considered as more suitable than the endpoint level because the impacts are analysed more differentiated and the results are more accurate and precise. The specific impact categories at midpoint level are chosen according to the ReCiPe 2008 approach [Goedkoop et al. 2014]. This approach is preferred because it considers nearly all impact categories in a consistent way.

In this screening LCA, however, some impact categories are excluded beforehand for various reasons. Impact categories, which are irrelevant for the SEEMLA value chains, are excluded from this study. This is the case for ionising radiation, for example. The reason behind this is that the selected impact categories should only cover the relevant environmental aspects of the SEEMLA value chains to avoid an information overload.

Furthermore, impact categories are excluded i) that are still under methodological development or ii) that cannot ensure sufficient LCI data quality for the year 2030 (i.e. impact categories on toxicity and water depletion). Important ecotoxicity impacts on biodiversity and local impacts on water resources are analysed within the LC-EIA instead (see chapter 5). On the other hand, specific issues on human health are covered in the categories particulate matter formation and photochemical ozone formation.

There are three main deviations from the ReCiPe 2008 approach:

- Ozone depletion is assessed according to [Ravishankara et al. 2009; WMO (World Meteorological Organization) 2010] which in contrast to the ReCiPe 2008 approach includes the impact of nitrous oxide (N_2O). Taking account nitrous oxide is important within the SEEMLA project because the biomass-related SEEMLA systems may lead to considerable N_2O emissions throughout their life cycles.
- The ReCiPe indicator 'Fossil fuel depletion' was substituted by the indicator cumulative non-renewable energy demand ('Non-renewable energy use, NREU') [Borken et al. 1999; VDI (Association of German Engineers) 2012] because the latter takes nuclear energy into account, too. Depletion of uranium ores used for the production of nuclear energy is accounted for by the ReCiPe indicator 'Mineral resource depletion', which is used in an adapted form in this study (see following bullet point).
- Two impact categories are added that cover environmental issues which are particularly affected by agricultural biomass production: phosphate rock demand (resource depletion) and land use footprint. The former issue is significantly characterised by the crops' phosphorus requirements. The associated impacts on phosphorus resources are covered by the impact category phosphate rock demand [Reinhardt et al. 2018]. The second

issue, namely impacts on natural land use, is addressed by the hemeroby approach according to [Fehrenbach et al. 2015; Fehrenbach, Keller, et al. 2018]. This approach includes both the degree of human influence on a natural area and the distance of that area to the undisturbed state [Fehrenbach et al. 2015]. Complementarily, the impact category land use is covered by the LC-EIA (see chapter 5).

Normalisation

The normalisation step leads to better understand the relative magnitude of the results for the different environmental impact categories by setting the results into relation with a defined reference value. A usual reference value within LCIA is the annual average resource demand and annual average emission per capita in a selected area resulting in the so-called inhabitant equivalents (IE).

Within the SEEMLA project, the value chains are characterised for Europe and the year 2030. Therefore, the resource demand and emissions per capita in European region are chosen. As an estimation of future emissions of the specific substances is uncertain, last available data from [Goedkoop et al. 2014] are taken. These values refer to the year 2000 and the EU 28 countries (see Table 4-2).

Table 4-2 EU 28 inhabitant equivalents (IE) for the year 2000 [Goedkoop et al. 2014 if not indicated otherwise].

Impact category	Notation this report	Inhabitant equivalent hierarchist	
Climate change	Climate change	11.22	kg CO_2 eq / year
Ozone depletion[1]	Ozone depletion	0.07	kg R11 eq / year
Particulate matter formation	Particulate matter	14.90	kg PM10 eq / year
Photochemical oxidant formation	Summer smog	56.85	kg NMVOC eq / year
Terrestrial acidification	Acidification	34.37	kg SO_2 eq / year
Freshwater eutrophication	Freshwater eutrophication	0.41	kg P eq / year
Marine eutrophication	Marine eutrophication	10.12	kg N eq / year
Land use[2]	Land use footprint	0.24	m² artificial land eq / year
Resource depletion: phosphate rock[3]	Phosphate rock demand	21	kg / year
NREU: Non-renewable energy use[4]	Energy use (NREU)	82.09	GJ / year

[1] [Ravishankara et al. 2009; WMO (World Meteorological Organization) 2010]
[2] [Fehrenbach, Keller, et al. 2018]
[3] [FAO 2018; Reinhardt et al. 2018]
[4] [Eurostat 2007]

4.1.4 Greenhouse gas balances according to European legal requirements

In the light of a controversial discussion on the net benefit of biofuels and bioenergy and the share of renewable energy in the transport sector, the European Renewable Energy Directive (2009/28/EC, RED) on the promotion of the use of energy from renewable sources [European Parliament & Council of the European Union 2009] sets out a mandatory share of 10% by the year 2020 and a number of sustainability criteria. These criteria have to be met

by biofuels and bioliquids to be able to be counted towards this target of 10% (Article 17(2) to 17(6)). Hence, the RED forms a relevant common framework for these energy carriers.

Following the RED, the Commission Report COM(2010)11 expanded the sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling [European Commission 2010]. In 2014, the report was updated by the staff working document on the state of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU (SWD/2014/259) [European Commission 2014a]. This document was supplemented by a report on the calculation of default and typical GHG emission [Giuntoli et al. 2015]. The requirements, which are set in these reports, influence the marketing opportunities of biofuels within Europe. Biofuels that comply with the defined criteria have better chances on the market. Therefore, biofuel producers are interested if their biofuels fulfil the criteria or not. However, these criteria are not crucial for political decision and strategies only.

Within the SEEMLA project, the climate change-related criteria of the RED and the SWD are most important: the greenhouse gas (GHG) emission savings from the use of biomass fuels. In the transport sector, the emission saving shall be at least 50% (all biofuels) to 60% (biofuels from new installations) – including emissions from direct land-use changes (dLUC) – compared to the defined emissions of the fossil fuel comparator (Article 17(2)) (for further details see [European Parliament & Council of the European Union 2009]). For electricity, heating and cooling, the emission saving shall be at least 70% accordingly [European Commission 2014a].

The rules for calculating the GHG emissions are defined in Annex V of the RED, Annex I of COM(2010)11, boxes 2 and 3 of SWD/2014/259, supplemented by [Giuntoli et al. 2015]. These rules follow a more pragmatic approach and differ considerably from the ISO standards 14040 and 14044 which stipulate the use of the substitution approach, as done within the environmental assessment of the SEEMLA project (see section 4.1.2). Therefore, the alternative calculation of GHG emissions according to the European legal requirements is carried out as excursus in section 4.4.2 by means of the BioGrace GHG calculation tool [RVO 2015]. BioGrace is approved by the European Commission to verify compliance with the GHG emission saving requirements of the European Union. There are two versions of the BioGrace GHG calculation tool: BioGrace I based on the RED and BioGrace II considering COM(2010)11 and SWD/2014/259.

In the SEEMLA project, only 2nd generation ethanol is regarded as fuel option (see section 3.1.3). As BioGrace I does not include any pathway of woody biomass or perennial grasses converted to 2nd generation ethanol, this value chain has to be omitted. Nonetheless, the following two energy products are considered according to SWD/2014/259: electricity and heat. The reference unit is 1 MWh of energy provision.

4.2 Results: Environmental performance of biomass crops

The selected biomass crops cultivated on marginal land differ regarding their potential yield and input of operating resources. Therefore, the different SEEMLA value chains vary regarding their environmental advantages and disadvantages.

Section 4.2.1 answers the question by means of the generic scenarios, which biomass crops show the best environmental performance in the considered climatic zones of Europe. Additionally, life cycle steps and unit processes are identified that significantly determine the results. From this, optimisation potentials are suggested to improve the environmental compatibility of the SEEMLA value chains (see section 4.2.2). In the subsequent sensitivity analysis in section 4.2.3, the impacts on local carbon stocks and changes are assessed. Besides these results, which are related to the annual occupation of agricultural land, two impact categories are selected for an excursus on resource efficiency in section 4.2.4. Namely, natural land use as well as the efficient use of the phosphorus resource are analysed.

The environmental performances of the biomass crops are presented as normalised results of the LCIA, the so-called inhabitant equivalents (see also section 4.1.3). Non-normalised results of the LCA are exemplarily shown for the categories climate change and marine eutrophication in the annex (see Fig. 9-6).

4.2.1 Environmental impacts of SEEMLA generic scenarios

The generic scenarios are characterised by the product systems and parameters described in section 3.1. Focusing on the biomass crops, the soil quality regarding the yield potential and the use option of the harvested biomass are identical for all investigated product systems. Therefore, marginal land (M1) with a Soil Quality Rating (SQR) score between 20 and 40 is set for site quality and a small combined heat and power (CHP) plant for use option. A small CHP plant is a realistic use option for biomass in rural areas as the supply of the required biomass is relatively feasible and the consumption of the produced heat quantity is given.

Fig. 4-1 shows the normalised results of the assessed environmental impact categories for the different biomass crops, cultivated on ten hectare of marginal land (M1) in the Continental zone. The portfolio of analysed biomass crops differs in the three climatic zones. The selection is identical for the Atlantic and Continental zone. For the Mediterranean zone, willow is not assessed. Instead, Calabrian pine and giant reed are analysed. For the results of the Mediterranean and Atlantic zone see Fig. 9-7 and Fig. 9-8 in the annex.

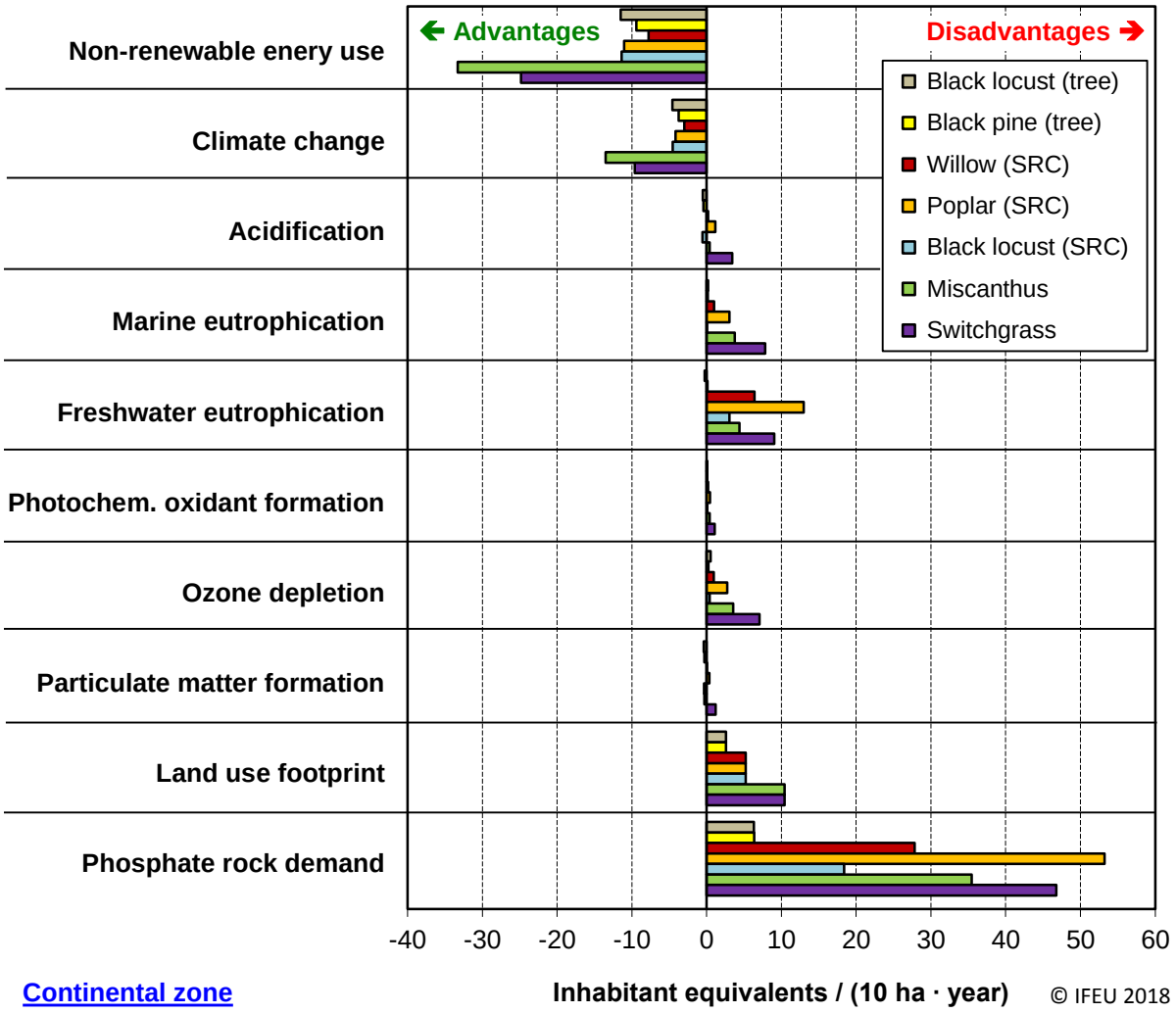

Fig. 4-1 Overall net results of the analysed biomass crops, cultivated on marginal land (M1) in the Continental zone and used in a small CHP plant, compared to fossil reference products in all investigated environmental impact categories.

How to read Fig. 4-1:

The first bar in section 'Non-renewable energy use' shows that the supply of black locust (tree) on marginal land (M1) from ten hectare in one year and its use for heat and power generation in a small CHP plant saves non-renewable energy resources. These savings are equivalent to the average annual energy resources consumption of 11 EU inhabitants (a negative value means an advantage for the SEEMLA value chain).

The first bar in section 'Phosphate rock demand' shows that the same value chain demands more phosphate rock than the conventional provision of the same amount of power and heat. The amount of these additional demands is comparable to the average annual phosphate rock demand caused by 7 EU inhabitants (a positive value means a disadvantage).

The cultivation of biomass crops on marginal land and its use for the conversion to bioenergy in small combined heat and power plants show a typical pattern of environmental advantages and disadvantages like other lignocellulosic biomass compared to fossil-based reference systems (see studies of [Rettenmaier et al. 2010, 2015]). All analysed biomass crops contribute to savings in the categories non-renewable energy use and climate change. The perennial grasses (Miscanthus, switchgrass as well as giant reed in the Mediterranean zone) show more advantages than the woody biomass here. Quantitatively, the avoided impacts by the use of perennial grasses are more than twice as high than those of the use of woody biomass. However, these advantages are at the same time linked to more disadvantages in the categories eutrophication, ozone depletion and land use (footprint). In these categories, all SEEMLA value chains are associated with higher impacts than the corresponding reference systems, even if the impacts of the trees are relatively low. Neither relevant advantages nor disadvantages of the investigated crops can be found in the categories photochemical oxidant formation and particulate matter formation. In the category acidification, the woody biomass could even avoid impacts, whereas the perennial grasses show additional environmental burdens. In general, the SEEMLA value chains based on woody biomass resemble each more closely than the SEEMLA value chains based on perennial grasses. Within the group of perennial grasses, giant reed leads to highest savings in the categories climate change and non-renewable energy use, followed by Miscanthus (second best) and switchgrass (for the results of giant reed see Fig. 9-8 in the annex).

The environmental performance of the lignocellulosic crops mainly depends on the dry matter yield and the nutrient content of the biomass. The higher the dry matter yield the higher are savings in the categories climate change and non-renewable energy use. The results in the category marine eutrophication follow the amount of applied nitrogen fertiliser which is determined by the nitrogen content of the harvested biomass. However, this statement does not apply for the tree species as their fertiliser input is based on one application at the beginning of the cultivation period (see Table 9-1 to Table 9-3 in the annex). Analogously, the phosphorus content and the corresponding use of phosphorus fertiliser are reflected in the impact category freshwater eutrophication and phosphate rock demand. Therefore, Miscanthus – with its relative high dry matter yield – shows best results in terms of climate change and non-renewable energy use for the Atlantic and Continental zone. The relatively high nitrogen requirement of switchgrass and giant reed makes them the most disadvantageous crops in the impact category marine eutrophication. Giant reed also has a high phosphorus requirement so that the product system based on giant reed has the second worst performance in the categories freshwater eutrophication and phosphate rock demand. In these categories, giant reed is only topped by poplar.

4.2.2 Dominance analysis and optimisation potentials

In the following, the contributions of the processes to the overall result in each impact category are analysed. Fertilising as a relevant influencing factor in the categories of eutrophication is already mentioned in the previous section. Fig. 4-2 illustrates the impacts of the product system on process level based on the biomass crop Miscanthus cultivated on marginal land (M1) in the Continental zone and its use in a small combined heat and power plant. A corresponding figure for black locust (tree) can be found in the annex (Fig. 9-9).

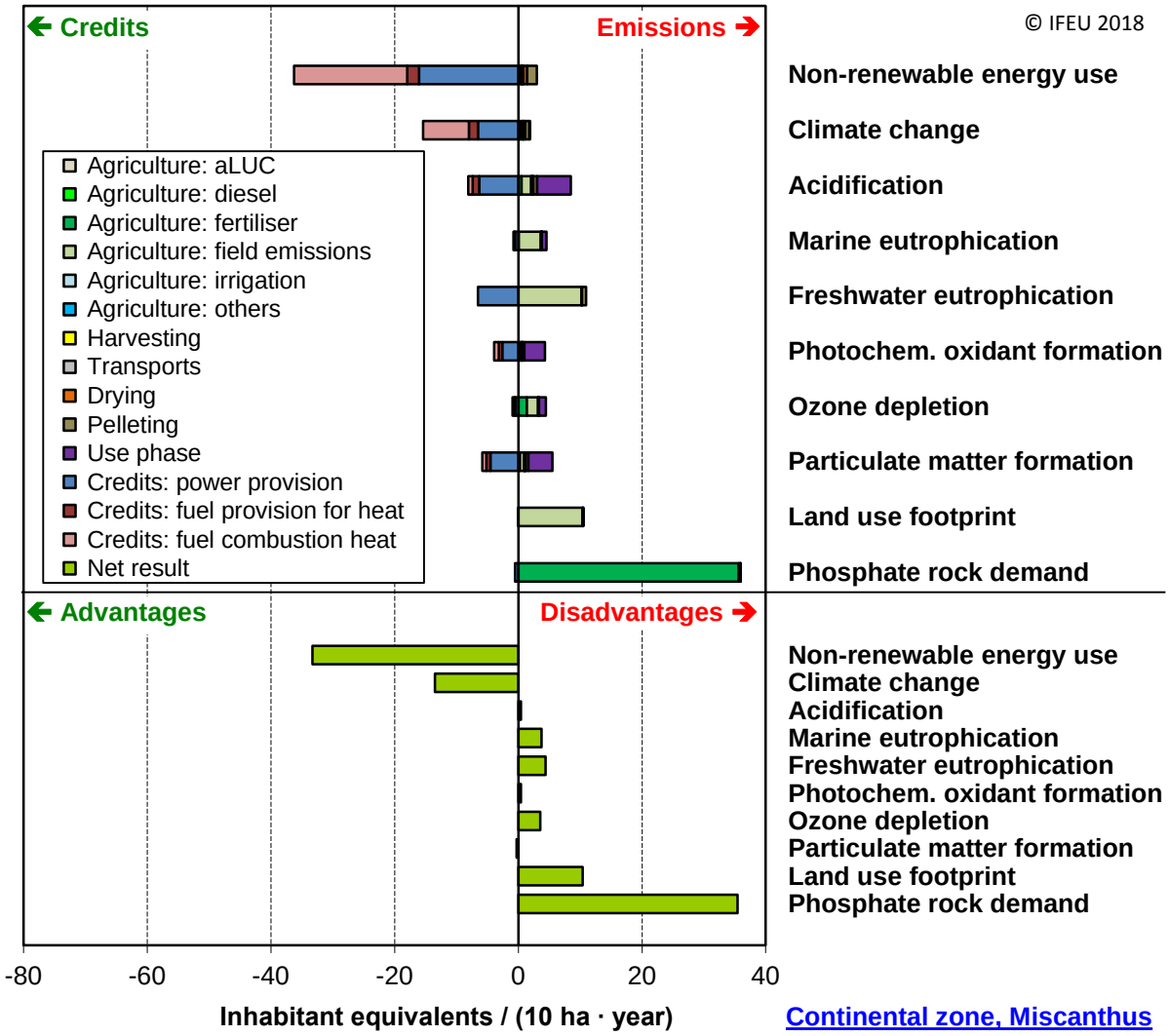

Fig. 4-2 Contributions of individual life cycle steps to the overall net results of Miscanthus, cultivated on marginal land (M1) in the Continental zone and used for small CHP.

How to read Fig. 4-2:

The 1st bar at right hand side shows that the drying and pelleting of Miscanthus biomass, produced on ten hectare, demand an amount of non-renewable energy use equal to the average annual demand of 3.5 EU inhabitants. The substitution of conventional heat and power saves emissions in the category freshwater eutrophication caused by 6.5 EU inhabitants.

As shown in Fig. 4-2, the results in the categories climate change and non-renewable energy use are dominated by the impacts of the energy-intensive processes. Regarding the additional environmental burdens, the processes of drying and pelleting have relevant contributions. On the side of the credits, the substitution of non-renewable energy resources for power and heat provision as well as the avoidance of carbon dioxide emissions from the combustion of fossil energy resources have significant effects. Agricultural processes are dominating the additional emissions in the categories eutrophication and ozone depletion due to the nitrogen and phosphorus emissions caused by fertilisation. The categories acidification, summer smog and particulate matter formation are dominated by the use phase, meaning the emissions of the combined heat and power plant. Regarding the credits, the substitution of conventional power leads to significant avoided emissions in these categories. The results of woody biomass, exemplarily analysed for black locust (tree) in Fig. 9-9 in the annex, are analogous to Miscanthus on the whole but with lower impacts related to the fertilisation processes.

Regarding drying and pelleting, it is provided that these processes are already very efficient. Open air-drying is implemented in all cases as best as possible. For reaching the required dry mass content of pellets and chips, further technical drying is necessary nevertheless. The energy source of technical drying is natural gas which shows less environmental impacts than light fuel oil [Rettenmaier et al. 2015]. Additionally, the environmental impacts could be reduced by using heat from biomass [Rettenmaier et al. 2015].

As the production of pellets and chips requires different maximum values of water content and different energy input, the type of bioenergy carrier influences the results of LCA. On one hand, drying and production of pellets needs more energy. But on the other hand, pellets have a higher energy content and lead to higher savings of GHG emissions therefore. Fig. 4-3 shows these effects by the variation of the type of bioenergy carrier for woody biomass combined with a small CHP plant. In case of choosing pellets instead of chips, no improvement of the results from environmental perspective can be stated. The few additional savings by the higher energy content do not totally compensate the higher energy efforts of the production.

A further process, which has dominant environmental effects and therefore is a logical starting point for optimisation, is fertilisation with the corresponding field emissions which cause eutrophication. Fertilisation processes are known to be dominant in agricultural processes [Rettenmaier et al. 2010, 2015]. Good agricultural practice is already assumed within the SEEMLA value chains so that further reduction of emissions due to improved fertilisation is not expected. If in the case of woody biomass, reduced respectively no application of nitrogen fertiliser could be an option, the impacts in the eutrophication categories could be significantly reduced.

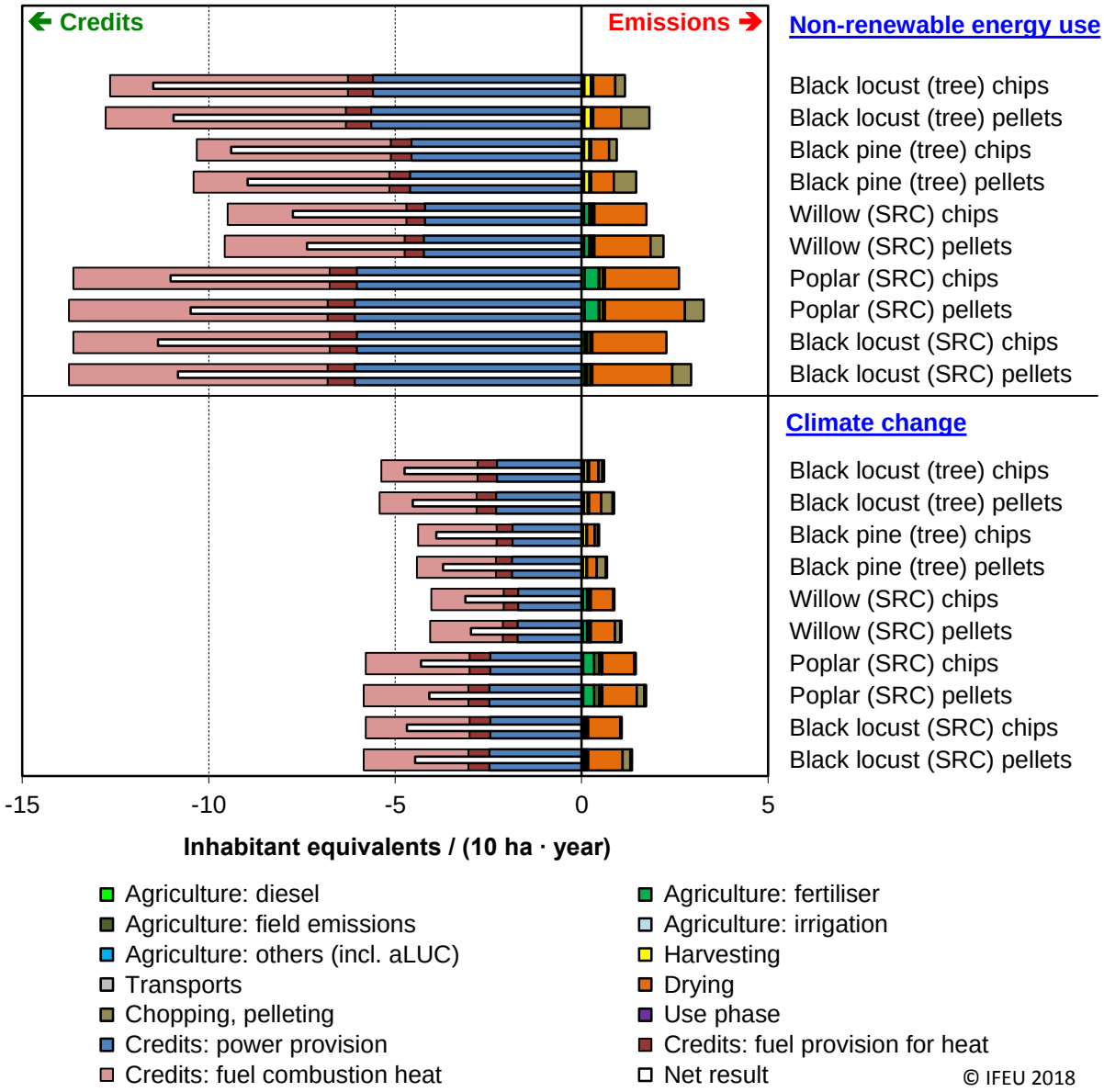

Fig. 4-3 Impact of kind of fuel (chips vs. pellets) on the result of the impact categories 'Non-renewable energy use' and 'Climate change' of all scenarios involving the cultivation of trees on marginal land (M1) in the Continental zone and their conversion in a small CHP pant.

How to read Fig. 4-3:

The annual production of black locust (tree) on ten hectare and its use in small heat and power plants as chips causes an amount of GHG emissions equal to the average annual emissions caused by 1 EU inhabitant. The provision of the corresponding amount of heat and power by non-renewable energy would lead to annual GHG emissions caused by about 13 EU inhabitants. In the net balance, the annual production of black locust saves the amount of GHG emissions equal to the average emission of about 12 EU inhabitants.

4.2.3 Sensitivity analysis on carbon stocks and changes

As the results in section 4.2.1 illustrate, the cultivation of energy crops on marginal land for bioenergy use leads to savings of GHG emissions. However, aspects of carbon stocks and changes have not been included. Therefore, the impact of carbon stocks and changes on the category 'climate change' is analysed in this section, exemplarily calculated for the cultivation of four crops on former grassland and shrubland in the Continental zone. The underlying calculation procedure and parameters are described in section 2.2.3.

Fig. 4-4 shows the results of the inclusion of carbon stock and changes effects in the impact category climate change. No other impact categories are affected by these effects. The results are illustrates as inhabitant equivalents per ten hectare and year.

The land use change from grassland to the cultivation of the investigated energy crops leads to additional burden in the impact category climate change amounting from 0.6 to 1.1 inhabitant equivalents per ten hectare and year. But the net result still shows advantageous effects of the biomass crops compared to the conventional reference products from the perspective of climate change. On the contrary, land use changes from shrubland cannot be totally compensated by all of the biomass crops. Only Miscanthus is still advantageous compared to the conventional reference products due to the relative high yields. Black locust, willow and poplar switch from benefits to additional burdens instead. In these cases, the credits for substituting the reference products cannot make up for the loss of carbon from the clearing of the former shrubland, at least if the amortisation period of 20 years is defined. However, as of an amortisation period of 35 years all crops, even willow, show in net advantages despite of effects from carbon stocks and changes.

The previous statements clearly show that the results within the impact category climate change are very sensitive to the effects of carbon stocks and changes and that the topic of direct land use change must not be ignored within the environmental assessment of bioenergy crops.

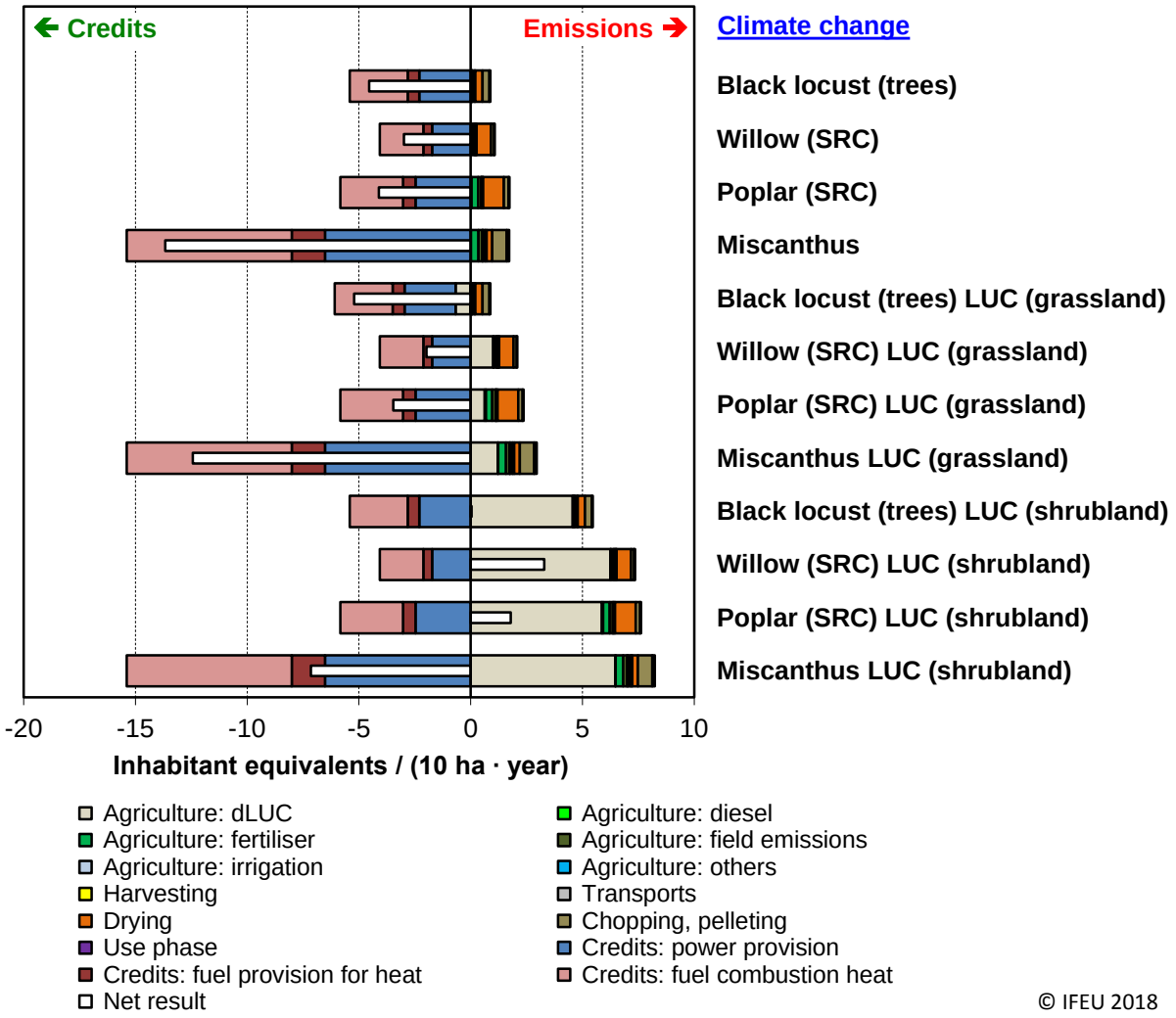

Fig. 4-4 Contributions of individual life cycle steps (coloured bars) in the impact category climate change to the overall net result (white bars) of four crops cultivated in the Continental zone and used in small CHP plant, compared to the conventional reference products. Emissions due to land use changes from grassland and shrubland are illustrated as beige coloured bars.

How to read Fig. 4-4:

The supply of poplar (3rd bar) from ten hectare of former grassland in one year and its use for bioenergy causes savings of greenhouse gas emissions equivalent to the average annual GHG emissions of 4 EU inhabitants. However, if poplar is cultivated on former shrubland instead (11th bar), additional greenhouse gas emissions equivalent to the average annual GHG emissions of 2 EU inhabitants are caused.

4.2.4 Excursus: Efficiency of phosphate rock demand and land use

The demand of phosphate and the land use are relevant topics which are often discussed in the context of agricultural production. As described in section 4.1.3, these topics are covered by new LCIA approaches [Fehrenbach, Keller, et al. 2018; Reinhardt et al. 2018]. Therefore, this section shows the efficiency of impacts that are related to the demand of phosphate rock and to the distance to the undisturbed state of the area. The target criterion is the saving of greenhouse gas emissions. Fig. 4-5 illustrates the efficiency regarding the phosphate rock demand for the crops, cultivated on marginal land (M1) in the Continental zone.

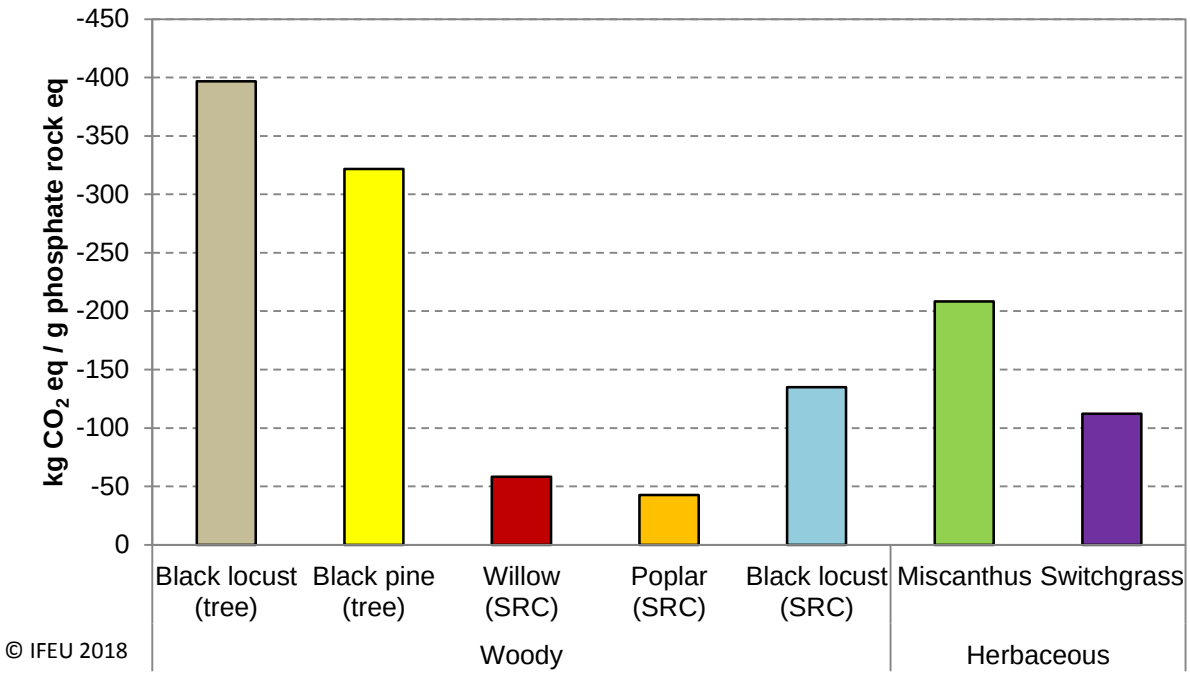

Fig. 4-5 Phosphate rock-efficiency on greenhouse gas savings at the example of the Continental zone and marginal land (M1). Not illustrated: giant reed in the Mediterranean zone -65 kg CO_2 eq / g phosphate rock eq.

How to read Fig. 4-5:

The 1st brown bar from the left shows that per gram of phosphate rock equivalents, the SEEMLA value chain of black locust (tree) leads to GHG emission savings of 353 kg CO_2 equivalents. In comparison the blue bar illustrates that black locust, cultivated as SRC, saves GHG emissions of 139 kg CO_2 equivalents per gram of phosphate rock equivalents.

The phosphate rock demand efficiency on GHG emission savings shows the best results for the trees, cultivated as short rotation plantation. In comparison to the other crops, the savings per hectare are lower, indeed (see Fig. 4-1). But the relatively low phosphorus demand of the trees results in a relatively high efficiency value. The SRC crops willow and poplar are characterised by the lowest efficiency values on phosphate rock demand. This can be explained by their relative high phosphorus demand that cannot be compensated by the GHG emission savings of the SEEMLA value chains.

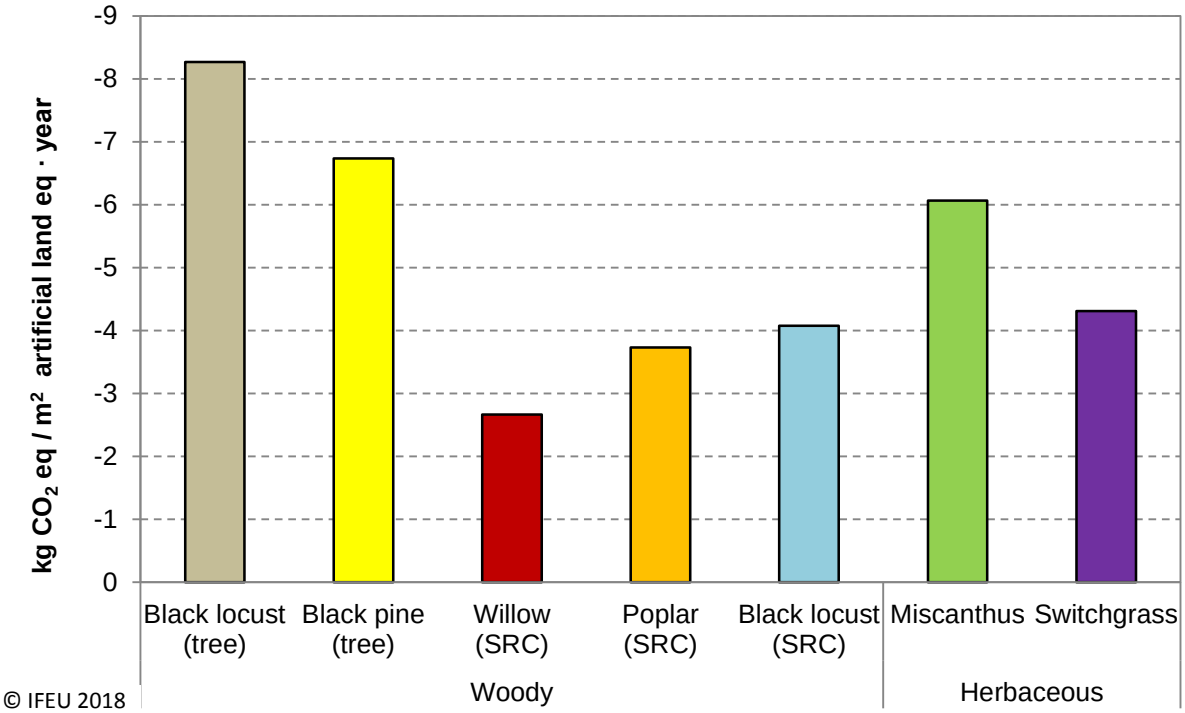

Fig. 4-6 Land use footprint on greenhouse gas savings at the example of the Continental zone and marginal land (M1). Not illustrated: giant reed in the Mediterranean zone -7 kg CO_2 eq / m^2 artificial land eq · year.

The GHG emission savings are also referred to the distance to the undisturbed state of the area caused by the cultivation of energy crops. In general, trees score well as the influence on the natural space is not as strong as for the other crops (see Fig. 4-6). But by reaching relative high GHG emission savings, the herbaceous crops can offset the relative high negative impacts on the area and lead to similar efficiency values as the trees.

How to read Fig. 4-6:

The first brown bar on the left hand side shows that per m² artificial land eq and year, the SEEMLA value chain of black locust (tree) leads to GHG emission savings of 8.5 kg CO_2 equivalents. In comparison the blue bar illustrates that black locust, cultivated as short rotation coppice, saves GHG emissions of 4.2 kg CO_2 equivalents per m² artificial land eq and year.

4.3 Results: Environmental performance of sites in the three climatic zones

In SEEMLA, three different climatic zones are considered for the cultivation of biomass: Atlantic, Continental and Mediterranean zone. Furthermore, two types of marginal land are set to cover different yield potentials. This section focusses on the generic scenarios and answers the question if there are sites or types of land that should be prioritised for bioenergy production (section 4.3.1). Concluding, the environmental performances of the SEEMLA value chains are compared to a non-agricultural use of the marginal land, namely the use of the area for the operation of photovoltaic systems (section 4.3.2).

4.3.1 Environmental impacts of SEEMLA generic scenarios

The environmental impacts of the SEEMLA value chains vary within the climatic zones due to the differences in soil quality. This variation is illustrated as a range (bandwidth) in the following figures. The derivation of the range is shown in Fig. 4-7, exemplified by the value chain of Miscanthus in the Continental zone, used in a small CHP plant. Although land of standard soil quality is not object of investigation within the SEEMLA project, standard soil quality with a SQR score between 40 and 80 is depicted for comparison.

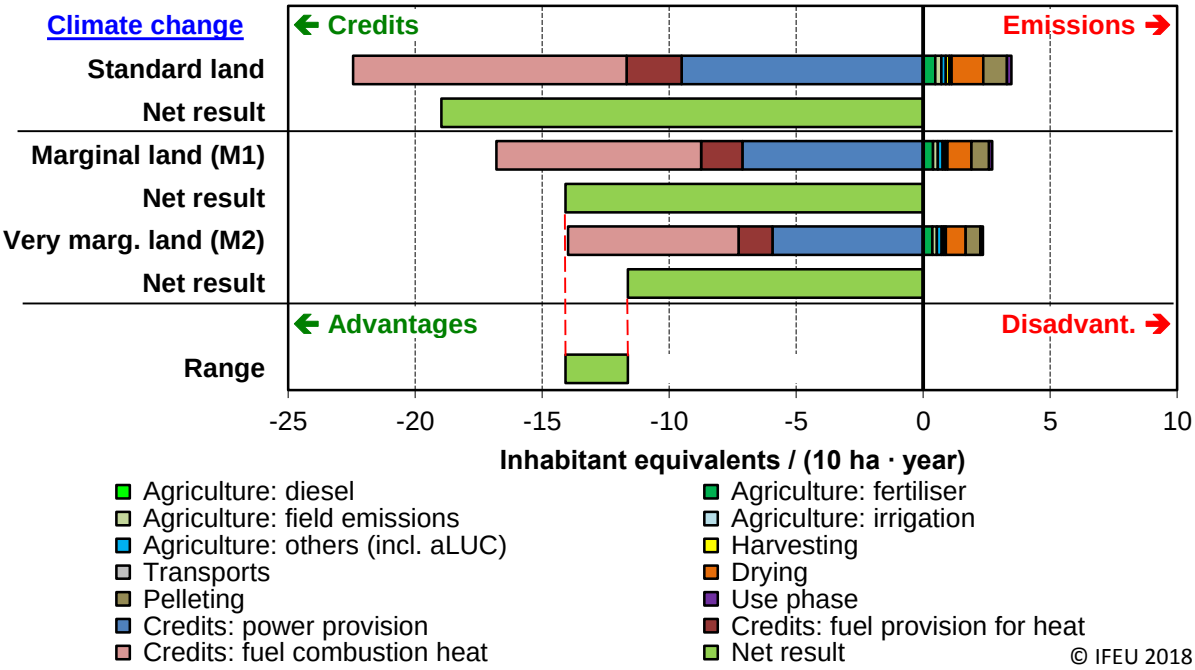

Fig. 4-7 Contributions of individual life cycle steps (coloured bars) to the overall net result (green bars) of the scenario 'Miscanthus in the Continental zone to small CHP plant' compared to the conventional reference products in the impact category climate change. Results are shown for low yields on marginal land (M1) as well as for very low yields (M2) and standard yields. The lowest bar displays the bandwidth of net results from marginal land (M1) and very marginal land (M2).

How to read Fig. 4-7:

The 3rd bar illustrates that the annual production of Miscanthus on marginal land (M1) and its use for CHP in a small plant cause greenhouse gas emissions of 3 inhabitant equivalents and avoid emissions of nearly 17 inhabitant equivalents. The 4th green bar represents the net result, meaning that the product system of Miscanthus for energy use saves greenhouse gas emissions of about 14 inhabitant equivalents per year. The lowest green bar shows that the range of the net results of marginal land (M1) and very marginal land (M2) is between -14 and -12 inhabitant equivalents per ten hectare and year.

As expected, higher soil quality leads to higher yields and therefore to higher credits due to the substitution of conventional energy resources. Although there are also higher burdens due to fertilisation and processing, the saving effects prevail. Considering climate change, the range of the environmental performance for Miscanthus in the Continental zone extends from -14 inhabitant equivalents for cultivation on marginal land (M1) to -12 inhabitant equivalents on very marginal land (M2).

Fig. 4-8 illustrates the ranges for the impact categories climate change and marine eutrophication for all energy crops in all analysed climatic zones by the SEEMLA generic scenarios. Regarding climate change, the ranges of all crops in all climatic zones are negative. That means that the cultivation of energy crops on marginal land even with very low yield potential saves greenhouse gas emissions. Considering the best performance in the impact category climate change, the use of marginal land with higher soil quality should be preferred for the cultivation of energy crops due to the higher environmental advantage. This advantage is more significant for the perennial grasses than for the woody biomass and lowest for the pine species. In contrast to climate change, the ranges of nearly all crops in the climatic zones are positive for the category marine eutrophication, meaning a disadvantage due to additional emissions for the SEEMLA scenarios. However, the disadvantages of the tree and of the black locust (SRC) scenarios are not very pronounced.

These results reflect the dependence of the biomass yields on the soil quality. Regarding the climatic zone, the environmental performance is more determined by the cultivated crop and less by the climatic zone itself. Therefore, no general preference of one climatic zone could be stated. Nevertheless, black locust and poplar show best performance on marginal land (M1) in the Mediterranean zone. Black pine has most advantages in the Continental zone as well as willow and Miscanthus in the Atlantic zone on marginal land (M1).

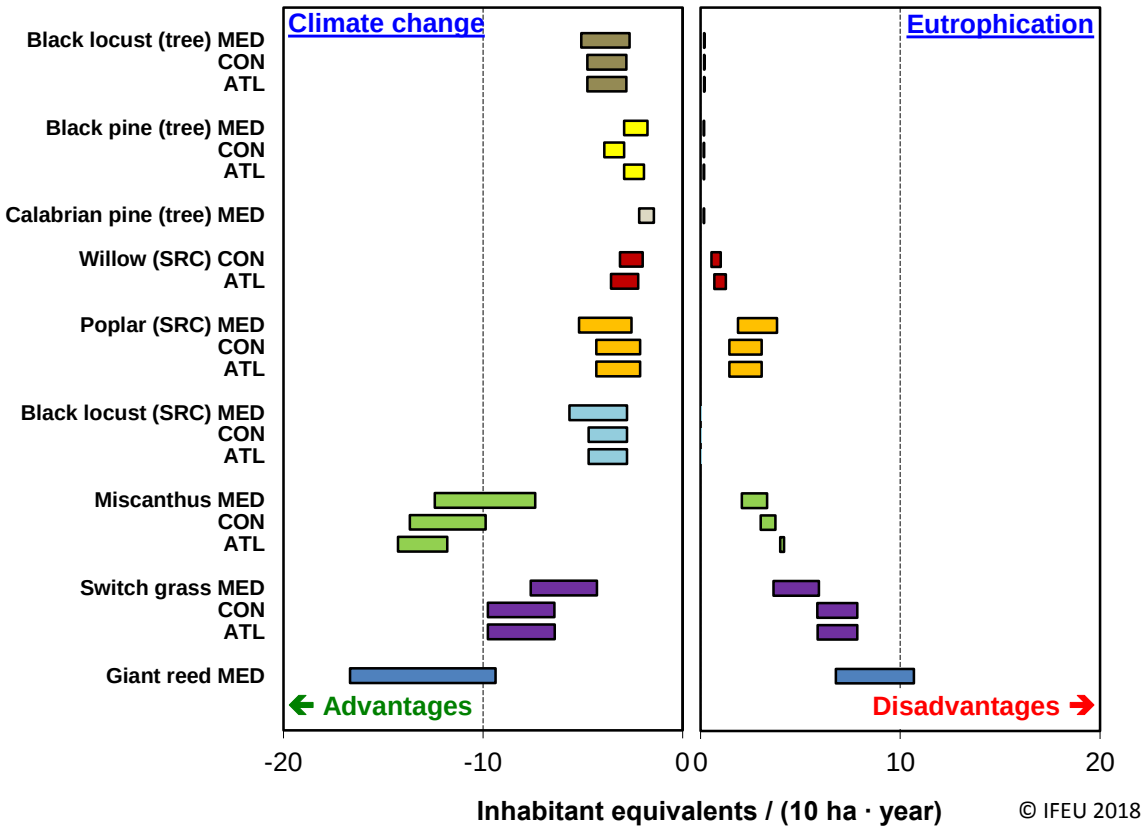

Fig. 4-8 Ranges of normalised impacts in the category climate change between the soil qualities marginal land (M1) and very marginal land (M2) for all crops in the three climatic zones and its use in a small CHP plant.

How to read Fig. 4-8:

The 1st three bars shows, that the use of black locust (tree) in small CHP plant leads to savings of greenhouse gas emissions compared to the average annual emissions which are caused by 3 EU inhabitants if cultivated on very marginal land (M2) in all climatic zones and up to 5 EU inhabitants if cultivated on marginal land (M1) in all climatic zones.

4.3.2 Excursus: Use of sites for photovoltaic systems

Besides the use of marginal lands for bioenergy, there are further land use options in the context of climate protection. One alternative is the use of marginal land for the installation and operation of ground-mounted photovoltaic (PV) systems. If the solar radiation is sufficient at the considered sites, marginal land is quite suitable for PV systems, provided that a minimum infrastructure (network connection, road access) is given. In this comprehensive excursus, the SEEMLA bioenergy value chains are compared to this alternative land use option. Therefore, the impacts on land use and on climate change per 1 kWh produced power of the SEEMLA bioenergy systems and of the PV system are compared to each other in Fig. 4-9.

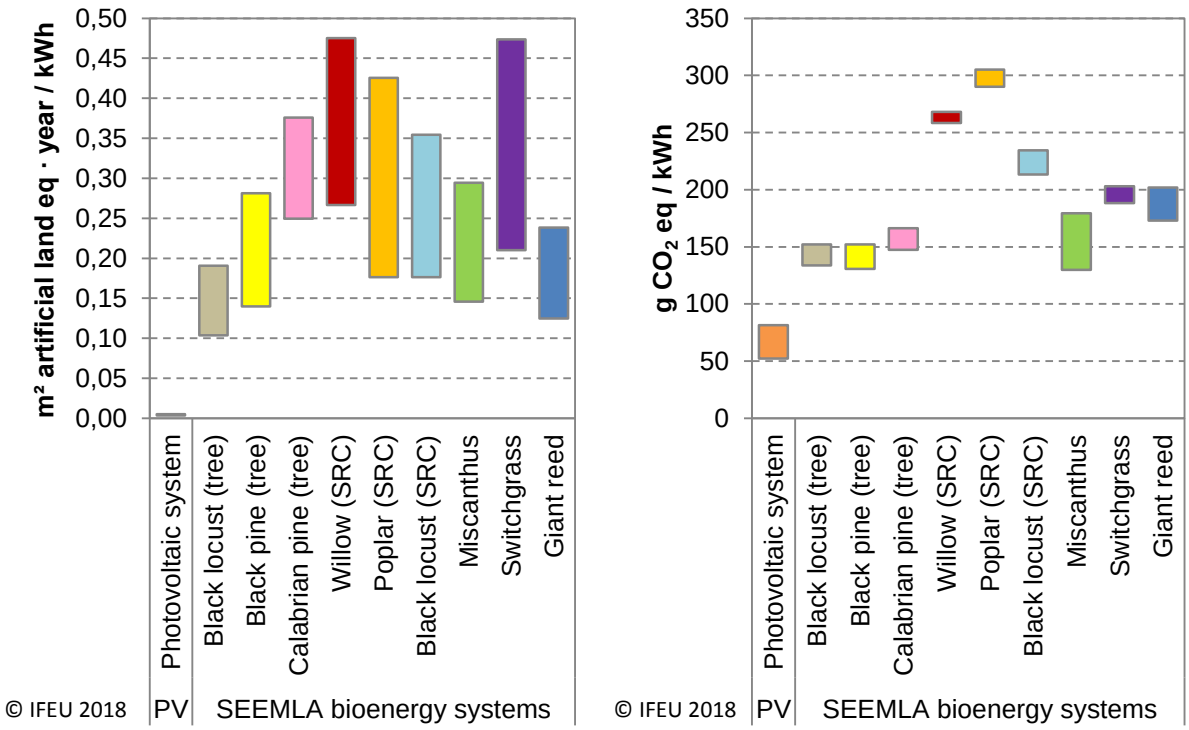

Fig. 4-9 Impacts on land use (left hand side) and on climate change (right hand side) per kWh of power. The figures illustrate the ranges between minimum and maximum values of the photovoltaic (PV) system and of the SEEMLA bioenergy systems.

As the figure above illustrates, the land use efficiency of PV systems is many times higher than that of the best SEEMLA value chain regarding climate protection aspects. Although the environmental advantages of PV systems in the impact category climate change are clear, other aspects have to be considered as well. For example, the PV modules would have a significant impact on the landscape. This and other local environmental impacts are covered by the LC-EIA approach in chapter 5.

4.4 Results: Environmental performance of use options

Within the SEEMLA project, the entire value chain from cradle to grave is considered so that the use phase is also analysed regarding its environmental performance. Therefore, different technologies which cover a broad range of energy use options (provision of power, heat and / or power, and fuel) are compared in the following section. In the second part of this section, an excursus looks into an alternative method of calculating greenhouse gas balances for the SEEMLA generic scenarios which follows European legal requirements. These legal requirements are mainly important for the market of energy products.

4.4.1 Environmental impacts of SEEMLA generic scenarios

As described in section 3.1.3, the following six energy uses are investigated in the SEEMLA project: domestic heat, district heat, small CHP, large CHP, power, and 2nd generation ethanol for fuel. Fig. 4-10 shows the normalised results for these use options at the example of Miscanthus on marginal land (M1) in the Continental zone for the analysed impact categories. The categories photochemical oxidant formation and particulate matter formation are no longer considered in the following because the investigated crops show neither relevant advantages nor disadvantages (see Fig. 4-1).The error bars illustrate the range of low and high efficiency of the conversion technologies.

Regarding the investigated use options, the results have a large range for the investigated impact categories. Within the categories acidification and particulate matter, the overall results even switch from advantageous to disadvantageous impacts, depending on the use option. Nevertheless, the effects in the impact category climate change always stay advantageous for the SEEMLA value chains, even if cultivation on very marginal land with very poor yield potential and low efficiency of the conversion technologies are considered (see Fig. 9-10 in the annex).

The best environmental performance is achieved by large combined heat and power (CHP) plants substituting heat and electricity from non-renewable resources. This conversion technology is characterised by an efficient use of the energy content, provided that the demands of electricity and especially heat are given. If the local demand of heat is not sufficient, even the provision of only power by a power plant is advantageous from an environmental perspective. The conversion of biomass to 2nd generation ethanol for fuel is not recommended under the defined conditions because this use option shows the poorest results compared to the other alternatives, confirming results by Rettenmaier et al. [2015].

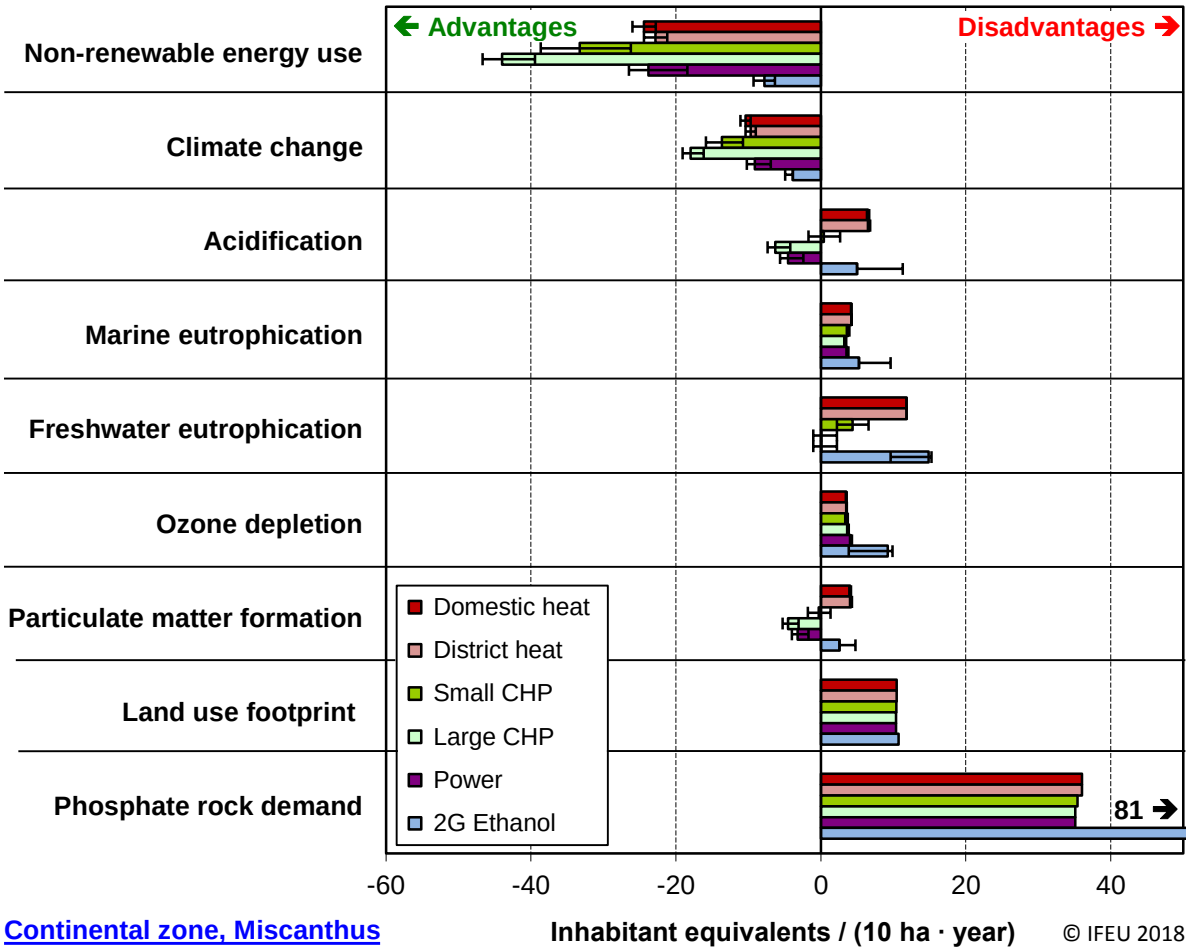

Fig. 4-10 Overall net results for Miscanthus, cultivated on marginal land (M1) in the Continental zone, used for different energy options compared to the reference system. Error bars shows the variation of results due to low and high conversion efficiency.

How to read Fig. 4-10:

The first red bar in the category 'Non-renewable energy use' shows that the annual production of Miscanthus on 10 ha and its use for domestic heat lead to savings of non-renewable energy resources which are consumed by 24 EU inhabitants in one year. The right hand error bar related to the bar illustrates that the low efficient conversion of Miscanthus to domestic heat reduces the savings by 2 EU inhabitant equivalents. The left hand error bar represents the high conversion efficiency which leads to an increase of the savings about 2 EU inhabitant equivalents.

4.4.2 Excursus: Greenhouse gas balances according to European legal requirements

This section addresses the application of the rules laid down in SWD/2015/259, supplemented by [Giuntoli et al. 2015], to the calculation of the GHG emissions of selected SEEMLA value chains, so that a statement regarding the fulfillment of the minimum emission savings defined in SWD/2014/259 can be made. The GHG emissions are calculated using the BioGrace II tool [RVO 2015]. In contrast to the previous results, the reference unit is not the annual occupied agricultural area, but expressed in units specific for each product energy output (see section 2.2.4).

The available biomass pathways in the BioGrace II tool match the following five SEEMLA value chains which are analysed both for marginal (M1) and very marginal (M2) land in the Continental zone:

- Poplar converted to domestic heat,
- Poplar converted to district heat,
- Poplar converted to heat in a small CHP plant,
- Poplar converted to electricity in a power plant, and
- Poplar converted to electricity in a small CHP plant.

These calculated GHG emissions are subsequently compared to the emissions of the fossil fuel comparator to check if defined minimum savings are reached (see section 4.1.4). The emissions of the fossil fuel comparator are defined as follows [European Commission 2014a]:

- Electricity = 670 kg CO_2 eq / MWh, and
- Heat = 288 kg CO_2 eq / MWh

Accordingly, minimum emission savings of 70% lead to life cycle emissions of less than or equal

- to 86 kg CO_2 eq per MWh of heat generated and
- to 201 kg CO_2 eq per MWh of electricity generated [European Commission 2014a].

Fig. 4-11 shows the results of the GHG balances for the selected SEEMLA value chains, calculated according to European legal requirements, and illustrates, if the minimum emission savings are reached.

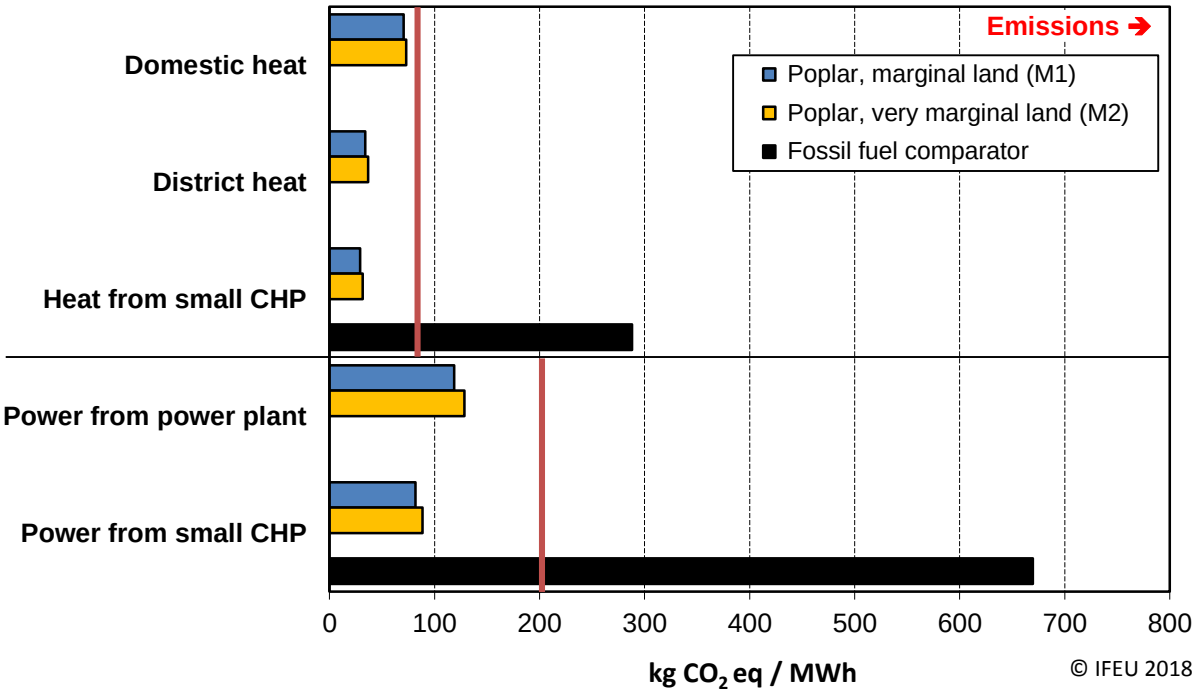

Fig. 4-11 Greenhouse gas emissions according to [European Commission 2014a] and calculated with the BioGrace II tool [RVO 2015] for selected SEEMLA value chains compared to the emissions of the fossil fuel comparators (black bars). The red lines illustrate 70% savings, which are specified as minimum savings for heat and electricity.

How to read Fig. 4-11:

The supply of electricity from poplar cultivated on marginal land (M1) in the Continental zone and converted in a small CHP plant causes 82 kg CO_2 equivalents per MWh energy content. The fossil fuel comparator is associated with emissions of 201 kg CO_2 equivalents per MWh energy content. Therefore, the SEEMLA value chain leads to emission savings of 88% compared to the fossil fuel comparator.

The figures illustrate that the investigated SEEMLA value chains comply the defined minimum GHG emission savings of 70%. For the provision of domestic heat, the SEEMLA value chain leads to emission savings of 75% compared to the fossil fuel comparator. Emission savings of almost 90% are reached by the SEEMLA value chains for the supply of heat from CHP and district heat. The small CHP plant also shows a clear reduction of GHG emissions by 87% for power production, compared to the fossil fuel comparator.

Nevertheless, calculation of GHG emissions according to SWD/2014/259 and statements on fulfilment of the defined minimum emission targets are not solely suitable for political decisions. As the focus is set on savings of GHG emissions per unit of product and not per unit of occupied agricultural area, statements according to SWD/2014/259 are not fully appropriate for the goals of the SEEMLA project as defined in chapter 1.

4.5 Environmental performance of SEEMLA case studies

Besides the generic scenarios, also the SEEMLA case studies are analysed by means of LCA. Section 4.5.1 gives an overview to the environmental impacts for the investigated impact categories. The sensitivity of the results on the country-specific electricity supply is checked in section 4.5.2.

4.5.1 Environmental impacts of SEEMLA case studies

For the calculation of the environmental impacts of the case studies, the country-specific agricultural inputs and yields provided by the project partners were implemented in the LCA model. The data for the agricultural inputs, especially fertiliser, represent actual applications and do not follow the methodical approach applied to the generic scenarios [Müller-Lindenlauf et al. 2014]. It should therefore be noted that comparability between the case studies and the generic scenarios is not unrestricted. For the conversion technologies, no case study-specific data were available, so that generic inventory data were used. The chosen use option for each country varies and represents a typical technology for the respective country. Domestic heat is defined for Greece, district heat for Ukraine and small CHP for Germany. The normalised results for all eight case studies are shown in Fig. 4-12.

In general, the pattern of the normalised results for the case studies is similar to that of the generic scenarios in section 4.2.1. This means that significant environmental advantages can be achieved regarding the impact categories non-renewable energy use and climate change. Furthermore, the case studies show environmental disadvantages in the other impact categories. The relatively small credits in the impact category acidification for the case studies in Germany, are mainly due to the use option of small CHP for conversion. The relatively high impact of black locust trees in Greece in the impact category freshwater eutrophication can be explained by the higher dose of applied phosphorus fertiliser compared to the other case studies.

Fig. 4-13 on page 62 shows the comparison of the case studies with the corresponding generic scenario. As discussed in Gärtner et al. [2018], the SQR scores of the case studies are determined on a basis of several basic soil and soil hazard indicators according to the Muencheberg Soil Quality Rating [Mueller et al. 2007]. However, the specific impacts of soil characteristics and hazards on the yield also depend on the crop species and cannot only be explained by the SQR scores. For example, if the nutrient supply is sufficient and the crop does not react sensitively on contamination, similar yields could be reached on marginal and on standard land. Therefore, the ranges of the generic scenarios are additionally expanded by the results for standard land with SQR scores between 40 and 80 to allow a broader basis for comparison.

Corresponding results between the case studies and generic scenarios are found for the pine species, poplar and black locust (SRC). For black locust (tree), willow and Miscanthus, the ranges of the case studies fall within the ranges of the generic scenario on standard land. In these cases, the yields of the case studies are higher than those of the generic scenarios indeed. Significant differences of the extent of ranges are stated for black locust (tree) and willow and are explained by the different yields in the generic scenarios and case studies. On the whole, the generic scenarios represent the case studies sufficiently well.

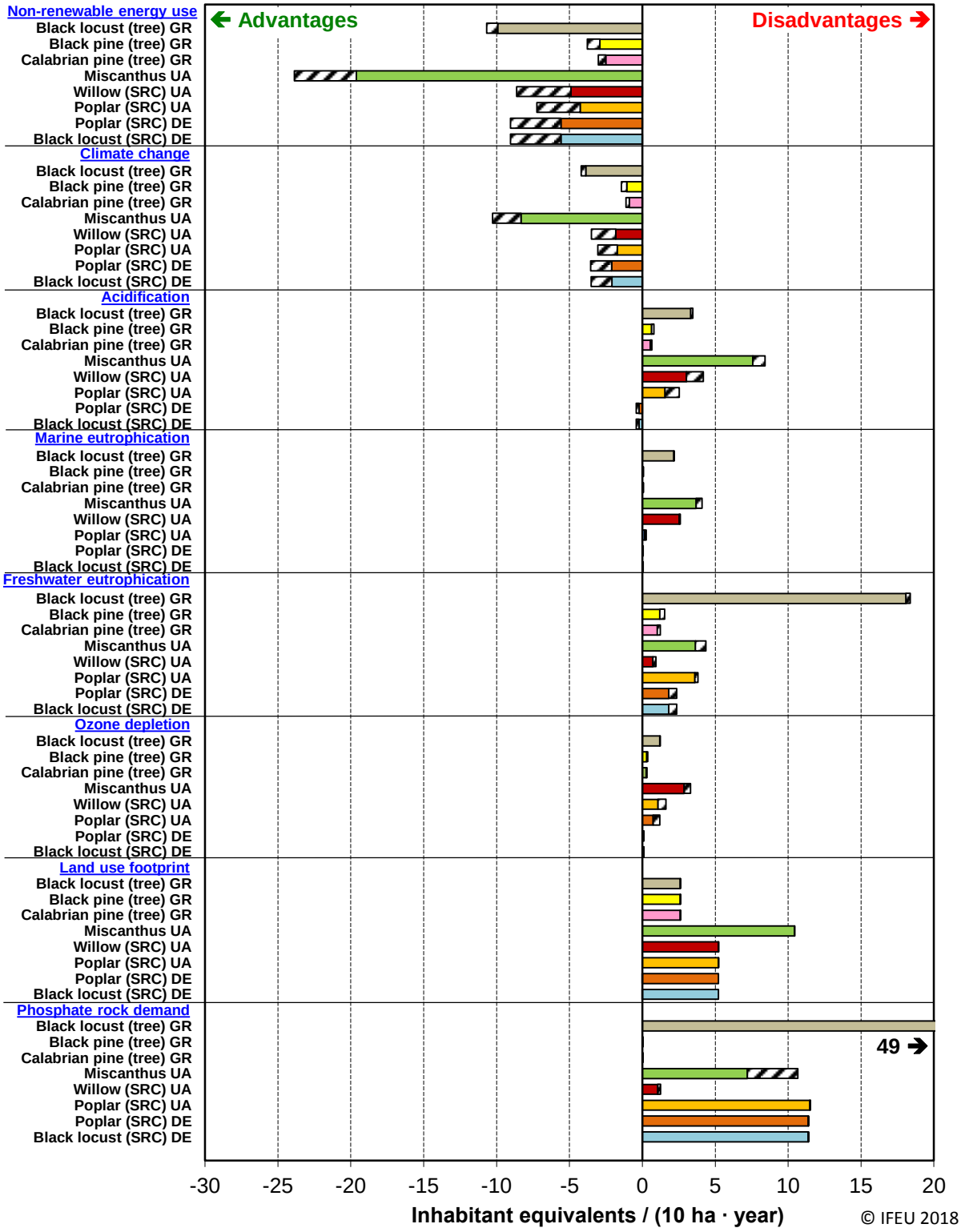

Fig. 4-12 Overall normalised net results of the eight analysed case studies, compared to the conventional reference system for selected impact categories. The range between marginal land (M1) and very marginal land (M2) is hatched.

How to read Fig. 4-12**:**

The 1st bar in the category 'non-renewable energy use' illustrates that the cultivation of black locust (tree) in Greece in one year and its use for domestic heat lead to energy savings from 10 to 11 EU inhabitant equivalents. The lowest bar in the category 'climate change' shows that the cultivation of black locust (SRC) in Germany in one year and its use in a small CHP plant lead to savings of greenhouse gas emissions from 2 to 3 EU inhabitant equivalents.

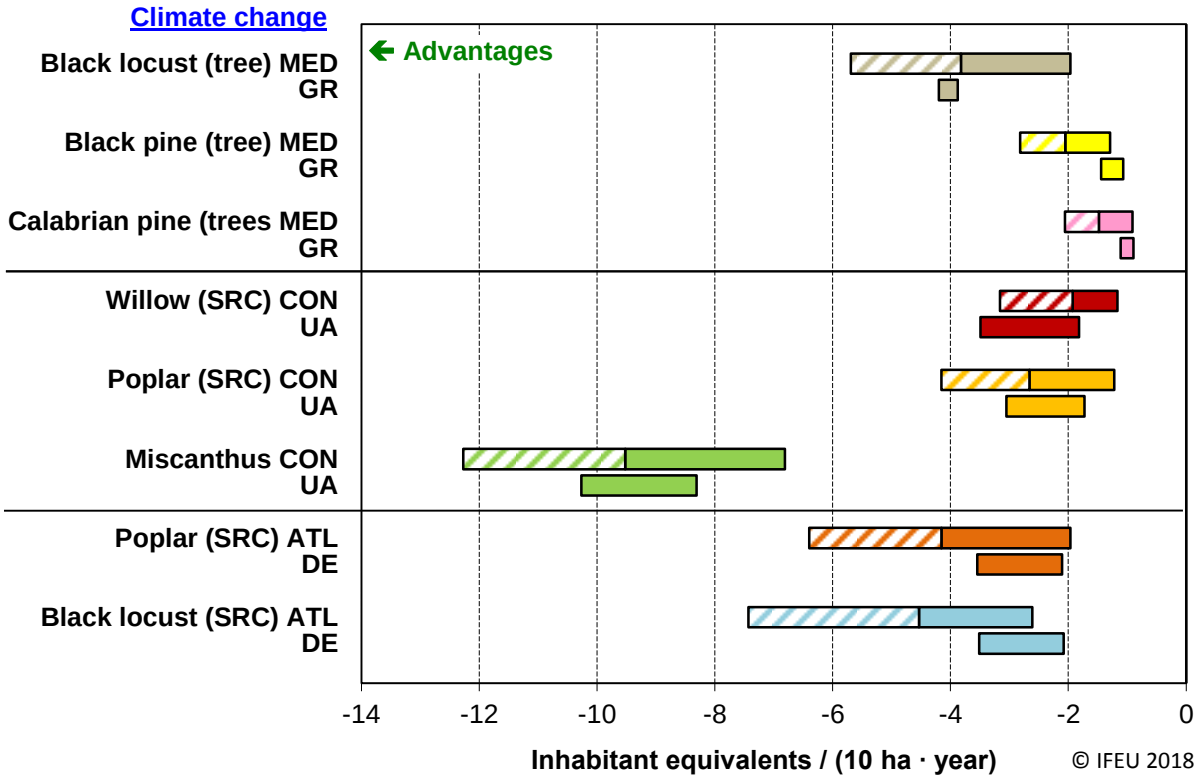

Fig. 4-13 Ranges of normalised impacts in the category climate change between the soil qualities marginal land (M1) and very marginal land (M2) for the product systems of the case studies (GR, UA, DE) and the corresponding generic scenarios (MED, CON, ATL). The generic scenarios additionally show the ranges between standard land and marginal land (M1) (hatched bar segments).

Furthermore, the impacts of the processes which contribute to the environmental burdens are analysed for the two soil qualities of the case studies compared to the generic scenarios. The reference unit is one ton dry matter to reduce / eliminate the effects of different dry matter yields. Fig. 4-14 presents the shares of all process emissions for the cultivation of willow in the generic scenario and in the case study. In the ideal case, the shares should be roughly similar for all sites and for scenarios and case studies as the reference to dry matter is given. For most processes, the shares for the scenarios and case studies are in relative good compliance with each other. Main differences between the generic scenarios and the case studies can be stated for the fertiliser-induced emissions of the very marginal land (M2) sites. The reason for this is the same fertiliser management both on marginal land (M1) and very marginal land (M2) for the cultivation of willow, despite different yield expectations.

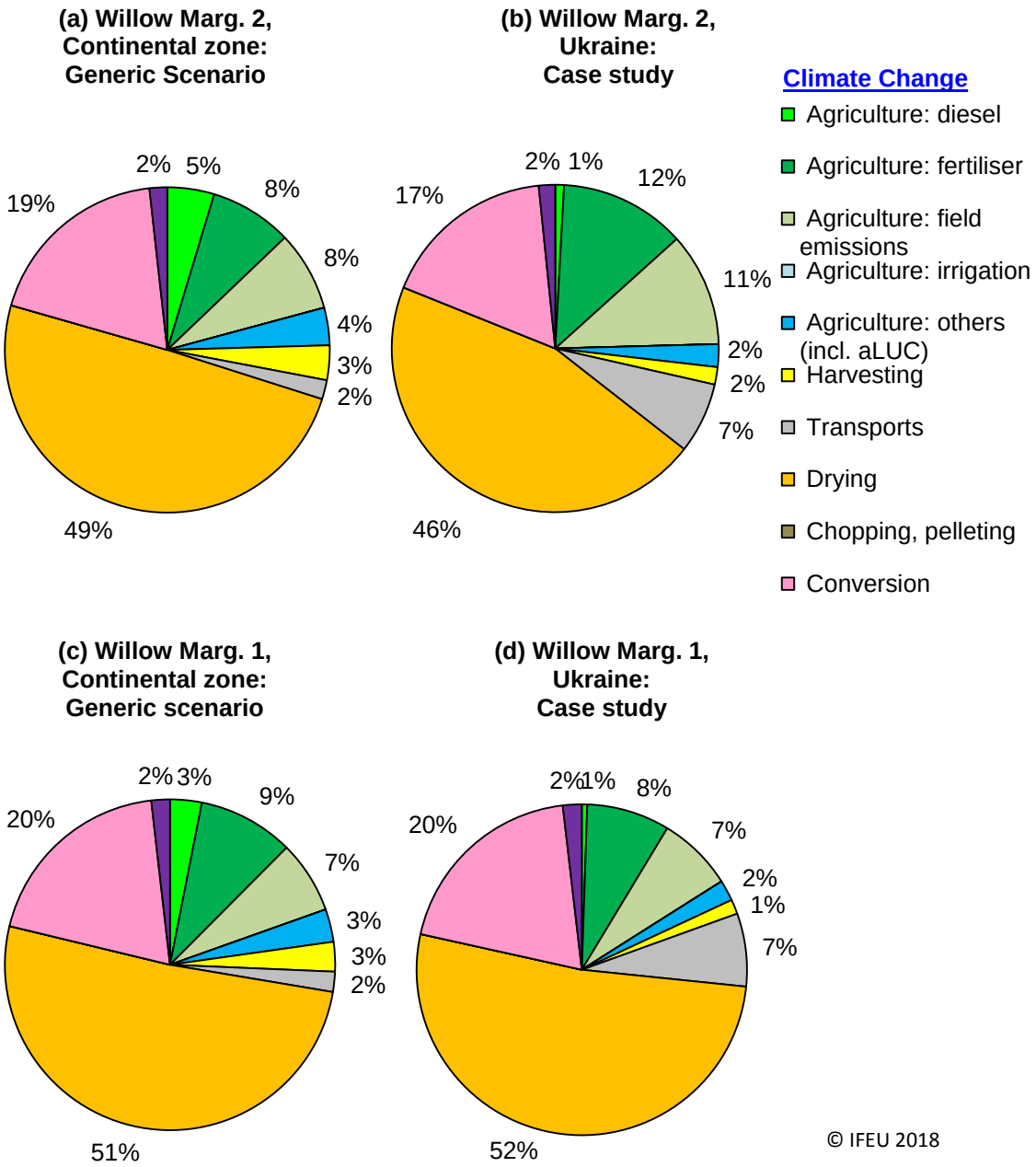

Fig. 4-14 Shares of all GHG emitting processes for very marginal land (M2) (a) and marginal land (M1) (c) of the generic scenarios as well as of the case studies (b and d).

How to read Fig. 4-14:

In the generic scenario, the provision of fertilisers for willow cultivation on very marginal land (M2) accounts for 8% of the total environmental impact in the impact category climate change. In the case study, this process has a share of 13%.

4.5.2 Sensitivity analysis on country-specific energy supply

In the previous sections, the SEEMLA value chains are modelled with the marginal European electricity mix for energy demand and for energy credits. In the following, data of country specific energy supply are used to analyse the potential impacts of SEEMLA value chains in the countries of the pilot cases, namely Germany, Greece and Ukraine. Furthermore, the impacts are identified if the average European electricity mix is set. In contrast to the marginal mix, the average mix does not only base on the fossil energy resources coal and gas but also on nuclear power and renewable energy resources.

The country specific energy supply is exemplarily considered in the SEEMLA value chains for these defined parameters: Miscanthus as energy crop, marginal land (M1) as soil quality and power generation as use option. Fig. 4-15 shows the normalised results for the impact categories climate change and marine eutrophication compared to the results based on the marginal and average European electricity mix.

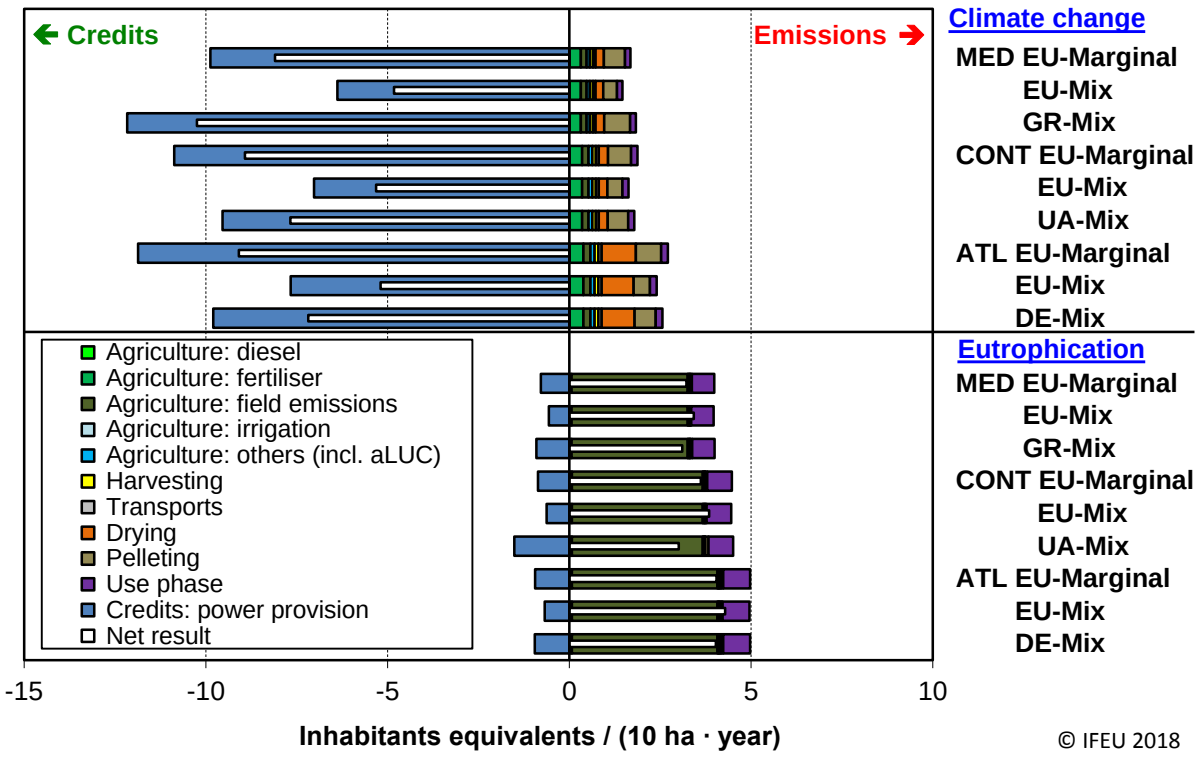

Fig. 4-15 Overall net results (white bars) and contributions of life cycle steps (coloured bars) of the scenario 'Miscanthus cultivated on marginal land (M1) and used in power plant' for the impact categories climate change and marine eutrophication. The energy supply and the reference power are varied regarding the European and the country-specific composition.

How to read Fig. 4-15:

The cultivation of Miscanthus on marginal land (M1) in one year and its use in a power plant lead to savings of greenhouse gas emissions amounting to 8 inhabitant equivalents if the marginal European mix for power supply and substitution are set (1st bar). The 2nd bar shows the results for the average European mix that lead to savings of greenhouse gas emissions about 5 inhabitant equivalents. If the country-specific power supply and substitution of Greece are defined, savings of greenhouse gas emissions about 10 inhabitant equivalents can be reached (3rd bar).

The results show that a significant impact of the electricity sources is given at the side of the credits while no significant impact is identified at the side of the emissions. In all countries of the pilot cases, the consideration of the country specific energy supply lead to an improvement of the net results due to the higher credits compared to the average European mix. This effect is obvious for the impact category climate change, but exists to a lesser extent, also for the impact category marine eutrophication. As the marginal European electricity only base on fossil energy resources the savings of greenhouse gas emissions are higher than those of the average electricity mixes in Germany and Ukraine. However, the average Greece electricity mix causes more greenhouse gas emissions than the marginal European electricity mix. Consequently, there are more positive effects of biomass for bioenergy in Greece.

Independent of the considered electricity mix, significant savings of greenhouse gas emissions can be stated for biomass for bioenergy from marginal lands in all countries of the case studies. The substitution of the average Greece electricity mix shows the highest positive effects in the impact category 'climate change' and also in 'eutrophication'.

4.6 Key results and conclusions for screening LCA

The screening life cycle assessment (LCA) carried out as part of the SEEMLA project included the evaluation of general, location-independent scenarios for the whole of Europe as well as case studies for Germany, Greece and the Ukraine. Different aspects along the life cycle from the cultivation of energy crops on marginal areas to the energy use of bioenergy carriers were investigated. The analysis (for details see sections 4.2 to 4.5) provided a number of main results and conclusions. These are divided into:

A comparison between bioenergy and conventional energy supply and

B comparison of the bioenergy pathways with each other.

Recommendations that can be derived from these main results and conclusions can be found in section 6.2.

A Comparison between bioenergy and conventional energy supply

Well-known pattern of environmental impacts confirmed: regarding the standard environmental impacts, there are no significant differences between bioenergy from conventional agricultural land and bioenergy from marginal land (in each case compared to conventionally provided energy): There are environmental advantages through the saving of greenhouse gas emissions and non-renewable energy, which tend to be offset by disadvantages such as acidification, eutrophication and ozone depletion.

Energy and GHG emission savings possible: The energy use of lignocellulose-containing biomass cultivated on marginal areas in Europe leads to savings in greenhouse gas emissions and non-renewable energy in comparison to conventionally provided energy. This result applies to all investigated plants, site qualities (yields) and use options - except in the case of large carbon stock changes due to land use changes (see below). The European minimum targets for greenhouse gas emission savings for stationary use for electricity and heat generation (SWD/2014/259) are met.


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The tendency is more towards disadvantages with other environmental impacts:


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The main disadvantages of bioenergy compared to conventional energy supply can be found in the environmental impact categories `Terrestrial acidification', 'Marine eutrophication', 'Freshwater eutrophication' and 'Ozone depletion'. These negative effects are primarily due to the nitrogen and phosphorus related emissions associated with fertilisation.

The range of results is wider than usual: The results for bioenergy production on marginal land show an exceptionally wide range, which is due to the many energy crops and use options available for selection as well as to the very different site qualities. This will be further explored in the following paragraphs.

Consideration of the entire life cycle and all environmental impacts is necessary to identify optimisation potentials: It is shown that optimisations are possible in many life cycle stages. Since, for example, relevant acidifying, eutrophying and particulate matter emissions occur in the biomass utilisation phase, it is essential to consider the entire life cycle. All relevant environmental impacts must also be taken into account in order to avoid one-sided optimisation (e.g. with regard to GHG) and shifting between environmental impacts. Three important fields of action are listed below:

- **Avoidance of indirect land-use changes is of central importance**: The identification of marginal land for energy crop cultivation using biophysical criteria in SEEMLA is an important step. However, indirect land-use changes (iLUC) are only avoided if the marginal areas are so far unused. This is decisive for the result of the life cycle assessment (see [Rettenmaier et al. 2015]). The main challenge is therefore to identify the unused areas from the totality of all marginal land. Despite great efforts, this has not been conclusively clarified within the SEEMLA project, so that further research work is necessary to quantify and localise unused marginal land.


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- **Convert only land with low biomass carbon stock**: In addition, the conversion of marginal land with a high carbon stock should be avoided, as in this case the direct land use change (dLUC) can lead to additional greenhouse gas emissions, for example when growing woody biomass on grassland with a high share of shrubs. High-yielding perennial grasses, on the other hand, can also compensate for the relatively high carbon loss resulting from the conversion of woody grassland / shrubland. This means that the cultivation of perennial energy crops on marginal land can in principle be recommended from the point of view of climate protection - as long as no major carbon stock changes are involved.


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- **Biomass drying expenditures must be minimised**: As already extensively investigated in other studies, biomass drying has a significant influence on the LCA results. The decisive factor here is that the water content at the time of removal from the field is as low as possible (< 15%), so that ideally no technical drying is necessary to preserve the harvested biomass. If technical drying is necessary (if necessary also to reduce the water content to 10% for subsequent pelleting), it should be as efficient as possible and an environmentally friendly energy carrier should be selected (see Rettenmaier et al. [2015]).

B Comparison of bioenergy pathways with each other

Environmental advantages and disadvantages increase with increasing site quality: Although greater energy and GHG emission savings can be achieved on marginal land (M1, SQR score 20–40) than on very marginal land (M2, SQR score 0–20), the energy and GHG balances are also positive for the latter. The simultaneous disadvantages in other

environmental impacts are less pronounced on very marginal land (M2), despite higher specific nutrient losses. However, these are lower in absolute terms due to the lower nutrient requirement due to the yield. Within this study, two soil quality classes (SQR score 0–20 and 20–40, respectively) were used for which average yields were derived. Depending on the type of biophysical restriction, the yield reductions may be significantly greater compared to standard land. A more detailed breakdown would be desirable in the future, especially in order to define – in addition to the upper limit of 40 SQR points for marginal land defined in the SEEMLA project – a lower SQR limit below which cultivation is too risky.

Woody biomass is sometimes better than herbaceous biomass: The perennial grasses Miscanthus, switchgrass and giant reed tend to have greater environmental advantages in terms of energy and GHG emission savings than the woody biomass due to the higher energy yields, but at the same time also have greater disadvantages in other environmental impacts. Woody biomass, on the other hand, has hardly any disadvantages. Due to their better phosphorus utilisation efficiency (CO_2 savings / phosphate rock equivalent input) and greater CO_2 savings per natural land use, trees with long rotation times (e.g. 20 years) are particularly recommended on sensitive sites.


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Stationary use for electricity and heat generation beats biofuels: Direct combustion of perennial energy crops for electricity, heat or combined heat and power generation currently achieves greater environmental benefits than conversion into and use of advanced biofuels such as lignocellulosic ethanol. This is the case as long as there are significant shares of fossil energy carriers in the conventional heat and electricity mix, respectiveöy. However, use options yielding advanced biofuels may represent valuable alternatives to the crude oil / natural gas pathways in a post-coal age.

Other renewables can be much more environmentally friendly than bioenergy: Bio-energy competes with other renewable energies, e.g. ground-mounted photovoltaic (PV) systems, for marginal land. The environmental advantages of PV electricity per unit of energy are significantly greater than those of electricity from biomass. In particular, the energy and GHG emission savings are several times higher than when the land is used to provide bioenergy.


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Recommendations that can be derived from these main results and conclusions can be found in section 6.2.

5 Life cycle environmental impact assessment (LC-EIA)

This chapter presents the methodology (section 5.1), the results (sections 5.2 – 5.3) and the conclusions (section 5.4) of the life cycle environmental impact assessment (LC-EIA). The LC-EIA in SEEMLA is performed both for the generic scenarios and for the pilot cases in Germany, Greece and Ukraine (see Table 3-9 on page 30).

5.1 Methodology

This section introduces the life cycle environmental impact assessment (LC-EIA) methodology (section 5.1.1) and provides the specific settings applied within the SEEMLA project (section 5.1.2).

5.1.1 Introduction to the LC-EIA methodology

There are a number of environmental management tools which differ both in terms of subject of study (product, production site or project) and in their potential to address environmental impacts occurring at different spatial levels. Life cycle assessment (LCA), as described in section 4.1.1, takes into account potential environmental aspects and impacts of a product system at a general, site-independent level. In the case of environmental impacts such as climate change or stratospheric ozone depletion, which occur on a global scale, the environmental impact is independent of the place of emission. The same applies to environmental impacts such as acidification or eutrophication, as gaseous emissions become effective at a supraregional level and are predominantly site-independent.

Other environmental impacts, such as the impacts of land use on the environmental factors soil, water and biodiversity, are particularly pronounced at local level. Here, the environmental impacts are strongly related to the very specific, site-dependent conditions. Generalising these for LCA is a major challenge. For some years now, methodological developments have been underway that aim to regionalise LCA and to make previously often neglected environmental impact categories such as land use quantifiable and operationalisable. However, this is not yet "state of the art". Thus, for the time being, LCA has to be supplemented by elements borrowed from other tools.

The methodology applied within the SEEMLA project borrows elements from environmental impact assessment (EIA) [and partly from strategic environmental assessment (SEA)] and is therefore called life cycle environmental impact assessment (LC-EIA) [Keller et al. 2014; Kretschmer et al. 2012].

Introduction to EIA

Environmental impact assessment (EIA) is a standardised methodology for analysing proposed projects regarding their potential to affect the local environment. It is based on the identification, description and estimation of the project's environmental impacts and is usually applied at an early planning stage, i.e. before the project is carried out. EIA primarily serves as a decision support for project management and authorities which have to decide on approval. Moreover, it helps decision makers to identify more environmentally friendly alternatives as well as to minimise negative impacts on the environment by applying mitigation and compensation measures.

The environmental impacts of a planned project depend on both the nature / specifications of the project (e.g. a biorefinery plant housing a specific production process and requiring

specific raw materials which have to be delivered) and on the specific quality of the environment at a certain geographic location (e.g. occurrence of rare or endangered species, air and water quality etc.). Thus, the same project probably entails different environmental impacts at two different locations. EIA is therefore usually conducted at a site-specific / local level. These environmental impacts are compared to a situation without the project being implemented ("no-action alternative").

An EIA generally includes the following steps:

- Screening
- Scoping
- EIA report
- Monitoring and auditing measures

Regulatory frameworks related to EIA

Within the European Union, it is mandatory to carry out an environmental impact assessment (EIA) for projects according to the Council Directive 85/337 EEC of 27 June 1985 "on the assessment of the effects of certain public and private projects on the environment" [CEC 1985]. This Directive has been substantially amended several times. In the interests of clarity and rationality the original EIA Directive has been codified[1] through Directive 2011/92/EU of 13 December 2011 [European Parliament & Council of the European Union 2011]. The latter has once again been amended in 2014 through Directive 2014/52/EU of 16 April 2014 [European Parliament & Council of the European Union 2014].

The list of factors has been significantly altered with the 2014 amendment (addition and deletion of factors) and currently includes the following factors:

- population and human health
- biodiversity (previously: fauna and flora)
- land (new), soil, water, air and climate
- material assets, cultural heritage and the landscape
- the interaction between the factors mentioned above.

Please note: the new factor "land" is indirectly addressed in the conflict matrices (via the factors "soil" and "landscape") since implementing rules for the new factor "land" are lacking or under development. Moreover, we continue to address the two factors "fauna" and "flora" separately, since we think that "biodiversity" alone wouldn't cover all aspects that were previously addressed under "fauna" and "flora" (e.g. the conservation / Red List status of species). This way, more specific recommendations can be derived.

[1] put together as a code or system, i.e. in an orderly form

5.1.2 Settings for life cycle environmental impact assessment (LC-EIA)

Within this project, a set of different concepts for bioenergy provision from perennial, lignocellulosic crops cultivated on marginal land is analysed. Each concept is defined by its inputs, the conversion and the final products. This is also reflected in the objectives of the sustainability assessment: the aim is to qualitatively assess the impacts associated with each of the (hypothetical) investigated concepts at a generic level. The assessment is not meant to be performed for a specific energy crop plantation or biomass conversion facility at a certain geographic location.

Environmental impact assessment (EIA), however, is usually conducted specifically for a planned (actual) project (see previous section 5.1.1). For the purpose of the SEEMLA project, which neither encompasses the establishment of large-scale energy crop plantations (only pilot cases / cultivation trials were established) nor the construction of a biomass conversion facility, it is therefore not appropriate to perform a full-scale EIA according to the regulatory frameworks. Monitoring and auditing measures, for example, become redundant if a project is not implemented, as they are post-project procedures. Consequently, monitoring and auditing measures are omitted within the SEEMLA project. Nevertheless, elements of environmental impact assessment (EIA) are used to characterise the environmental impacts associated with the SEEMLA systems at a generic level. The elements of EIA used in this project are shown in Fig. 5-1**.**

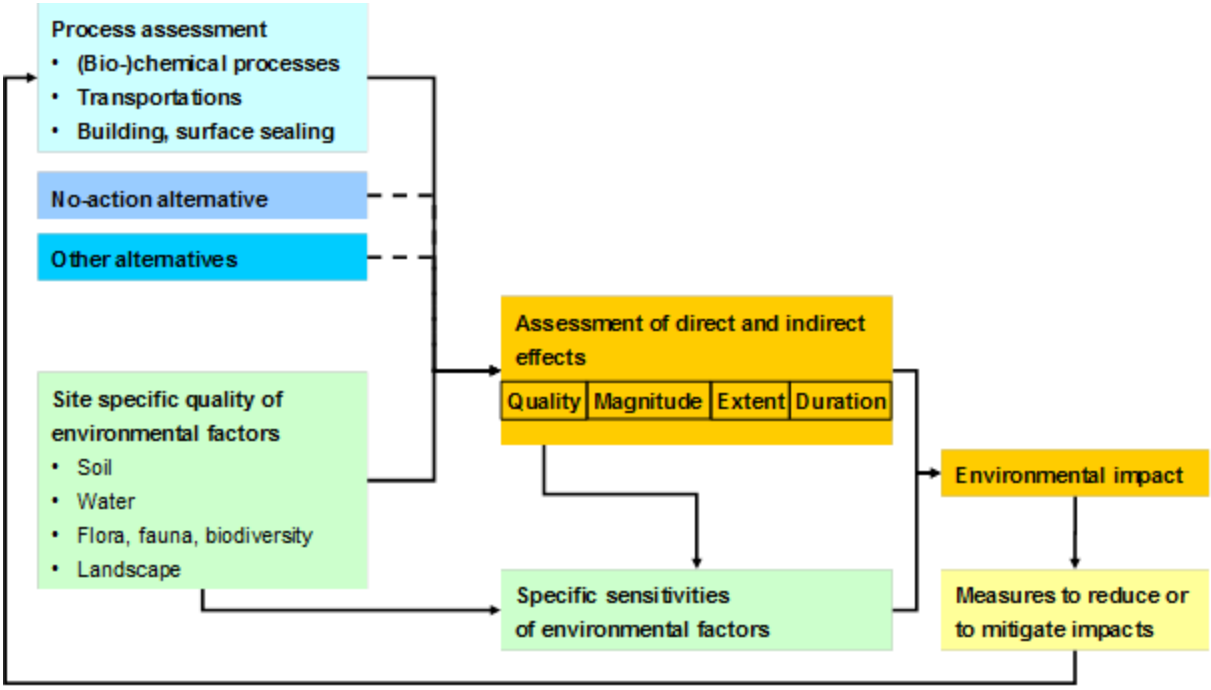


Fig. 5-1 Structure of the LC-EIA within the SEEMLA project. © IFEU 2018

For the SEEMLA project, the scope, and therefore also the reference system, of the LC-EIA was chosen to encompass all life cycle stages from raw material (e.g. biomass) provision through conditioning / refining up to the conversion and use of the energy carriers. This corresponds to a life cycle perspective and goes beyond the regulatory frameworks for EIA.

The following steps were taken to analyse the local environmental impacts of the SEEMLA scenarios:

- Step 1: Identification of the main impacts on nature and landscape associated with biomass production
- Step 2: Comparative site-independent evaluation of the SEEMLA scenarios with regard to their major impacts on the basis of expert assessments

Reference systems

Generally, an EIA compares a planned project to a so-called "no-action alternative" (a situation without the project being implemented) in terms of environmental impacts. This assessment is restricted to one specific project or site such as an energy crop plantation or biomass conversion facility. Production sites for raw material inputs (e.g. biomass) and / or the impacts associated with the end use of the manufactured products are usually not considered in an EIA, but in an LC-EIA, they are. The reference systems are specified in section 3.3.

Impact assessment

The assessment of local environmental impacts along the life cycle is carried out as a qualitative, site-independent benefit and risk assessment. This is useful if no certainty exists regarding the possible future sites of biomass production and conversion.

For site-independent impact analysis this means:

- only risks of impairment of the environmental factors can be presented,
- the actual impacts depend on the site characteristics, the crop rotation and the working steps / procedures.

The main impacts of agricultural and forestry activities on nature and the landscape include:

- The erosion of soils by wind and water, depending on the soil cover and thus on the crop rotation and the specific characteristics of the crops as well as on tillage.
- Soil compaction, depending on soil properties, the type of agricultural machinery including tyres and tyre pressure as well as frequency and time of passage with negative effects on all soil functions.
- The eutrophication of biotopes, which leads to a change in the biological activity in the soil and to changed characteristics of the soil as a substrate for crops, depending on the use of fertilisers, crop rotation and soil cultivation.
- The exposure to pesticides affecting soil micro-organisms and soil properties as a substrate for crops.
- The contamination of groundwater, in particular by nitrates and pesticides.

- The contamination of surface waters by nutrients and pesticides.
- Loss of landscape elements, e.g. field margins and hedges, in the cultural landscape affecting both biodiversity and the landscape.
- As a consequence, a loss of habitats and biodiversity in the cultural landscape.

Deduction of conflict matrices

For the qualitative benefit and risk assessment, so-called conflict matrices are used which reflect the impacts of raw material (e.g. biomass) provision on the selected environmental factors. Raw material-specific conflict matrices were developed (see sections 9.3.1 and 9.3.2 in the annex). An example for biomass provision is given in the following Table 5-3.

Table 5-1 Risks associated with the cultivation a specific perennial lignocellulosic crop (intentionally left blank, i.e. for illustration only).

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

Categories: positive – neutral – negative

In this crop-specific conflict matrix, the environmental impacts of biomass cultivation are compared to the reference system (relative evaluation) and evaluated as follows:

- "positive": compared to the reference system, biomass cultivation is more favourable
- "neutral": biomass cultivation shows approximately the same impacts as the reference system
- "negative": compared to the reference system, biomass cultivation is less favourable.

Similar conflict matrices were developed for fossil raw material provision (reference system for biomass provision) and for raw material conversion (both biomass and fossil raw material).

The assessments made in the aggregated conflict matrices reflect the authors' assessment.

Finally, mitigation measures could be deducted from these conflict matrices. However, since the SEEMLA project is not targeting a specific location, mitigation measures are omitted.

Comparison and ranking of scenarios

The significance of the main effects and the differences between the SEEMLA scenarios are compared in tabular form in the form of a ranking.

These tables present in an aggregated manner the types of risk associated with each of the scenarios including a ranking of the impacts into five categories from A (low risk) to E (high risk). An example is given in the following Table 5-4.

Table 5-2 Comparison of scenarios regarding the risks associated with their implementation (intentionally left blank, i.e. for illustration only).

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

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

5.2 Results for the generic scenarios

Local environmental impacts associated with the SEEMLA systems and conventional reference systems were studied following the life cycle environmental impact assessment (LC-EIA) methodology (see section 5.1). Section 5.2.1 focusses on the impacts of the SEEMLA systems whereas section 5.2.2 presents the impacts associated with the conventional reference systems. A comparison of all investigated systems is shown in section 5.2.3.

5.2.1 Local environmental impacts of the SEEMLA systems

Following the system description in chapter 3, the SEEMLA systems are divided into several life cycle stages. For the purpose of the LC-EIA, the following stages are evaluated:

- Biomass feedstock provision
- Biomass feedstock conversion

Biomass provision takes place in one location and biomass conversion is spatially separated. Thus, intermediate transport and logistics steps are required.

Biomass feedstock provision

The cultivation of perennial energy crops includes both risks as well as opportunities, dependent on the type of crop. The assessment of crop-specific risks primarily depends on the comparison with alternative uses, i.e. on the agricultural reference system. As described in section 3.3.1, the agricultural reference system defined within the SEEMLA project is idle land with a grassy vegetation cover, possibly interspersed with shrubs and trees, i.e. grassland or shrubland / woody grassland.

The risks of cultivating each perennial energy crop were evaluated against this reference system (by means of a qualitative, site-independent benefit and risk assessment) and led to crop-specific conflict matrices. These conflict matrices are displayed in section 9.3.1 in the annex.

Subsequently, these risks were aggregated and categorised from A (low risk) to E (high risk), allowing for a comparison and ranking of the scenarios. The results are depicted in Table 5-3. The lowest risks are associated with the short rotation (tree) plantations (harvested after 20 years), followed by short rotation coppice (rotation periods 3–7 years). Herbaceous crops such as Miscanthus, switchgrass and giant reed show a higher water demand, which leads to a less favourable classification. Giant reed requires a higher fertiliser input which increases eutrophication and nutrient leaching risks. The risk of loss of habitat types and species is increased if species are considered invasive. This is definitely the case for black locust [Nehring et al. 2013], but the invasiveness of herbaceous crops is still under discussion. Giant reed is considered invasive in areas outside the Mediterranean zone, especially near surface waters [Global Invasive Species Database 2018]. Uncontrolled propagation of Miscanthus (through rhizomes) and switchgrass (through seeds) could pose a risk, especially near nature conservation areas, although the risk associated with switchgrass is considered low by NL Agency [2013]. More scientific evidence is needed here, though.

Table 5-3 Risks associated with the cultivation of the investigated perennial energy crops compared to the agricultural reference system idle land (grassland). © IFEU 2018

Type of risk	Perennial crop / feedstock				
	Black pine / Calabrian pine	Black locust (tree)	Willow / poplar / black locust (SRC)	Miscanthus / switchgrass	Giant reed
Soil erosion	A	A	B	B	B
Soil compaction	A	A	A	B	B
Loss of soil organic matter	B	B	B	B	B
Soil chemistry / fertiliser	A	A	B	B / C	C
Eutrophication	A	A	A / B	B / C	C
Nutrient leaching	A	A	A / B	B / C	C
Water demand	B	B	C	D	D
Weed control / pesticides	A	A	B	B	B
Loss of land-scape elements	C	C	C	C	C
Loss of habitat types	C	D*	C / D*	C	C
Loss of species	C	D*	C / D*	C	C

Impacts are ranked into five comparative categories (A, B, C, D, E); "A" is assigned to the best options concerning the factor, "E" is assigned to unfavourable options concerning the factor; agricultural reference system: idle land (grassland)
* Increased impact due to invasiveness of black locust

Transport and logistics

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

Storage facilities for biomass can either be constructed at the site of biomass provision (decentralised storage on the field margin) and/or at the site of biomass conversion. In any case, additional buildings cause sealing and compaction of soil, loss of habitats (plants, animals) and biodiversity as well as reduced groundwater infiltration.

Overall, the impacts associated with transportation and logistics are not expected to be significant.

Biomass feedstock conversion

Biomass conversion and provision of bioenergy is done in a biomass conversion facility. The local environmental impacts associated with the implementation of such a facility (compared to the reference scenario) are considered in this section.

Impacts from implementing a biomass conversion facility are expected from:

- the construction of the facility
- the facility itself: buildings, infrastructure and installations and
- the operation of the facility.

Impacts related to the **construction of the facility** are temporary and not considered to be significant.

Biomass conversion facilities need **buildings, infrastructure and installations**, which are usually associated with soil sealing. Differences are expected regarding the facility's location, depending on whether the project is developed on a greenfield site or on a brownfield site:

- A greenfield site is land currently used for agriculture or (semi)natural ecosystems left to evolve naturally.
- A brownfield site is land that was previously used for industrial, commercial or military purposes (often with known or suspected contamination) and is not currently used. Most of the area is expected to be already sealed and traffic infrastructure might (at least partly) be available.

Other impacts might vary in quantity but not in quality, which in case of a generic approach on potential environmental impacts of technologies is negligible. Significant impacts are expected on water, soil, plants, animals and landscape and are highly dependent on local conditions.

Impacts from the **operation of the facility** are expected from:

- emission of noise
- emissions of gases and particulate matter
- drain of water resources for production
- waste water production and treatment
- traffic (collision risks, emissions)
- electromagnetic emissions
- risk of accidents (explosion, fire in the facility or storage areas, release of genetically modified organisms (GMO))

Significance of impacts might vary with the type of technology and the location of a potential facility. This variability cannot be taken into account by this generic LC-EIA. Moreover, this LC-EIA cannot replace a full-scale EIA according to Directive 2014/52/EU.

5.2.2 Local environmental impacts of the reference systems

Alike the SEEMLA systems, also the reference systems are divided into several life cycle stages. For the purpose of the LC-EIA, mainly feedstock provision and feedstock conversion are distinguished. Transport and logistics are considered separately.

Fossil feedstock provision

Although impacts might vary in detail, the provision of different fossil feedstocks shows similar impacts on the environment on a generic level. Major impacts are caused by land requirements which in the case of mining (provision of coal especially lignite and uranium ore) might exceed land requirements associated with crude oil or natural gas provision, even if the land necessary for the construction of pipelines is taken into account. The considered value chains are associated with heavy impacts on water, either by draining (coal), washing (uranium ore) or the use of process water (crude oil). Heavy impacts are expected from dusts in case of coal and uranium ore provision showing high intensities in open pit mining and because of toxic and radioactive dusts in uranium ore mining as well. The risk combined with accidents might be highest in crude oil and natural gas provision since these value chains are dealing with hazardous substances. Table 5-4 summarises major implications of the considered value chains in comparison with the no-action alternative. Detailed conflict matrices for each fossil energy carrier are displayed in section 9.3.2 in the annex.

Table 5-4 Potential impacts on the environment related to different fossil feedstocks which are used for the provision of heat and / or power in conventional systems; reference system: no use. © IFEU 2018

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

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

[1] Increased land requirements in on-shore production

[2] Increased impacts with open pit mining

[3] Increased impact in crude oil provision

Transport and logistics

Crude oil, coal and yellow cake (concentrated uranium ore) are usually shipped to Europe. Long-distance transportation increases exhaust gases (cargo ships, lorries) with potential impacts on water (ocean), related organisms (plants, animals, biodiversity), air quality and landscape. Natural gas is supplied via pipelines with additional impacts on the environment. The distribution within Europe is basically done via pipelines and vessels. Transportation of high-level radioactive waste from nuclear power plants poses a special risk (in case of accidents) since the transported substances are irradiating and partly highly poisonous (e.g. plutonium) and thus potentially dangerous to the environment.

Fossil feedstock conversion

Impacts from implementing facilities for conversion and use of conventional (fossil) feedstocks, i.e. refineries and heat / power / cogeneration units, are expected from:

- the construction of the facility
- the facility itself: buildings, infrastructure and installations and
- the operation of the facility.

Impacts related to the **construction of the facility** are temporary and not considered to be significant.

Refineries and energy conversion facilities need **buildings, infrastructure and installations** (e.g. conversion facilities, administration buildings, waste water treatment etc.), which are usually associated with soil sealing. Other impacts might vary in quantity but not in quality, which in case of a generic approach on potential environmental impacts of technologies is negligible. Significant impacts are expected on water, soil, plants, animals and landscape and are highly dependent on local conditions.

Impacts from the **operation of the facility** are expected from:

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

Significance of impacts might vary with the type of technology and the location of a potential facility. This variability cannot be taken into account by this generic LC-EIA. Moreover, this LC-EIA cannot replace a full-scale EIA according to Directive 2014/52/EU.

5.2.3 Comparison: SEEMLA systems vs. reference systems

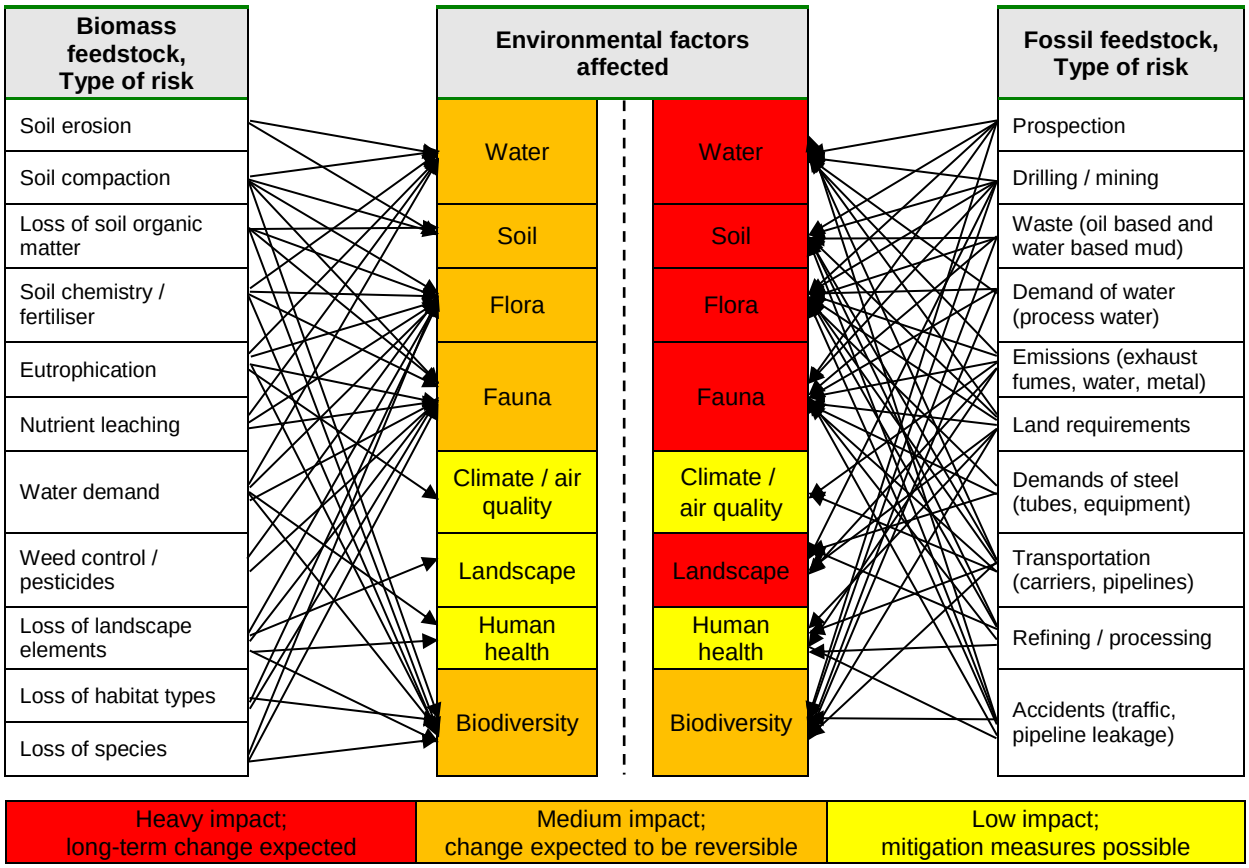
In this section, the local environmental impacts associated with the SEEMLA systems are compared to those associated with the conventional reference systems.

Feedstock provision

The supply of feedstock is linked to local environmental impacts that vary depending on the type of feedstock and technology. Both biomass feedstock and fossil (non-renewable) feedstock can be converted to energy. However, there are fundamental differences in the provision technologies which in case of biomass feedstock are linked to different soil management and cultivation methods (agricultural practices).

Since the type of risks associated with these technologies are completely different in quality and quantity, a direct comparison is not possible. Nevertheless, Table 5-5 shows a comparison of impacts on environmental factors (in both cases, the reference system is 'no use'). Impacts are classified using three different impact levels: heavy, medium and low.

Table 5-5 Comparison of impact on environmental factors due to provision of bio-based and conventional feedstock regarding impact sustainability in three different categories; reference system: no use. © IFEU 2018



The types of risks expected from provision of fossil (non-renewable) feedstock are generally based on extraction / mining technologies focussing on components below the surface. Regeneration is usually not possible. Risks related to the provision of biomass feedstock are expected to be mostly reversible. For instance, soil erosion due to agricultural activities,

depletion of water due to use of fertiliser and pesticides or loss of habitats and species due to changes in land use can be compensated over a certain period of time, if the risk factor responsible for the impact no longer prevails. However, most of the impacts associated with fossil feedstock provision, especially those on water, soil, flora, fauna and landscape, are expected to be long-term and non-reversible. Open pit mining for coal provision, for example, leads to a destruction of all vegetation and soil above the coal layer.

Feedstock conversion

The conversion of feedstock causes local environmental impacts. The comparison of biomass feedstock conversion and fossil feedstock conversion leads to the following results, which are summarised in Table 5-6.

No significant differences are expected regarding the impacts related to the **construction of the facility**. In both cases, the impacts are temporary and not considered to be significant.

Regarding the impacts related to **buildings, infrastructure and installations**, no differences are expected either since both types of feedstock conversion need them. In both cases, significant impacts are expected due to soil sealing, if the conversion facility is developed on a greenfield site. On a brownfield site, in contrast, impacts are not expected to be significant. Other impacts might vary in quantity but not in quality, which in case of a generic approach on potential environmental impacts of technologies is negligible.

Some impacts from the **operation of the facility** are expected to be comparable, e.g. regarding noise, light and electromagnetic emissions (the latter except for heat provision). The same holds for water demand and wastewater production. However, differences are expected in terms of:

- emission of gases and particulate matter: coal-fired and biomass-fired conversion facilities emit higher levels of particulate matter than the other conversion technologies. Crude oil refineries are more likely to be linked to emissions of harmful gases.
- traffic (emissions, collision risk): Emissions related to biomass supply will concentrate around the facility, resulting basically in an increase of vehicle movements (delivery of feedstock and products) in combination with an increase in emissions and the risk of accidents. Impacts are expected to be local. The supply of fossil feedstocks to facilities for conversion and use is usually linked to long distance transportation by ship / railway and / or pipelines with little impacts on local traffic.
- disposal of waste materials / residues: Residues from biomass conversion are often biodegradable (potential use as fertiliser) or combustible with potentially lower impacts on the environment. Considerable risks are expected from wastes originating from crude oil refineries and high risks are linked to radioactive wastes (no final disposal available).
- risk of accidents (explosion, fire in the facility or storage areas, release of GMO): Biomass conversion is generally associated with a lower risk of accidents. In case of 2G ethanol production, genetically modified organisms (GMO) could potentially be released.

Table 5-6 Potential impacts on the environment related to different technologies regarding feedstock conversion and transport. © IFEU 2018

Technology / Product Technology related factor	SEEMLA				Reference system		
	Biorefinery	Boiler	Boiler	CHP-plant	Gas- / oil-driven facility	Coal power plant	Nuclear power plant
	2G ethanol	Heat	Power	Heat and power	Heat and / or power, gasoline	Power	Power
Impacts resulting from construction phase							
Construction works	C	C	C	C	C	C	C
Impacts related to buildings, infrastructure and installations							
Buildings, infrastructure and installations (size and height)	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]
Impacts resulting from operation phase							
Emission of noise (refinery)	D	D	D	D	D	D	D
Emission of gases and particulate matter (refinery)	C	D	D	D	C	D	C[5]
Emission of light (refinery)	C	C	C	C	C	C	C
Drain of water resources for production (refinery)	D	D	D	D	D	D	D
Waste water production and treatment (refinery)	D	D	D	D	D	D	D
Traffic (collision risk, emissions)	D / E	D / E	D / E	D / E	C[3]	C[3]	E[6,7]
Electromagnetic emissions from high-voltage transmission lines	C	A	C	C	C	C	C
Disposal of wastes / residues	B	B / C	B / C	B / C	C	C	E[6,7]
Risk of accidents (explosion, fire in the facility or storage areas, release of GMO)	C / D[4]	C	C	C	E[3,5,6]	E[3,5,6]	E[3,5,6,7]

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

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

5.3 Results for the pilot cases in Germany, Greece and Ukraine

As mentioned earlier, the LC-EIA in the SEEMLA project is performed not only for the generic scenarios (section 5.2) but also for the pilot cases in Germany, Greece and Ukraine. After an overview in section 5.3.1, the results are presented in sections 5.3.2 to 5.3.4. Lessons learnt and recommendations are summarised in section 5.3.5.

5.3.1 Overview

Within the SEEMLA project, pilot cases were established in Germany, Greece and Ukraine. Major characteristics of biomass production in the pilot cases are listed in Table 5-7.

Table 5-7 Overview on biomass production in the pilot cases established in WP 5 [Ivanina & Hanzhenko 2016].

No	Country	Pilot case name	Cultivated crops	Alternative vegetation	Alternative land use
1	Germany	German Railways	Poplar, Black locust (SRC)	Woody vegetation	No use
2	Germany	Welzow	Black locust (SRC)	Woody vegetation	No use
3	Greece	Fillyra / Drosia	Black pine, Black locust (tree)	Sparse grassy vegetation	No use / periodically extensive pasture
4	Greece	Ismaros / Pelagia	Calabrian pine	Mixed vegetation (forests, bushes, grassland)	No use
5	Greece	Kalhantas / Sarakini	Black locust (tree)	Sparse grassy vegetation	Periodically extensive pasture
6	Ukraine	Poltava	Willow, Miscanthus	Woody vegetation	No use
7	Ukraine	Vinnitsa	Willow, Miscanthus	Sparse grassy vegetation	No use
8	Ukraine	Volyn A	Poplar*, Paulownia	Grassland / shrubland	No use
9	Ukraine	Volyn B	Willow	Grassland / shrubland	No use
10	Ukraine	Volyn C	Willow	Grassland / shrubland	No use
11	Ukraine	Lviv A	Poplar*, Paulownia	Grassland / shrubland	No use
12	Ukraine	Lviv B	Poplar*	Grassland / shrubland	No use
13	Ukraine	Lviv C	Willow	Grassland	No use
14	Ukraine	Lviv D	Poplar*	Grassland	No use

* In Ukraine, poplar cuttings and rods are cultivated. The latter are not part of this study.

On the occasion of project meetings in the three countries, the pilot cases were visited by IFEU staff. Visual impressions and observations were noted which led to an evaluation and recommendations from an environmental point of view.

5.3.2 Pilot cases in Germany

The pilot cases in Lusatia region in eastern Germany (State of Brandenburg) were visited on 23 June 2016.

5.3.2.1 German Railways

This pilot case is located in the city of Cottbus on an abandoned railway area (wagon repair shop), at an altitude of 77 m. Starting in 2009, this brownfield area was stabilised and revegetated in order to produce renewable energy from biomass.The size of the plot is ~1 ha and it is used for the cultivation of hybrid poplar (*Populus spp.*) and black locust (*Robinia pseudoacacia* L.). The site is generally flat and the groundwater table is located ~9.3 m below surface, i.e. the site is very dry. Soils have a sandy texture, are of low nutrient and humus content and moreover contain significant amounts of gravel and construction debris (about 50% w/w). However, they are not contaminated [Kiourtsis & Keramitzis 2016]. The SQR value is 9.1 [Gerwin & Repmann 2016].

Fig. 5-2 Struggling poplar plants at DB site.

Fig. 5-3 Adjacent ruderal flora at DB site.

Observations:

- The surrounding vegetation which is a result of natural succession seems to thrive better than the actual pilot case on which a low-input poplar cultivation system has been established. Water availability is a problem and plant growth is very heterogeneous.

Evaluation and recommendations from an environmental point of view:

- Site selection: Ideally, the former railway area should have been kept open as a habitat for lizards and ruderal flora. Using the area for ground-mounted photovoltaic systems instead of bioenergy could have provided this opportunity (plus a higher energy return).
- Crop selection: Black locust is considered an invasive species with (negative) impacts on nutrient dynamics, soil chemistry and vegetation structures. A spread to adjacent areas, especially to dry grasslands, must be prevented [Nehring et al. 2013]. It is unclear whether this can be guaranteed in this particular location. Species / genetic diversity could be further increased by alternating double rows of different species or varieties.

5.3.2.2 Welzow

This pilot case is located in the north part of the Welzow-Süd lignite mine, approximately 20 km south of the city of Cottbus. The location is in a former dump area, which was designated for renewable energy production from biomass, at an altitude of 110 m. The size of the plot is ~3 ha and it is used for the cultivation of black locust (*Robinia pseudoacacia* L.) in a short rotation scheme. Soils are degraded due to the earlier mining activities and can be characterised as unfavourably to poorly structured, compacted, low in nutrient and humus content and partly highly acidic (pH 3–6). Soil texture is sand to weakly loamy sand [Kiourtsis & Keramitzis 2016]. SQR values range from 14.0–20.5 [Gerwin & Repmann 2016].

Fig. 5-4 Black locust (SRC) in Welzow.

Fig. 5-5 Adjacent ruderal flora in Welzow.

Observations:

- The pilot case is embedded in a varied post-mining landscape consisting of forests (mainly pines, oaks, some juniper), agricultural areas (ryegrass, winter cereals and leguminous crops such as alfalfa and lupine), vineyards and energy crop plantations.
- Soil improvement requires large inputs of limestone and fertilisers; nutrient leaching could be an issue on the sandy soil.
- Situated in the Natura 2000 site 'Lausitzer Bergbaufolgelandschaft' (special protection area (SPA), identification code DE4450421)

Evaluation and recommendations from an environmental point of view:

- Site selection should be compatible with nature conservation aspects since in this exceptional case, environmental aspects have already been taken into account in the 'Ordinance on the Lignite Plan for the Welzow-Süd opencast mine', issued by the State Government of Brandenburg. However, a long-term active management and regular monitoring of the measures in this plan has to be ensured. Experiences from other projects in the past show that the latter has not always been the case.
- Crop selection: Black locust is considered an invasive species which affects nutrient dynamics, soil chemistry and vegetation structures. Its cultivation in this clearly defined and managed area is acceptable, but spread to adjacent areas must be prevented.

5.3.3 Pilot cases in Greece

The pilot cases in the region of Eastern Macedonia and Thrace (regional unit Rhodope) in northeastern Greece were visited on 28 and 30 November 2017.

5.3.3.1 Pelagia (Ismaros)

This pilot case is located in the public forest of Ismaros, near Pelagia village (41°00'02.1"N 25°27'43.9"E). The location is 22 km southeast of Komotini, at an altitude of 100 m. The size of the plot is 0.1 ha and the current land use is forest land (artificial plantation of *Pinus brutia* Ten.). The former land use was shrubs, bushes and grasslands. Soils are of clayey texture [Kiourtsis & Keramitzis 2016]. SQR values range from 7.6–11.6 [Gerwin & Repmann 2016].

Fig. 5-6 Artificial plantation of Calabrian pine at Pelagia.

Fig. 5-7 Surrounding natural vegetation.

Observations:

- The pilot case is situated on a hilltop, whose slopes are covered by trees (mainly oaks), shrubs (e.g. *Paliurus spina-christi* Mill., *Juniperus, Erica*) and sclerophyllic plants incl. thistles. The artificial plantation has very little understorey vegetation (some *Quercus coccifera* L. and other oak shoots). Exceptionally many beehives were observed nearby.
- On two sides, the plantation borders grazing land which seems to be used frequently.
- Approx. 3 km north is the Natura 2000 site 'Potamos Filiouris' (special area of conservation (SAC), identification code GR1130006).

Evaluation and recommendations from an environmental point of view:

- From an erosion protection point of view, the site is well selected. However, the plantation could contribute to a crowding-out of animal husbandry and lead to undesired indirect effects, including indirect land use changes (iLUC). Reliable statistics on livestock in the area are therefore urgently needed.
- Crop selection: The Calabrian pines were originally intended for paper pulp production. For bioenergy, however, there is no need for straight conifers. Crooked broad-leaved trees would do as well. We recommend planting mixed forests, including native species such as oak.

5.3.3.2 Drosia (Fillyra)

This pilot case is located in the public forest of Fillyra, near Drosia village (41°11'22.7"N 25°38'45.2"E). The location is 33 km northeast of Komotini, at an altitude of 595 m. The size of the plot is 0.1 ha and the current land use is grassland on which an artificial plantation of *Pinus nigra* J.F.Arnold and *Robinia pseudoacacia* L. was established in autumn 2017. The former land use was grassland, pasture and occasional, limited cultivation. Soils are of sandy or sandy-loamy texture [Kiourtsis & Keramitzis 2016]. SQR values range from 8.8–13.2 [Gerwin & Repmann 2016].

Fig. 5-8 Artificial plantation of black pine and black locust at Drosia.

Fig. 5-9 Heavily grazed hilltop at Drosia.

Observations:

- The pilot case is situated on a hilltop, whose slopes are covered by coppice forests (mainly oaks, some juniper). The area was / is used as a grazing area and both the extremely short grass and animal faeces point at a very high grazing pressure. Therefore, the pilot case is fenced.
- Approx. 2 km east is the Natura 2000 site 'Koilada Filiouri' (special protection area (SPA), identification code GR1130011).

Evaluation and recommendations from an environmental point of view:

- From an erosion protection point of view, the site is well selected. However, the plantation could contribute to a crowding-out of animal husbandry and lead to undesired indirect effects, including indirect land use changes (iLUC). Reliable statistics on livestock in the area are therefore urgently needed.
- Mixing two species is positive. However, black locust is considered an invasive species. An uncontrolled spread to the adjacent coppice forest must be prevented. It is unclear whether this can be guaranteed in this particular location. We recommend planting other native broad-leaved species instead, including oak. Black pine is acceptable, but for bioenergy, there is actually no need for straight conifers (as for paper pulp production). Crooked broad-leaved trees would do as well.

5.3.3.3 Sarakini (Kalhantas)

This pilot case is located in the public forest of Kalhantas, near Sarakini village (41°17'44.3"N 25°32'57.9"E). The location is 42 km north of Komotini, at an altitude of 505 m, close to the border between Greece and Bulgaria. The size of the plot is 0.1 ha and the current land use is artificial plantation (*Robinia pseudoacacia* L.). The former land use was grassland, pasture and occasional, limited cultivation. Soils are of sandy or sandy-loamy texture [Kiourtsis & Keramitzis 2016]. The SQR value is 19.3 [Gerwin & Repmann 2016].

Fig. 5-10 Artificial plantation of black locust at Sarakini.

Fig. 5-11 Surrounding vegetation: oak forests with some artificial pine plantations.

Observations:

- The pilot case is situated on a hillside and is terraced and fenced. Old natural stone walls and two old walnut trees (*Juglans regia* L.) point at former agricultural use. The lush green grassy understorey vegetation is poor with a few blackberries found on the fence.
- The plot is surrounded on all sides by oak / (beech) mixed forests (*Quercus petraea* (Matt.) Liebl., *Quercus pubescens* Willd., *Juniperus* spec., *Fagus sylvatica* L.), which are used as coppice forests for firewood production and as forest pasture. Despite the high inclination, grazing pressure (especially goats, but also cows) is very high.
- On the Bulgarian side of the border, there is a huge Natura 2000 site 'Rodopi-Iztochni' (site of community importance (SCI), identification code BG0001032). On the Greek side, however, the forest is not protected.

Evaluation and recommendations from an environmental point of view:

- Site selection is considered suboptimal since the reforestation of the valley (with forests on both slopes) reduces open habitats.
- Crop selection: Black locust is considered an invasive species. An uncontrolled spread to the adjacent coppice forest must be prevented. It is unclear whether this can be guaranteed in this particular location. We recommend planting other native broad-leaved species instead, including oak.

5.3.4 Pilot cases in Ukraine

The pilot cases in Volyn and Lviv region in western Ukraine, close to the border between Ukraine and Poland, were visited on 1 and 2 June 2017.

5.3.4.1 Volyn

Three pilot cases are located in Volyn region near the villages of Zubylne and Kysylyn, approximately 40 km west of the city of Luzk. The total size of the plots is 3.7 ha and they are used for cultivation of poplar and Paulownia (Volyn A) and willow (Volyn B, C), respectively. These sites are abandoned agricultural lands which were previously used as pastures and hayfields. Because of their low productivity, cultivation was stopped 20 years ago. These sites are characterised by poor soil organic matter content and nutritional status, high moisture content (frequent flooding after rains and snowmelt) and shallow soil depth. Soil texture is sandy with gleyic features and the groundwater table is within 0.5 – 2 m [Kiourtsis & Keramitzis 2016]. SQR values are 37.1 (Volyn A), 39.0 (Volyn B) and 27.0 (Volyn C) [Gerwin & Repmann 2016].

Fig. 5-12 Volyn A: Field bordering mainly open landscape.

Fig. 5-13 Volyn C: Field surrounded by grassland and annual crops.

Fig. 5-14 Volyn B: Field surrounded by tall (perennial) vegetation on all four sides, of which two are bordered by natural vegetation and two by SRC.

Observations:
Volyn A:

- **One field border is fairly close to a natural surface water** which is a habitat for Eurasian beavers (*Castor fiber* L.). Here, a greater distance of ~20 m would be more appropriate in order to create a buffer zone. At the same time, this would lower the risk of nutrient leaching and lateral transfer of nutrients.

- **The three other field borders** (one to SRC, one to open landscape and one to a transition zone towards natural vegetation) **are good examples**. The fact that the pilot case borders another SRC plantation on one side is considered acceptable in this specific case (not generally, see Volyn B) since the additional size of the pilot case is limited and at least two of the other field borders are compatible with nature conservation.
- **Too close to the groundwater table:** In some places, the field is too close to the groundwater table which not only creates agronomic difficulties but also increases the risk of nutrient leaching and soil compaction.

Volyn B:

- On all four sides, the field is surrounded by tall (perennial) vegetation, two of which are other SRC plantations. On the other two sides, the pilot case borders natural vegetation. This way, a piece of land with a different, lower vegetation structure has been 'filled up' with tall willows. This lead to a **decrease in structural diversity of the area**.
- From a point of view of **species / genetic diversity**, different energy crops or at least different willow varieties should have been chosen since the two bordering SRC plantations have the same genetics as the pilot case. This increases the risk of pest outbreaks and consequently the need for pesticide applications.

Volyn C:

- On all four sides, the field is surrounded by low vegetation. In this respect, the willow plantation will reduce wind erosion, contribute to **increased structural diversity** (in contrast to Volyn B) and provide shelter for animal species.
- However, it has to be ensured that species included in the European (or national) Red List of Threatened Species are not displaced, e.g. ground-breeding birds which are dependent on open landscape. Also, if the area is important for roosting migratory birds, a **local / regional concept for SRC plantations compatible with nature conservation** is needed.

Evaluation and recommendations from an environmental point of view:

- Site selection: Apart from Volyn B, site selection seems to be compatible with nature conservation aspects – at least from a visual impression. However, no detailed mapping / inventory of breeding birds or other species groups has been performed. It has to be ensured that the cumulative impact of SRC plantations in an area doesn't decrease structural diversity and the ability of species (especially threatened ones) to thrive there. Therefore, neighbouring perennial energy crop plantations should be established in consecutive years in order to avoid large areas being harvested at the same time.
- Crop selection: Apart from Volyn B, crop selection is compatible with nature conservation aspects. Species / genetic diversity could be increased by alternating different species or varieties, e.g. alternating double rows of willow and poplar, respectively.

5.3.4.2 Lviv

Four pilot cases are located in Lviv region near the town of Welyki Mosty, approximately 50 km north of the city of Lviv. The total size of the plots is 7.6 ha and they are used for cultivation of poplar and Paulownia (Lviv A), poplar (Lviv B, D) and willow (Lviv C), respectively. Like in Volyn region, these sites are abandoned former agricultural lands. The characteristic features of this area are poor / medium soil organic matter content and nutritional status, high moisture content (frequent flooding after rains and snowmelt) and shallow soil depth. Soil texture is sandy or sandy-loamy with gleyic features. Soils are partly and strongly compacted and the groundwater table is within 1–2 m [Kiourtsis & Keramitzis 2016]. SQR values are 18.0, 38.0, 29.5 and 33.3 for Lviv A–D, respectively [Gerwin & Repmann 2016].

Fig. 5-15 Lviv A: Gnaw marks of beavers.

Fig. 5-16 Lviv B: Field surrounded by annual crops.

Fig. 5-17 Lviv C: Valuable buffer zone between field and adjacent forest.

Fig. 5-18 Lviv D: Field surrounded by tall (perennial) vegetation on three sides.

Observations:
Lviv A:

- **One field border is fairly close to a natural surface water** which is a habitat for Eurasian beavers (*Castor fiber* L.). Here, a greater distance of ~20 m would be more appropriate in order to create a buffer zone. At the same time, this would lower the risk of nutrient leaching and lateral transfer of nutrients.

Lviv B:

- On all four sides, the field is surrounded by annual crops. In this respect, the willow plantation will reduce wind erosion, contribute to **increased structural diversity** and provide shelter for animal species. In this respect, there is no need for a buffer zone.
- With a SQR score of 38.0 [Gerwin & Repmann 2016], the soil quality of this pilot case is just below 40, which is the upper threshold for marginal land defined in the SEEMLA project. Theoretically, also food and feed crops could be cultivated here. If this was the case, the cultivation of lignocellulosic crops would lead to undesired indirect effects.

Lviv C:

- Site selection is nature-compatible since a **buffer zone** between the pilot case and the adjacent forest (oak, birch, pine) has been kept. The buffer zone shows a dry grassland flora which is partly species-rich and also contains a number of small shrubs.
- Nutrient and agrochemicals leaching could be an issue on the sandy soil, especially under flooding conditions.

Lviv D:

- On three sides, the field is surrounded by tall (perennial) vegetation, two of which consist of natural vegetation (forest and shrubland, respectively). On the third side, the pilot case borders another SRC plantation (willow). This way, a piece of land with a different, lower vegetation structure has been 'filled up' with tall poplars. This lead to a **decrease in structural diversity of the area**. Moreover, there are almost no transition zones.
- With a SQR score of 33.3 [Gerwin & Repmann 2016], the **soil quality** of this pilot case **is relatively high** (for marginal land). Theoretically, also food and feed crops could be cultivated here. In this case, the cultivation of lignocellulosic crops would lead to undesired indirect effects, including iLUC. Due to high nutrient availability, weed pressure was high and had to be controlled chemically through the use of glyphosate.

Evaluation and recommendations from an environmental point of view:

- Site selection: The selected pilot cases are partly compatible with nature conservation aspects – at least from a visual impression. Buffer zones would have been beneficial at Lviv A and D. However, due to the relatively high soil quality (for marginal land), undesired indirect effects such indirect land use change (iLUC) cannot be 100% excluded, since the land could theoretically be used for food and feed crops.
- Crop selection: The selected crops are compatible with nature conservation aspects. Cultivating poplar at Lviv D (next to an existing willow plantation), is positive from a species / genetic diversity point of view. However, structural diversity was decreased at Lviv D. If SRC plantations are established next to each other, they should be planted in consecutive years in order to avoid large areas being harvested at the same time.

5.3.5 Lessons learnt and recommendations

Marginal land often has special site conditions compared to most standard agricultural land. These must be particularly taken into account when selecting areas for energy crop cultivation or when selecting suitable energy crops for the respective location. The 'good farming practice' as defined in Council Regulation (EC) 1257/1999 [European Commission 1999] (and which is often referred to in the common agricultural policy (CAP)) is not sufficient for marginal land – at least not for sensitive sites. Therefore, guidelines for environmentally compatible cultivation of energy crops which go beyond the existing requirements are necessary. These could take up – in a generalised form – a number of lessons learnt from the evaluation of the pilot cases in sections 5.3.2 to 5.3.4 and include the following recommendations:

1. Buffer / transition zones are needed:

- Sufficient distance to adjacent surface waters should be kept. For standard agricultural land, a distance of 10 m is recommended / stipulated in Germany. This distance should be doubled if a) the surface water is a habitat for species such as the Eurasian beaver and / or b) the soil is prone to nutrient and / or agrochemicals leaching.
- Buffer zones to natural vegetation are needed. Such buffer zones are also important to avoid the spread of invasive or potentially invasive species such as black locust, Miscanthus or giant reed into adjacent natural ecosystems.
- Staged transition in vegetation height from low-height (e.g. annual crops) via medium-height (e.g. perennial crops) to tall vegetation (e.g. forest) (see picture to the right) and staged forest edges are recommended instead of a sharp transition.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2. The structural diversity of the area should be maintained or increased:

- Fields that are surrounded by tall (perennial) vegetation on two or more sides should not be used for the cultivation of perennial energy crops.
- Neighbouring perennial energy crop plantations should be established consecutively (see picture to the right) in order to avoid large 'clear-cuts' (if all of them were harvested in the same year) – even if this was attractive from an economic point of view.


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3. Nature conservation aspects need to be considered:

- Land that a) has been subject to so-called agri-environment programmes in the last 10 years and / or b) is classified as 'High nature value farmland' (HNV) should not be used at all for biodiversity conservation reasons.
- A local / regional concept for SRC plantations compatible with nature conservation is needed which ensures that species included in the European (or national) Red List of

Threatened Species are not displaced (e.g. ground-breeding birds which are dependent on open landscape) or that the area is kept sufficiently open for roosting migratory birds.

- Brownfield areas are not necessarily species-poor and sometimes provide special niches for highly adapted species. Site-specific investigations are needed to avoid adverse effects before possibly converting such areas into energy crop plantations.
- Invasive or potentially invasive species such as black locust, Miscanthus or giant reed should not be cultivated near nature conservation areas in order to avoid damage.

4. Adapted agricultural management practices are needed:


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- A high genetic diversity of crops can reduce pest pressure and thus the need to apply pesticides. This could be achieved by alternating double rows of two different species (see picture to the right). This would also lower the risk of complete plantation failure.
- Sites with groundwater table close to the surface are unsuitable because of the risk of nutrient and / or agrochemicals leaching.


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- Sensitive soils require adapted agricultural machinery such as track tractors (see picture to the right) which can lower the risk of soil compaction.

5. Alternative land uses need to be considered:

- For example, ground-mounted photovoltaic (PV) systems with ecologically oriented management plans tend to be more nature-compatible than bioenergy due to their lower land footprint.

6. Bioenergy on marginal land as a compensation measure for other projects:

- If energy crops are cultivated on marginal land as a compensation measure for another project (e.g. an infrastructure project), for which an EIA according to Directive 2014/52/EU has been conducted, a long-term active management and regular monitoring of this compensation measure has to be ensured. The latter has not always been the case in the past.

These recommendations should be taken up by the guidelines for environmentally compatible cultivation of energy crops on sensitive sites.

5.4 Key results and conclusions for LC-EIA

The life cycle environmental impact assessment (LC-EIA) carried out in the framework of the SEEMLA project included the assessment of general, location-independent scenarios for the whole of Europe as well as specific pilot cases (or concrete locations of energy crop plantations) in Germany, Greece and Ukraine. The analysis of the local environmental impacts (for details see sections 5.2 and 5.3) provided a number of key results and conclusions, which are listed below. Recommendations that can be derived from these can be found in section 6.2.

High land use footprint of bioenergy, especially on marginal areas: The land use associated with the provision of bioenergy is many times higher per unit of energy than the land use associated with the provision of conventional energy. This is due in particular to the provision of cultivated biomass. Land use by conversion plants for biogenic or conventional energy carriers is roughly comparable, but orders of magnitude smaller than land use by biomass cultivation. In addition, land use per unit of energy is (still) higher than on standard land due to the lower biomass yields on marginal land. This must be taken into account when formulating targets for bioenergy from marginal land.


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Grasses require less land than SRC or trees, but this is more strongly affected: The investigated perennial grasses show slightly higher yields per area than SRC or trees, i.e. less land is required per unit of energy. On the other hand, the intensity and frequency of agricultural activities due to the annual harvest is higher for grasses than for SRC (2–3 years rotation time) or trees (up to a maximum of 20 years rotation time). For example, the use of large agricultural machinery (harvesters, chippers) with a high noise level can cause stress in noise-sensitive animal species and frighten them away. In order to rule out any adverse effects, e.g. on bird brood, care should be taken to ensure that the harvest time for fast-growing tree species is during the biologically inactive late winter months. The bottom line, however, is that the positive effect of the higher area yield predominates.


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Predominantly neutral effects on soil and water: The land use associated with the provision of lignocellulosic biomass for bioenergy production leads to impacts on soil and water. These actually depend strongly on the specific, site-dependent conditions, but have been generalised within the framework of this LC-EIA where possible. In comparison to the reference system idle land, which comprises unused grassland or woody grassland / shrubland (which is mulched at least once a year to prevent succession), the provision of perennial energy crops is predominantly to be assessed neutrally. As far as the soil as a protected good is concerned, there may even be positive effects on the factor of soil compaction. The cultivation of Miscanthus, willow or giant reed is associated with high water consumption and can lead to a reduction in groundwater recharge, depending on the location. In the context of this study, it was also assumed that no irrigation takes place. These aspects must be taken into account when selecting the energy crops (species and varieties) to be used.

Individual consideration of impacts on fauna, flora, biodiversity and landscape necessary: Due to their height (several metres) and density, the energy crop plantations represent a considerable change in the vegetation / biotope structure (including impacts on the microclimate), which can have a positive effect on some groups of organisms (e.g. birds, ground beetles, spiders or earthworms), but can also have a negative effect on others (e.g. ground breeding birds, steppe dwellers, roosting migratory birds). Effects on flora and biodiversity are highly location-dependent. Due to the definition of marginal land assumed in the SEEMLA project (see Deliverable D 2.1, [Ivanina & Hanzhenko 2016]) and the authors' assumption that the (grassland) areas are not used (reference system), it is very likely that areas with high biological diversity, e.g. species-rich grassland, are also included. Conversion of such areas into energy crop plantations may have very negative impacts on biodiversity. Even impacts on the landscape, which are to be expected in particular from the cultivation of perennial energy crops, cannot be assessed unambiguously without a concrete location reference. Therefore, the impacts in individual cases must always be assessed against the background of the respective habitat functions (including neighbouring areas) and nature conservation objectives.

Other renewables can be more nature conservation compatible than bioenergy: Bio-energy competes with other renewable energies, e.g. ground-mounted photovoltaic (PV) systems, for marginal land. The land footprint of PV electricity per energy unit is significantly lower than that of electricity from biomass. If, in addition, the maintenance of the land under and between the PV modules is oriented towards ecological criteria, such PV systems can ideally offer ecological added value compared to agricultural use.


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Biodiversity at risk due to (further) intensification of land use: in view of i) alarming biodiversity losses due to agricultural activities in the EU (e.g. -33% of farmland bird population in France since 2001 [Geffroy 2018] and -80% of insect biomass in Germany in the last 30 years [Hallmann et al. 2017]), ii) the re-cultivation of former set-aside land after changes to the CAP in 2009 and iii) the encroachment into grasslands [Bundesamt für Naturschutz 2009], it will be (partly) decisive for biodiversity in Europe how much pressure is increasing on marginal land (e.g. through financial incentives for its use for bioenergy). Marginal land is often still the last retreat for species that already suffer from the intensive agricultural use of standard land. A broad public discussion is therefore needed as to which proportion of marginal land should be reserved for bioenergy production, other renewable energies or nature conservation. These conflicting objectives could be addressed and resolved with the help of national or supranational land use and land allocation plans for marginal land.


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Guidelines for environmentally compatible cultivation of energy crops on sensitive sites necessary: Marginal land often has special site conditions compared to most standard agricultural land. These must be particularly taken into account when selecting areas for energy crop cultivation or when selecting suitable energy crops for the respective location. The 'good farming practice' as defined in Council Regulation (EC) 1257/1999 [European Commission 1999] (and which is often referred to in the CAP) is not sufficient for marginal land – at least not for sensitive sites. This may also require adapted management, for example in terms of fertilisation. Since such areas often also have a high nature conservation value due to these special site conditions, energy crop cultivation must be designed to be nature (conservation) compatible. Guidelines that could take up – in a generalised form – a number of lessons learnt from the evaluation of the pilot cases would be very helpful.


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Recommendations that can be derived from these key results and conclusions can be found in section 6.2.

6 Synopsis and recommendations

In the context of this study, the environmental impacts of various options for the cultivation and use of perennial energy crops (grasses and woody biomass with up to 20 years rotation time) on marginal land were assessed. The analysis included both screening life cycle assessments (LCA) and life cycle environmental impact assessments. Their key results and conclusions are summarised below (section 6.1) and recommendations derived from them (section 6.2).

6.1 Synopsis of results and conclusions from screening LCA and LC-EIA

In order to cover the spectrum of all environmental impacts of a bioenergy supply of marginal land as completely as possible, the environmental assessment was carried out using a combination of two methods: the screening Life Cycle Assessment (LCA) and the Life Cycle Environmental Impact Assessment (LC-EIA). For more information, see section 5.1. The synopsis of the key results and conclusions of the two partial analyses leads to the following overall picture:

- LCA and LC-EIA complement each other well. LC-EIA is still necessary in order to analyse local environmental impacts, in particular to identify differences between energy crops. This is not possible even with the innovative hemeroby approach used here for the first time in LCA.
- Ultimately, the numerous conclusions drawn in sections 4.6 and 5.4 can be summarised as the main conclusion that non-renewable energy and greenhouse gas emissions can be saved. This, however, at the cost of other negative environmental impacts such as higher ozone depletion, acidification and eutrophication and a high risk of biodiversity loss.


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- For these reasons, no general 'certificate of compliance' can be issued for the bioenergy of marginal land from an environmental point of view. The opportunities associated with this are certainly great. However, a whole series of boundary conditions must be taken into account here, which have led to the following recommendations.

6.2 Recommendations


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It is undisputed that a significant expansion of biomass production to marginal land in Europe can only be achieved through financial incentives such as support programmes (see [Keller et al. 2018]). This creates great opportunities to design the necessary framework conditions in such a way that sustainability aspects are taken into account in the best possible way. From the point of view of environmental protection, the protection of biodiversity is a priority. Other environmental impacts such as greenhouse gas emission savings , on the other hand, are of secondary importance. This results in the following recommendations:

1. Which marginal land should be used in the future?

- When defining the marginal land eligible for support, the main criterion should be the previous non-utilisation (e.g. not used at all for at least 5 years, i.e. not even extensively), since environmental benefits only arise from the (renewed) use of previously unused (idle / abandoned) agricultural land. Only in this way indirect land-use changes (iLUC) can be avoided.


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- In contrast, the low land quality (SQR score <40) used in the SEEMLA project is a secondary criterion. The biophysical criteria used in the common agricultural policy (CAP) for classification as 'area facing natural constraints' (ANC)[2] are basically suitable for determining land quality or marginality.

This means that future support programmes should be based on these criteria.

2. Which marginal land should not be used in the future?

- Land worthy of protection should be excluded from support. This concerns both 'land with high carbon stock (e.g. wetlands, forests) and peatland' and 'land with high biodiversity value'[3], e.g. highly biodiverse grasslands[4]. These categories are not necessarily congruent, i.e. 'land with high carbon stock' does not automatically have a high biodiversity value and vice versa. In addition, woody grassland / shrubland with a high biomass-carbon stock should not be converted into energy plantations, since the initial carbon loss associated with this is only compensated after 2–3 plantation generations (up to 60 years).


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- It is to be feared that biodiversity will decline as a result of the renewed cultivation of certain marginal land (see section 5.4). A pull effect towards the cultivation of perennial energy crops, which would destroy all extensification and protection efforts of recent years, should be prevented at all costs. For this reason, the following areas should not be allowed to be used for the cultivation of perennial energy crops:
    - Land that has been subject to so-called agri-environment programmes in the last 10 years. These programmes are designed to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services.
    - 'High nature value farmland' (HNV)

This means that future support programmes should exclude the transformation of such land.

[2] See Regulation 2003/1305/EU [European Parliament & Council of the European Union 2013] and [van Orshoven et al. 2014]

[3] See definition in Directive 2009/28/EC [European Parliament & Council of the European Union 2009].

[4] See definition in Commission Regulation (EU) No 1307/2014 [European Commission 2014b]

3. How should the designated marginal land be used in the future?

For such marginal land which is suitable for use according to the criteria listed above, the following recommendations result from an environmental point of view:

- The greatest benefit is achieved with perennial energy crops if they are used in direct combustion plants for the generation of electricity, heat or combined heat and power – at least as long as there are significant shares of fossil energy carriers in the conventional heat and electricity mix, respectively.
- If it is politically intended to produce biofuels from biomass, any financial incentives for the crediting of biofuels from marginal land (e.g. through bonus regulations in the German Renewable Energy Sources Act or double counting in the RED) should be well thought out and should not lead to double subsidies (if cultivation were also promoted).
- In particular, alternative land uses such as ground-mounted photovoltaic (PV) systems should also be considered, some of which offer several times greater environmental benefits than biomass production (see section 4.3.2). However, nature conservation aspects in particular should also be given special consideration in these cases, e.g.


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  - only minimal soil sealing, e.g. by anchoring without foundations
  - no use of pesticides
  - a locally adapted ecological care concept

4. The implementation of publicly funded support programmes and concrete projects (e.g. through investment grants), should include:

- Depending on the scope, the preparation or application of a land allocation plan at EU, national or regional level.
- Preparation or application of a land use concept in each case.
- For a biomass production based on this, the preparation or application of a biomass use concept, especially at regional level.
- Stakeholder processes for the integration of local / regional actors. A good example for such a stakeholder process is described by Di Lucia et al. [2018].


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5. Guidelines for environmentally compatible cultivation of energy crops on sensitive sites are necessary:

- The 'good farming practice' as defined in Council Regulation (EC) 1257/1999 [European Commission 1999] (and which is often referred to in the CAP) is not sufficient for marginal land – at least not for sensitive sites. Therefore, guidelines for environmentally compatible cultivation of energy crops which go beyond the existing requirements are necessary.

- These could take up – in a generalised form – a number of lessons learnt from the evaluation of the pilot cases, e.g. regarding:
    - Buffer / transition zones
    - Structural diversity of an area
    - Nature conservation aspects
    - Adapted agricultural management practices

6. Research funding:

- High priority should be given to ensuring that total plantation failures can be largely avoided.
    - To this end, research into cultivation systems and development of varieties of perennial energy crops suitable for marginal areas should be further promoted.
    - Great attention should also be paid to loss-reducing cultivation systems, such as the use of different plants on the cultivated area (such as alternating rows of poplar and willow) or alternating harvesting cycles.
- Biomass on marginal land may differ in its composition from biomass on standard land, e.g. in terms of ash or nitrogen content. This may limit potential use options both in the field of bioenergy and bio-based products. Emissions depend in part on these parameters, which is why they need to be researched in more detail.

7. Measures in the field of agriculture

- For the sustainable establishment of perennial energy crops, it is essential to build up the farmers' competencies for the selection of suitable crops and varieties.
- The optimal choice of harvest time is also of great importance, especially with regard to the lowest possible water content of the biomass. This could be realised, for example, in the form of advisory services for farmers.
- The development of cultivation systems and varieties (see above) is also of particular importance.
- An optimisation of agricultural production from a sustainability point of view should aim first and foremost at yields, yield security and as far as possible a reduction in nitrogen fertilisation, but also a minimisation of phosphate losses. This would have a positive impact on most of the sustainability indicators examined.

All in all, this opens up large fields of action from an environmental point of view for a future provision of bioenergy from marginal land, but also bio-based products or other renewable energy such as solar energy. For this purpose, however, social aspects such as rural development and jobs should be included in addition to economic aspects, in order to guarantee the development of marginal land for the benefit of the environment and society.

7 Abbreviations

2G	Second generation
aLUC	Attributional land use change
ATL	Atlantic zone
CAP	Common agricultural policy
CHP	Combined heat and power
CON	Continental zone
DE	Germany (German: Deutschland)
dLUC	Direct land use change
DM	Dry matter
EC	European Commission
eq	Equivalents
FM	Fresh matter
GHG	Greenhouse gas
GMO	Genetically modified organism(s)
GR	Greece
iLUC	Indirect land use change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LC-EIA	Life cycle environmental impact assessment
LCT	Life cycle thinking
LUC	Land use change
MagL	Marginal land
MED	Mediterranean zone
MJ	Megajoule
MWh	Megawatt hour
RED	Renewable Energy Directive
SETAC	Society of Environmental Toxicology and Chemistry
SAC	Special Area of Conservation (under Habitats Directive)
SCI	Site of Community Importance (under Habitats Directive)
SPA	Special Protection Area (under Birds Directive)
SQR	Soil Quality Rating

SRC	Short rotation coppice
SWD	Staff working document
UA	Ukraine
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WP	Work package

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9 Annex

9.1 Supplements to system description

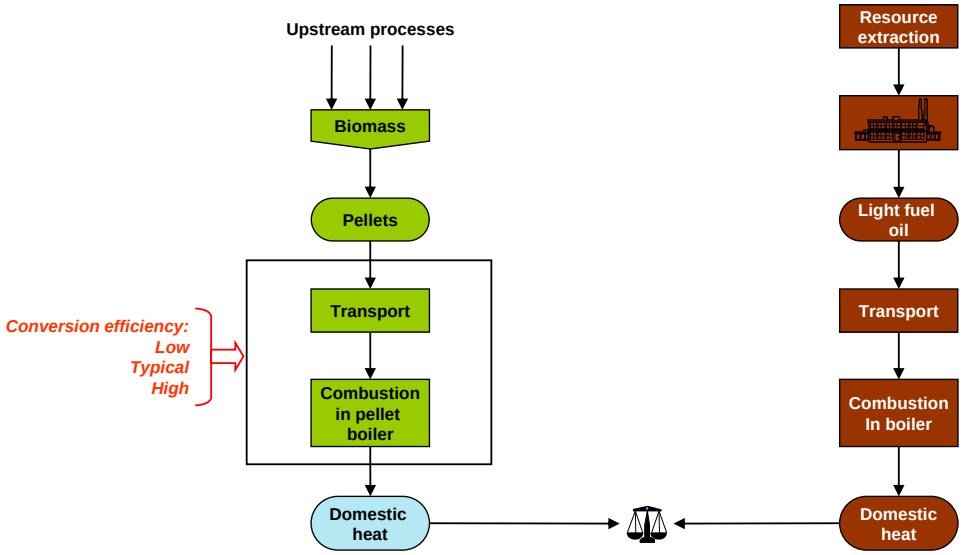

Fig. 9-1 Life cycle comparison of the production of domestic heat. © IFEU 2018

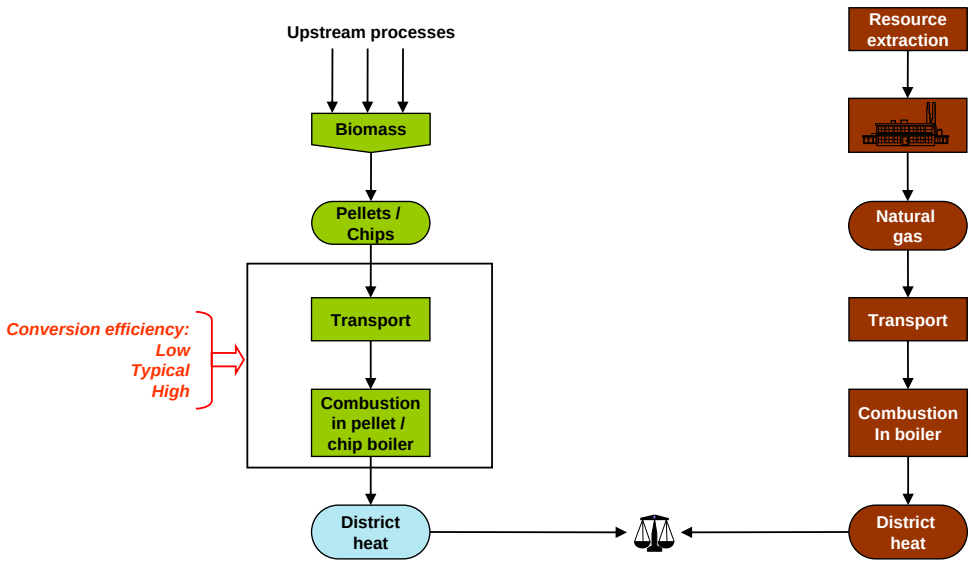

Fig. 9-2 Life cycle comparison of the production of district heat. © IFEU 2018

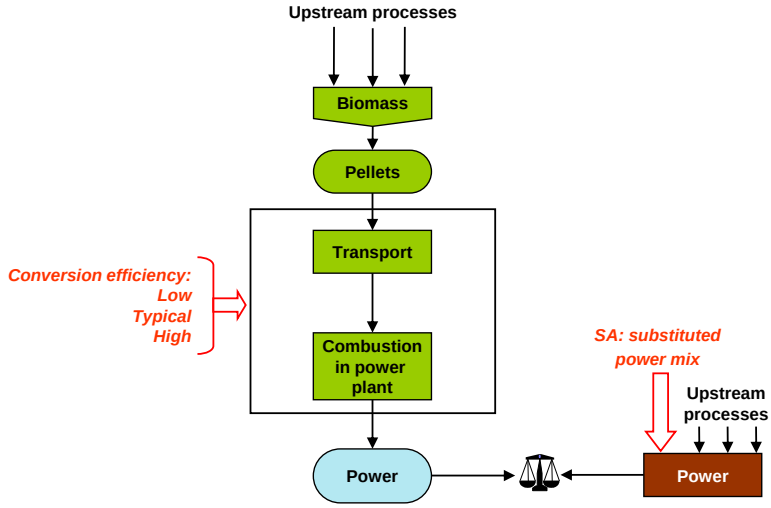

Fig. 9-3 Life cycle comparison of the production of power. © IFEU 2018

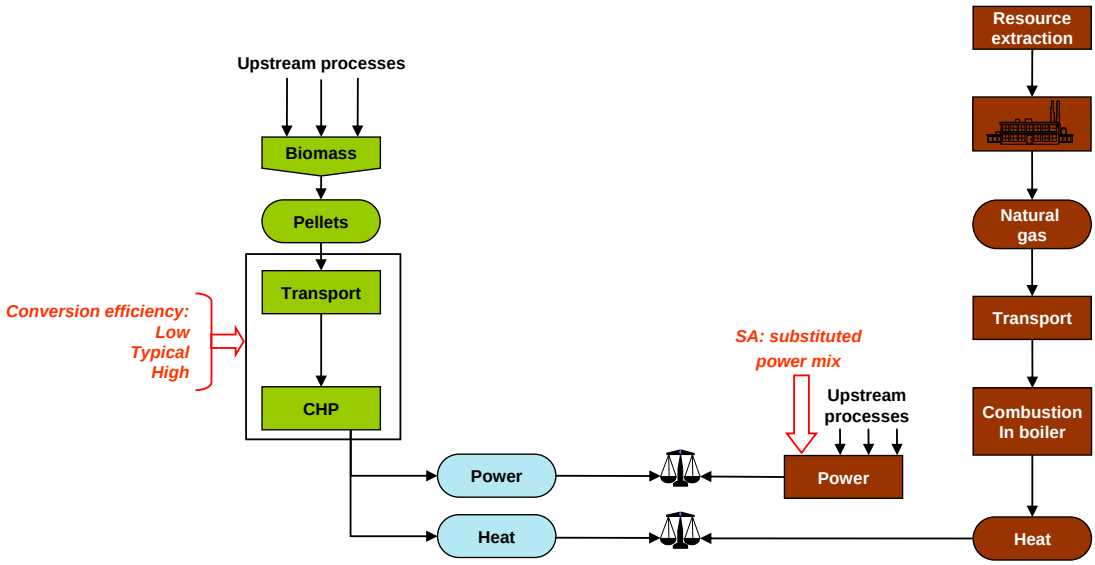

Fig. 9-4 Life cycle comparison of the production of heat and power. © IFEU 2018

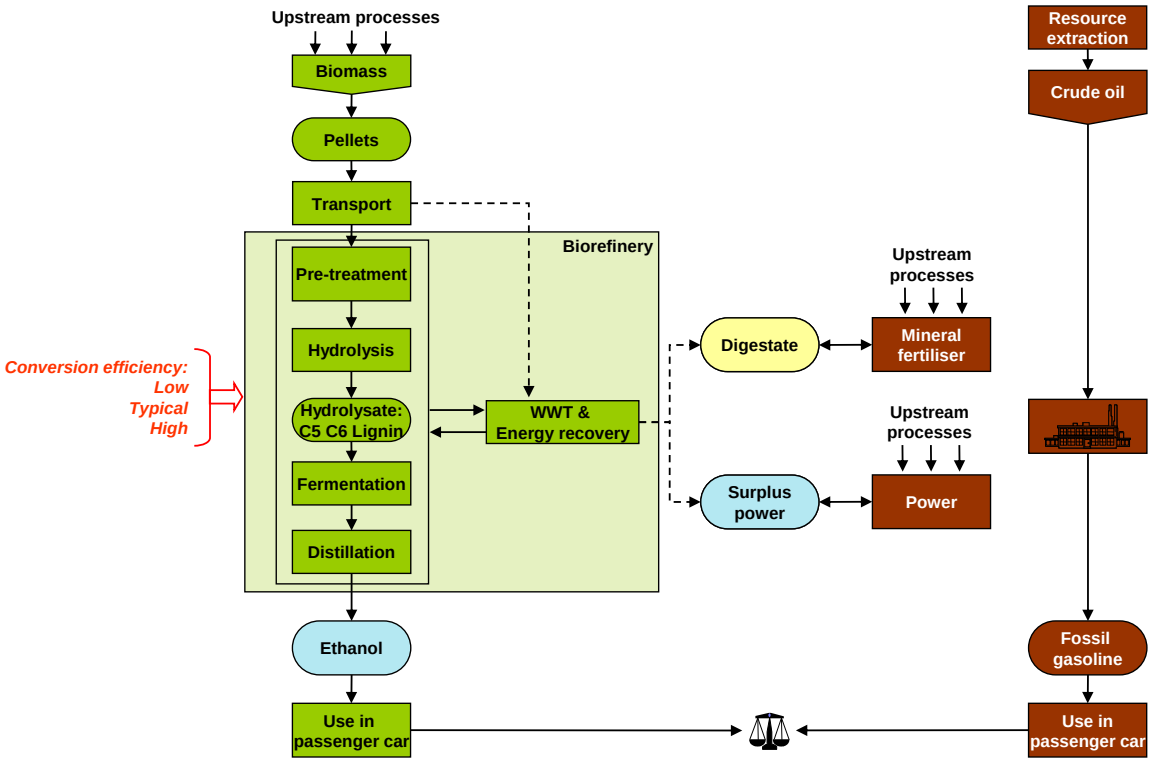

Fig. 9-5 Life cycle comparison of the production of 2nd generation ethanol. © IFEU 2018

9.2 Supplements to LCA

9.2.1 Parameter on agricultural systems of the generic scenarios

This section summarizes important agricultural data for the life cycle assessment (see Table 9-1 to Table 9-3). All data stem from IFEU's internal database [IFEU 2018] and are partially based on expert judgments by SEEMLA partners and external experts. The cultivation of biomass is assessed in the way that full expenditures of crop cultivation are ascribed to the harvested crop based on a sustainable cultivation practise. This includes that nutrients replaced by fertilisation compensate the amount removed by harvest as well as emission to air and water. They exceed the deposition of nutrients from the atmosphere (in case of nitrogen) [Müller-Lindenlauf et al. 2014]. For the trees, the usual fertilising procedure in forestry is a basic fertiliser application at the beginning of the plantation.

Table 9-1 LCA input data on cultivation in the Atlantic zone [IFEU 2018].

Parameter	Unit	Soil marginality class	Black locust (tree)	Black pine (tree)	Willow (SRC)	Poplar (SRC)	Black locust (SRC)	Mis-can-thus	Switch grass
Cultivation life time	years	Marg. 1	15	20	25	20	20	15	15
		Marg. 2							
Seedlings / Seeds	kg / (ha · year)	Marg. 1	25	25	25	25	25	167	0.3
		Marg. 2							
Nitrogen fertiliser	kg N / (ha · year)	Marg. 1	2	2	16	39	0	52	99
		Marg. 2			9	18		50	74
Phosphorus fertiliser	kg P_2O_5 / (ha · year)	Marg. 1	3	3	16	27	10	20	24
		Marg. 2			11	14	6	17	16
Potassium fertiliser	kg K_2O / (ha · year)	Marg. 1	6	6	23	56	15	110	28
		Marg. 2			15	28	9	91	19
Diesel for field work	L / (ha · year)	Marg. 1	34	22	27	32	32	45	34
		Marg. 2	22	17	23	27	28	40	29
Yield (fresh matter)	t FM / (ha · year)	Marg. 1	10.0	6.0	8.0	10.0	10.0	25.0	13.3
		Marg. 2	6.0	4.0	5.0	5.0	6.0	20.8	8.8

Table 9-2 LCA input data on cultivation in the Continental zone [IFEU 2018].

Parameter	Unit	Soil marginality class	Black locust (tree)	Black pine (tree)	Willow (SRC)	Poplar (SRC)	Black locust (SRC)	Mis-can-thus	Switch grass
Cultivation life time	years	Marg. 1	15	20	25	20	20	15	15
		Marg. 2							
Seedlings / Seeds	kg / (ha · year)	Marg. 1	25	25	25	25	25	167	0.3
		Marg. 2							
Nitrogen fertiliser	kg N / (ha · year)	Marg. 1	2	2	12	39	0	47	99
		Marg. 2			7	18		38	74
Phosphorus fertiliser	kg P_2O_5 / (ha · year)	Marg. 1	3	3	14	27	10	18	24
		Marg. 2			10	14	6	14	16
Potassium fertiliser	kg K_2O / (ha · year)	Marg. 1	6	6	20	56	15	100	28
		Marg. 2			13	28	9	73	19
Diesel for field work	L / (ha · year)	Marg. 1	34	28	26	32	32	42	33
		Marg. 2	22	22	23	27	28	35	28
Yield (fresh matter)	t FM / (ha · year)	Marg. 1	10.0	8.0	7.0	10.0	10.0	22.9	13.3
		Marg. 2	6.0	6.0	4.6	5.0	6.0	16.7	8.8

Table 9-3 LCA input data on cultivation in the Mediterranean zone [IFEU 2018].

Parameter	Unit	Soil marginality class	Black locust (tree)	Black pine (tree)	Calab. pine (tree)	Poplar (SRC)	Black locust (SRC)	Mis-can-thus	Switch grass	Giant reed
Cultivation life time	years	Marg. 1	15	20	20	20	20	15	15	15
		Marg. 2								
Seedlings / Seeds	kg / (ha · year)	Marg. 1	25	25	25	25	25	167	0.3	167
		Marg. 2								
Nitrogen fertiliser	kg N / (ha · year)	Marg. 1	2	2	2	48	0	42	75	135
		Marg. 2				24		26	46	86
Phosphorus fertiliser	kg P_2O_5 / (ha · year)	Marg. 1	3	3	3	33	11	17	19	72
		Marg. 2				17	6	10	11	42
Potassium fertiliser	kg K_2O / (ha · year)	Marg. 1	6	6	6	67	18	91	22	395
		Marg. 2				34	9	55	13	220
Diesel for field work	L / (ha · year)	Marg. 1	37	22	18	34	34	37	34	42
		Marg. 2	22	17	14	28	28	31	27	34
Yield (fresh matter)	t FM / (ha · year)	Marg. 1	11.0	6.0	4.5	12.0	12.0	20.8	10.3	35.0
		Marg. 2	6.0	4.0	3.0	6.0	6.0	12.5	5.9	20.0

9.2.2 Results for climate change and marine eutrophication

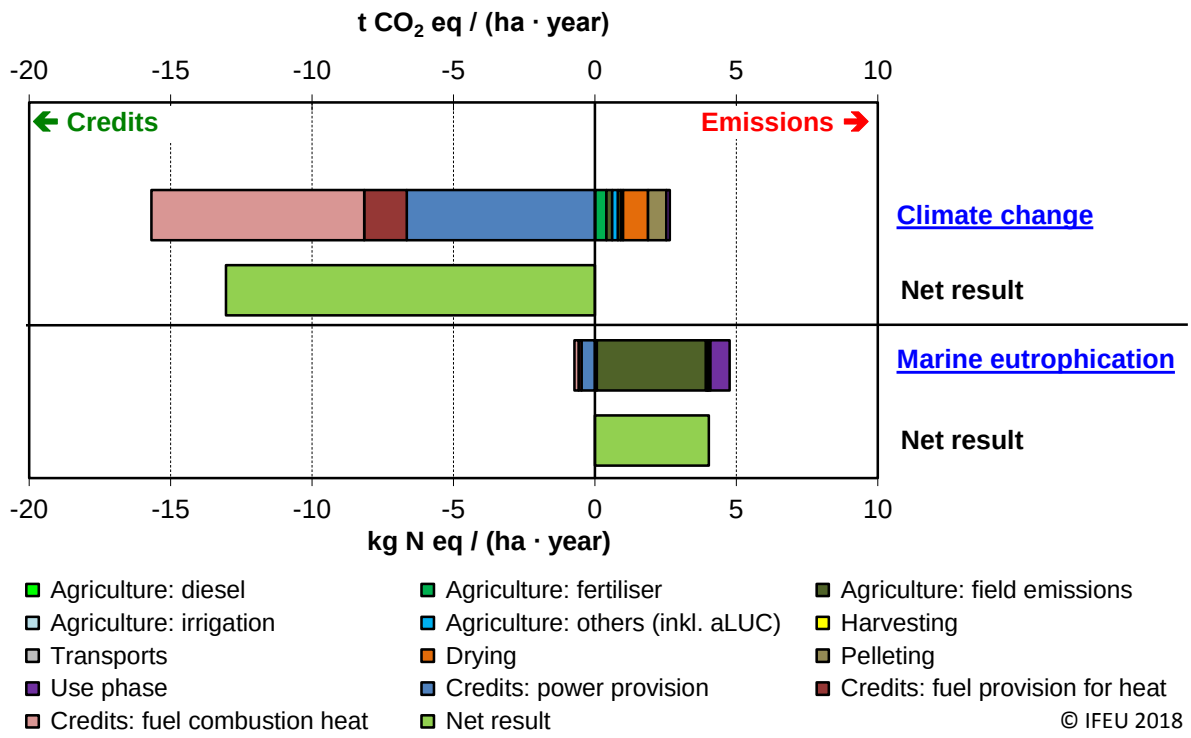

Fig. 9-6 Contributions of individual life cycle steps to the overall net result of the scenario 'Miscanthus, cultivated on marginal land (M1) in the Continental zone, used in small CHP' compared to the fossil reference in the environmental impact categories climate change and marine eutrophication.

9.2.3 Environmental performance of biomass crops in the Atlantic and Mediterranean zone

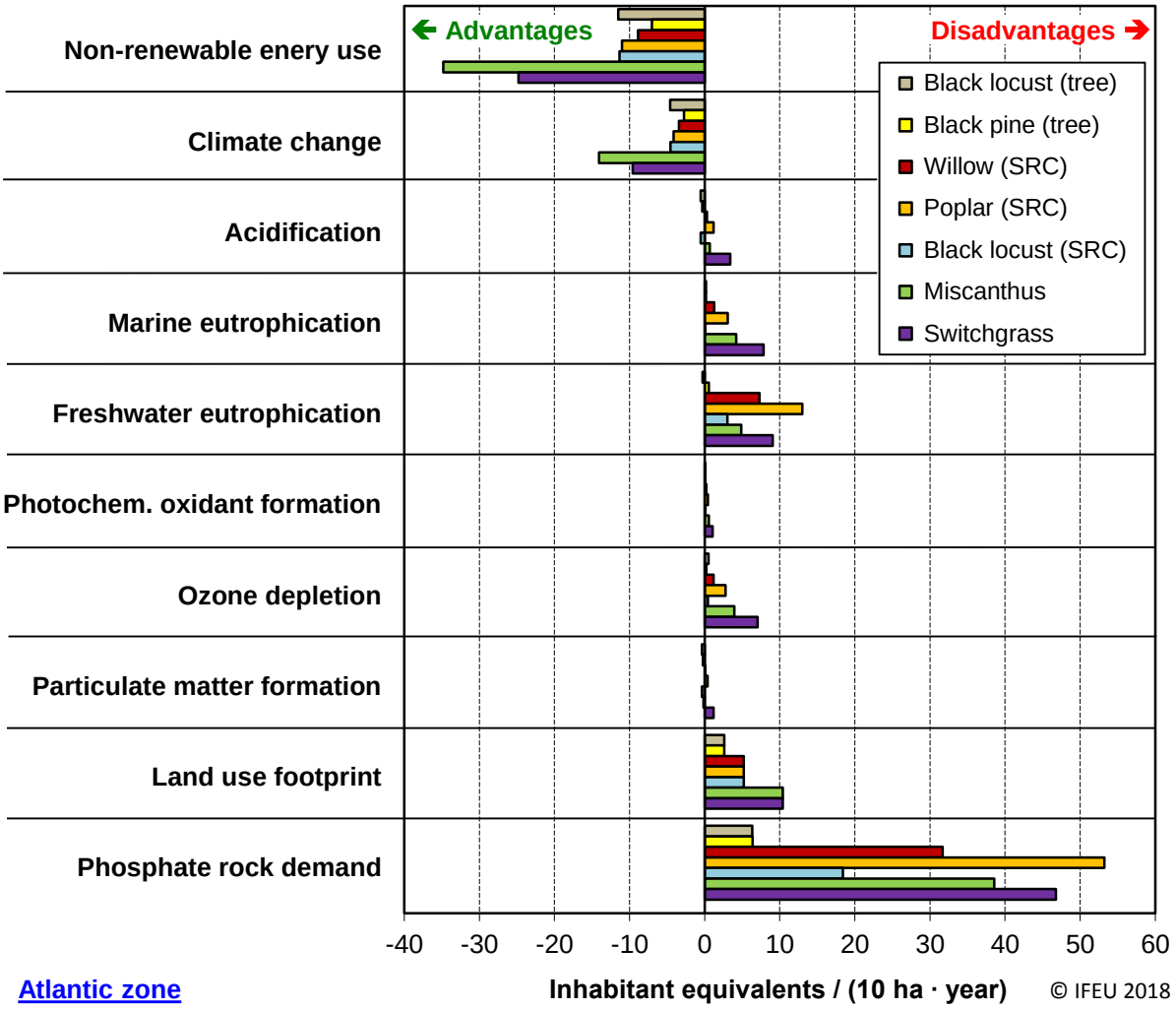

Fig. 9-7 Overall net results of biomass crops, cultivated on marginal land (M1) in the Atlantic zone and used in a small CHP plant, compared to fossil reference products in all environmental impact categories.

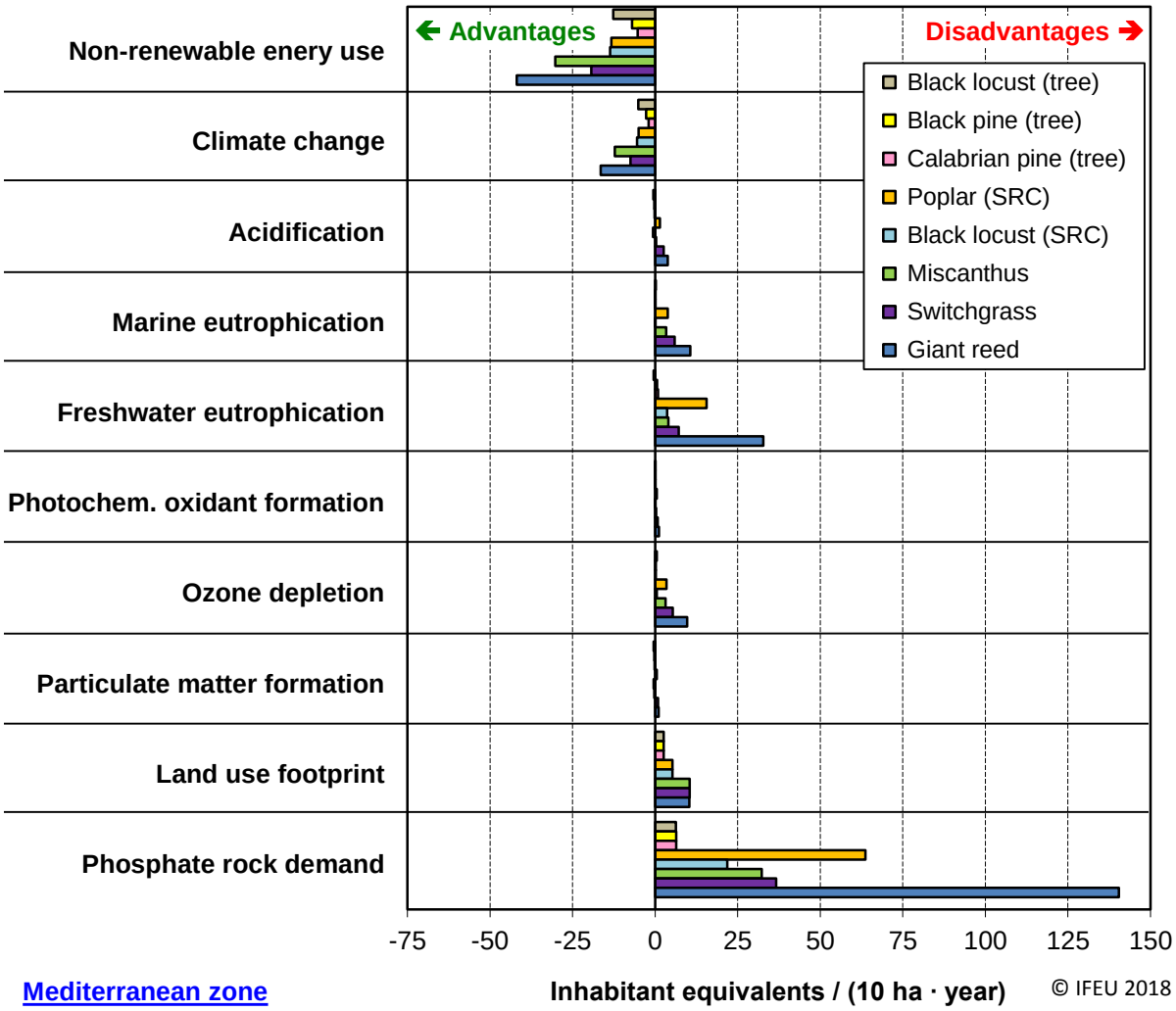

Fig. 9-8 Overall net results of biomass crops, cultivated on marginal land (M1) in the Mediterranean zone and used in a small CHP plant, compared to fossil reference products in all environmental impact categories.

9.2.4 Dominance analysis for woody biomass

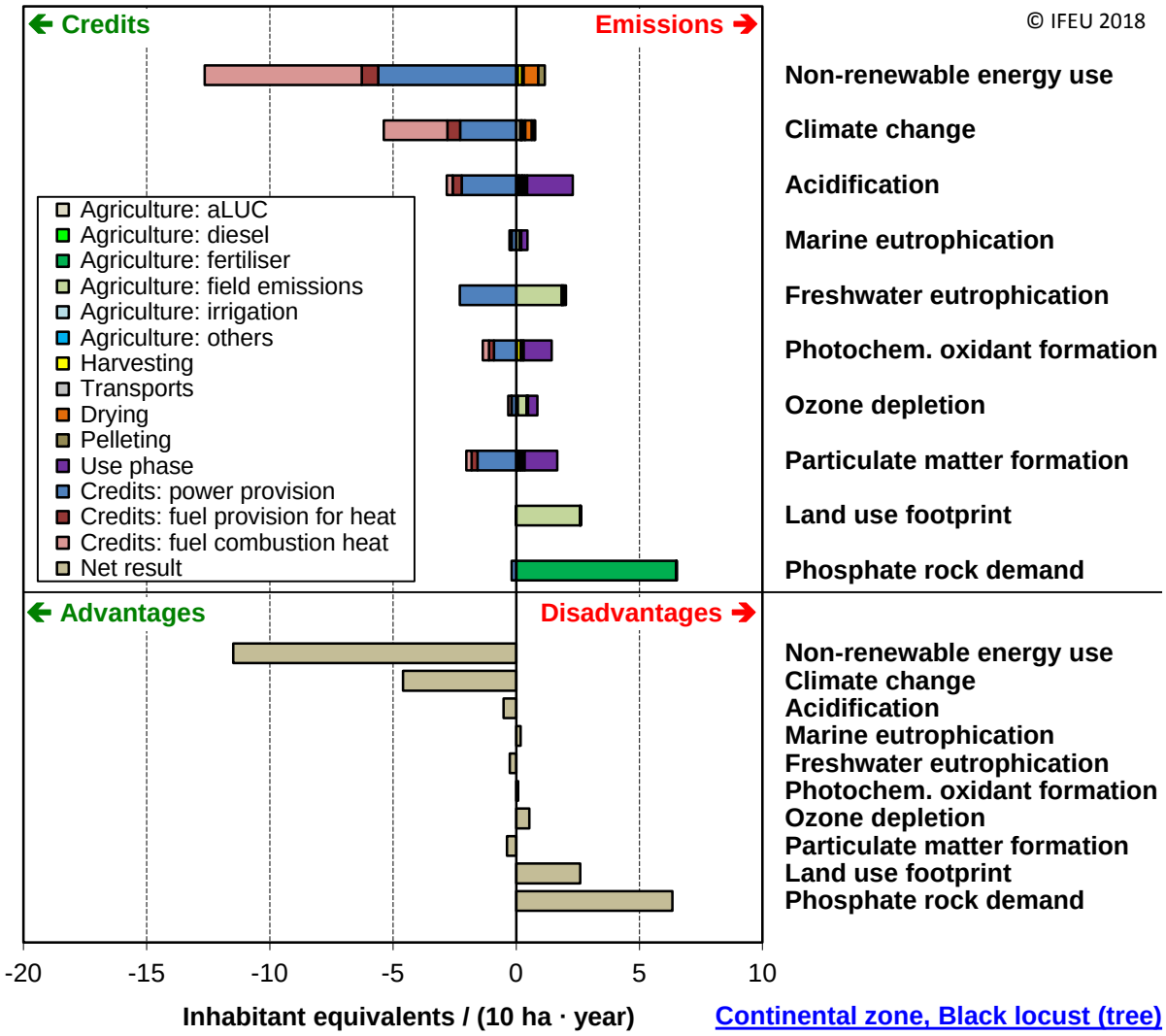

Fig. 9-9 Contributions of individual life cycle steps (coloured bars) to the overall net results of black locust (tree), cultivated on marginal land (M1) in the Continental zone and used in a small CHP plant for the analysed impact categories.

9.2.5 Environmental performance of use options at low efficient conditions

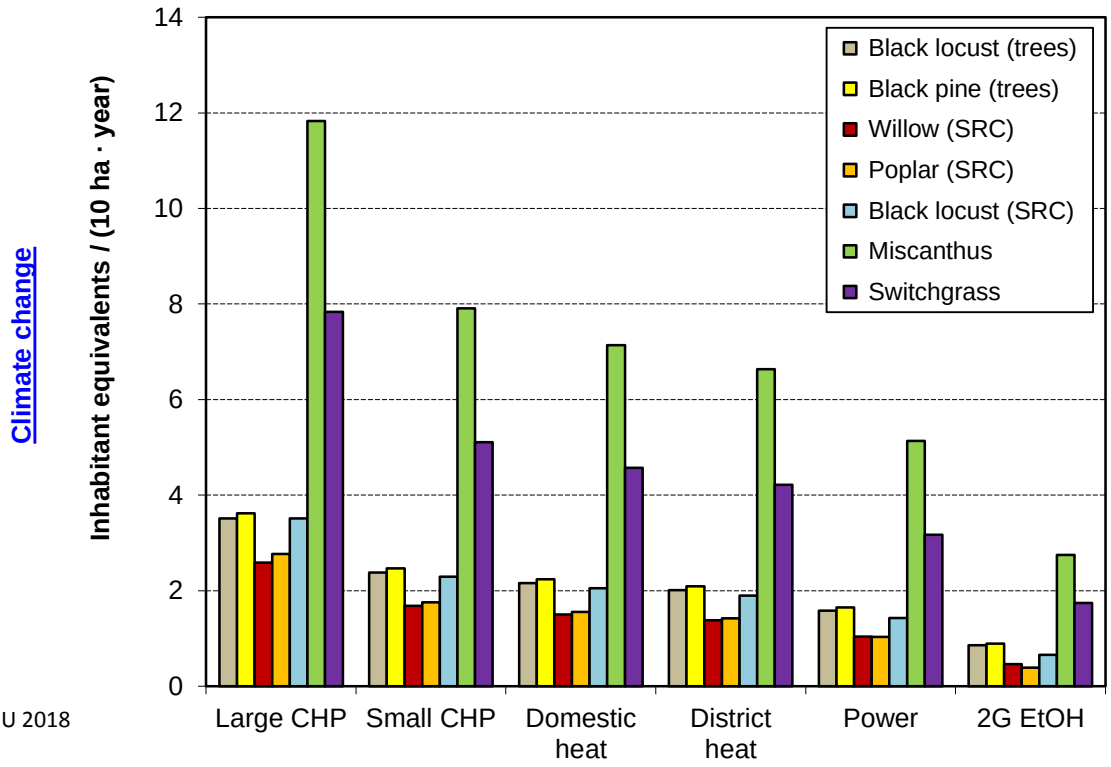

Fig. 9-10 Overall net results for analysed crops in the Continental zone, cultivated on very marginal land (M2), used for different energy options with low conversion efficiency compared to the reference system.

9.3 Supplements to LC-EIA

9.3.1 Local environmental impacts of biomass provision

Black pine and Calabrian pine

Table 9-4 Risks associated with the cultivation of black pine and Calabrian pine compared to the reference system idle land (with predomin. grassy vegetation cover). © IFEU 2018

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

[1] Slightly negative in the first year, neutral over the total cultivation period

[2] Depending on the structure of the surrounding landscape positive or negative impacts are expected

Black locust (tree)

Table 9-5 Risks associated with the cultivation of black locust (tree) compared to the reference system idle land (with predominantly grassy vegetation cover). © IFEU 2018

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health & recreation	Bio-diversity
Soil erosion	neutral[1] / positive		neutral[1] / positive						
Soil compaction	neutral / positive	neutral		neutral	neutral				neutral
Loss of soil organic matter	neutral / pos. / neg.			neutral	neutral				neutral
Soil chemistry / fertiliser	neutral	neutral	neutral						
Eutrophi-cation	neutral[1]	neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Nutrient leaching		neutral							
Water demand		neutral		neutral	neutral				neutral
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Loss of land-scape elements				negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / positive[2]
Loss of habitat types				negative / positive[2]	negative / positive[2]				negative / positive[2]
Loss of species				neutral / negative	negative / positive[3]				neutral / negative

[1] Slightly negative in the first year, neutral over the total cultivation period

[2] Depending on the structure of the surrounding landscape positive or negative impacts are expected

[3] Negative due to invasiveness but increased number of blossom visiting insects during flowering period

SRC (basket willow, poplar, black locust)

Table 9-6 Risks associated with the cultivation of SRC compared to the reference system idle land (with predominantly grassy vegetation cover). © IFEU 2018

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health & recreation	Bio-diversity
Soil erosion	neutral[1]		neutral[1]						
Soil compaction	neutral / positive	neutral		neutral	neutral				neutral
Loss of soil organic matter	neutral / pos. / neg.			neutral	neutral				neutral
Soil chemistry / fertiliser	neutral	neutral	neutral						
Eutrophi-cation	neutral[1]	neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Nutrient leaching		neutral							
Water demand		neutral / negative[2]		neutral / negative[2]	neutral / negative[2]				neutral / negative[2]
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Loss of land-scape elements				negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]
Loss of habitat types				negative / positive[3]	negative / positive[3]				negative / positive[3]
Loss of species				neutral / negative	negative / positive[4]				neutral / negative

[1] Slightly negative in the first year, neutral over the total cultivation period
[2] Negative in case of SRC cultivation in areas with (seasonal) water scarcity
[3] Depending on the structure of the surrounding landscape positive or negative impacts are expected
[4] Negative for willow and poplar. Ambivalent for black locust due to invasiveness (negative) but increased number of blossom visiting insects during flowering period (positive)

Miscanthus and switchgrass

Table 9-7 Risks associated with the cultivation of Miscanthus and switchgrass compared to the reference system idle land (with predominantly grassy vegetation cover). © IFEU 2018

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health & recreation	Bio-diversity
Soil erosion	neutral[1]		neutral[1]						
Soil compaction	neutral	neutral		neutral	neutral				neutral
Loss of soil organic matter	neutral / pos. / neg.			neutral	neutral				neutral
Soil chemistry / fertiliser	neutral	neutral / negative[2]	neutral						
Eutrophi-cation	neutral[1]	neutral[1] / negative[2]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Nutrient leaching		neutral / negative[2]							
Water demand		neutral / negative[3]		neutral / negative[3]	neutral / negative[3]				neutral / negative[3]
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Loss of land-scape elements				negative / positive[4]	negative / positive[4]	negative / positive[4]	negative / positive[4]	negative / positive[4]	negative / positive[4]
Loss of habitat types				negative / positive[4]	negative / positive[4]				negative / positive[4]
Loss of species				neutral / negative	neutral / negative				neutral / negative

[1] Slightly negative in the first year, neutral over the total cultivation period
[2] A higher risk is associated with switchgrass
[3] Negative in case of perennial grass cultivation in areas with (seasonal) water scarcity
[4] Depending on the structure of the surrounding landscape positive or negative impacts are expected

Giant reed

Table 9-8 Risks associated with the cultivation of giant reed compared to the reference system idle land (with predominantly grassy vegetation cover). © IFEU 2018

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health & recreation	Bio-diversity
Soil erosion	neutral[1]		neutral[1]						
Soil compaction	neutral	neutral		neutral	neutral				neutral
Loss of soil organic matter	neutral / pos. / neg.			neutral	neutral				neutral
Soil chemistry / fertiliser	neutral negative	neutral / negative	neutral negative						
Eutrophi-cation	neutral[1] negative	neutral[1] / negative	neutral[1] negative	neutral[1] negative	neutral[1] negative				neutral[1] negative
Nutrient leaching		neutral / negative							
Water demand		neutral / negative[2]		neutral / negative[2]	neutral / negative[2]				neutral / negative[2]
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Loss of land-scape elements				negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]	negative / positive[3]
Loss of habitat types				negative / positive[3]	negative / positive[3]				negative / positive[3]
Loss of species				neutral / negative	neutral / negative				neutral / negative

[1] Slightly negative in the first year, neutral over the total cultivation period
[2] Negative in case of perennial grass cultivation in areas with (seasonal) water scarcity
[3] Depending on the structure of the surrounding landscape positive or negative impacts are expected

9.3.2 Local environmental impacts of fossil feedstock provision

Crude oil / gas provision

Table 9-9 Impacts on environmental factors related with crude oil / gas provision; potentially significant impacts are marked with thick frames; reference scenario: no use. © IFEU 2018

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

Coal provision

Table 9-10 Impacts on environmental factors related with coal provision; potentially significant impacts are marked with thick frames; reference scenario: no use. © IFEU 2018

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

Uranium ore provision

Table 9-11 Impacts on environmental factors related with uranium ore provision; potentially significant impacts are marked with thick frames; reference scenario: no use. © IFEU 2018

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

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