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 of definitions and settings for WP 4

Heidelberg, August 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 thread. 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

This report corresponds to D 4.2 Final report of definitions and settings for WP 4. It has been prepared by:

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III. Background

This 'Final report of definitions and settings for WP 4' (Deliverable D 4.2) contains an update of the definitions and settings used in WP 4 and supersedes the earlier 'Interim report of definitions and settings for WP 4' (Deliverable D 4.1) of December 13th, 2016. It is the final, consolidated version of a document which has continuously been updated throughout the project until June 2018. It corresponds to the work description of task 4.1 as summarised in the Grant Agreement Annex I of the Horizon 2020 project SEEMLA (GA no. 691874).

- Task T4.1 *Short description* (Lead: IFEU)

This task will establish the scope and goals of the assessment and provides all the initial settings, including technological parameters. Some part of the definition of the general system boundaries and settings will be received from WP 2. Additionally, specific definitions and settings with reference to the case study sites will be delivered through WP 5. Both sets will be extended by the definitions and settings not necessarily covered in WP 2 and WP 5, but required for an identical basis for the approach in the different tasks 4.2 to 4.4 or needed specifically in these tasks.

Current state of the art in cultivation, biomass conversion and bioenergy usage will provide the initial description of the systems, which will be progressively refined and tailored to SEEMLA using input from other WPs, notably WP 2 and WP 5. Nevertheless, whenever possible the initial settings and definitions will reflect specific aspects of the SEEMLA approach.

The so-called reference systems, necessary in life cycle approaches, will be chosen among typical fossil energy provision systems. If e. g. in one option biofuels for transport are chosen, these will be compared against fossil fuels for transport such as petrol and diesel fuel. If green power is investigated, the conventional power mix from the grid or the marginal power mix will be chosen. If heat from biomass is examined, typical conventional boilers will be investigated, for instance fired with natural gas or light fuel oil.

In month 10, an internal workshop with all partners will be held where a first set of settings and definitions will be agreed. This will ensure the optimal execution of the work in the following tasks. However, during the course of the investigations, due to new findings, revisions of the settings and definitions might be necessary. These will be considered in the following tasks and communicated within the consortium.

A further workshop in month 15 will help to establish the way of communication in interlinkages between the tasks in WP 4 and the different other WPs involved in data request and result transfer.

Results from this task will constitute input for tasks 4.2 to 4.4 as well as for WP 5 regarding the pilot case. Once the assessment is underway, data generated in those tasks will feed back into task 4.1 in order to refine and finalise the settings and references. Similarly, task 4.1 will be tightly interlinked with WP 2 to warrant the congruence between the two WPs.

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1 Introduction

Section 1.1 explains the background of the EU-funded SEEMLA project (Sustainable exploitation of biomass for bioenergy from marginal lands in Europe, GA No. 691874). The concept of the environmental and socio-economic sustainability assessment is described in section 1.2.

1.1 The SEEMLA project

Focuses 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).

1.2 Environmental and socio-economic sustainability assessment

Sustainability assessment is a comprehensive topic which can be interpreted and applied in different ways depending on the project goals. Therefore, the following sections describe the approach of the environmental and socio-economic assessment within the SEEMLA project.

1.2.1 Motivation for a sustainability assessment within this project

The implementation of the concepts proposed by the SEEMLA project can have significant impacts on the society and the environment. This is even more valid since one goal of the project is to provide a basis for a large-scale implementation which might affect millions of hectares of land. Obviously, various advantages but also disadvantages are related to the use of marginal lands for biomass production. Whether the advantages or the disadvantages predominate cannot be determined a priori. Against this background, detailed analyses are necessary to obtain a holistic answer to the following question: Which changes will occur, if SEEMLA pathways are implemented in the future? This is the major aim of WP 4.

1.2.2 The pillars of sustainability

The most well-known definition of sustainability can be found in the report of the Brundtland Commission: 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [UN 1987]. At the 2005 World Summit it was noted that this requires the reconciliation of environmental, social and economic demands – the 'three pillars' of sustainability. This view has been expressed as a scheme using three overlapping circles indicating that the three pillars of sustainability are not mutually exclusive and can be mutually reinforcing (Fig. 1-1).

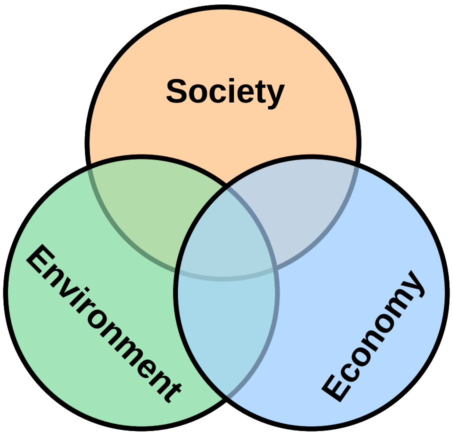

Fig. 1-1 Scheme of sustainable development: at the confluence of three constituent parts.

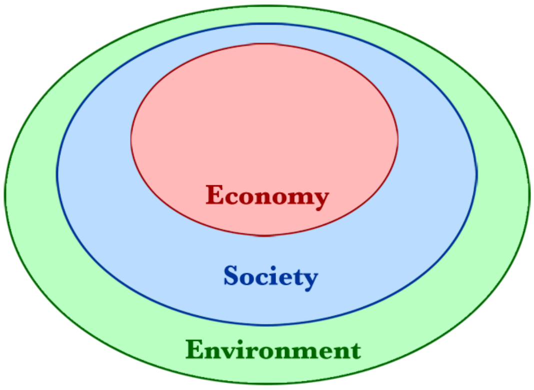

Fig. 1-2 Scheme indicating the relationship between the three pillars of sustainability [Scott-Cato 2008].

The UN definition has evolved and undergone various interpretations. For example, many environmentalists think that the idea of sustainable development is an oxymoron as development seems to entail environmental degradation. From their perspective, the economy is a subsystem of human society, which is itself a subsystem of the ecosphere, and a gain in one sector is a loss from another. This can be illustrated as three concentric ellipses (Fig. 1-2). Nevertheless, other interpretations exist as well.

As a result of the growing pressure on the environment and increased scarcity of natural resources, the sustainability discussion is often focussed on the environment, as both society and economy are constrained by environmental limits. There is abundant scientific evidence that humankind is currently living unsustainably and is jeopardising the living conditions of future generations, e.g. by excessive use of resources and excessive use of the environment as a sink, e.g. for greenhouse gas emissions. Hence, strong efforts are needed to identify and develop sustainable technologies which are able to reconcile economic, social and environmental demands.

1.2.3 Implementation of the sustainability assessment within this project

As stated above, the environmental and socio-economic sustainability assessment within the SEEMLA project is carried out by WP 4. The objective of WP 4 is to provide a comprehensive evaluation of the implications associated with the SEEMLA value chains on the main pillars of sustainability. WP 4 is subdivided into the following tasks:

- Task 4.1: Definitions and Settings,
- Task 4.2: Life cycle assessment (LCA),
- Task 4.3: Life cycle environmental impact assessment (LC-EIA), and
- Task 4.4: Socio-economic assessment.

The structure of WP 4 is depicted in Fig. 1-3. As illustrated, task 4.1 on definitions and settings forms the basis for the subsequent tasks.

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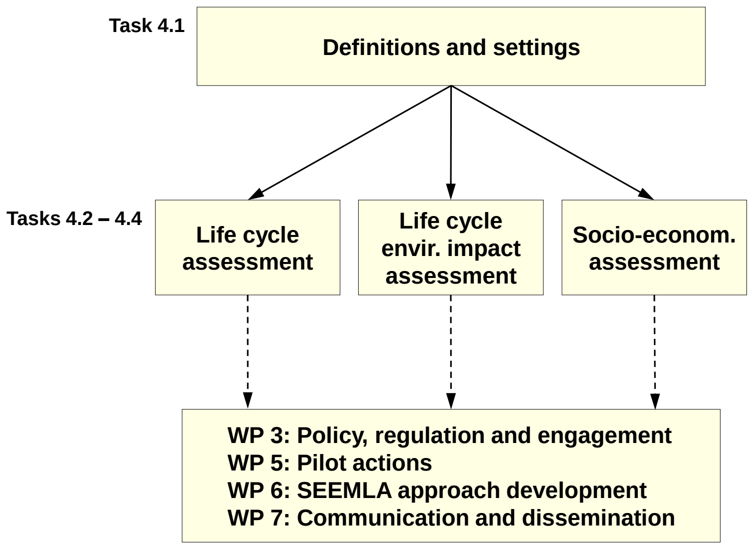

Fig. 1-3 Structure of WP 4 on environmental and socio-economic assessment.

In order to achieve reliable and robust sustainability assessment results, it is inevitable that the principles of comprehensiveness and life cycle thinking (LCT) are applied. Life cycle thinking means that all life cycle stages for products are considered, i.e. the complete supply or value chains, from agricultural production of energy crops, through harvesting, pre-treatment, to product use and if applicable end-of-life treatment and final disposal (see Fig. 1-4). Through such a systematic overview and perspective, the unintentional shifting of environmental burdens, economic benefits and social well-being between life cycle stages or individual processes can be identified and possibly mitigated or at least minimised.

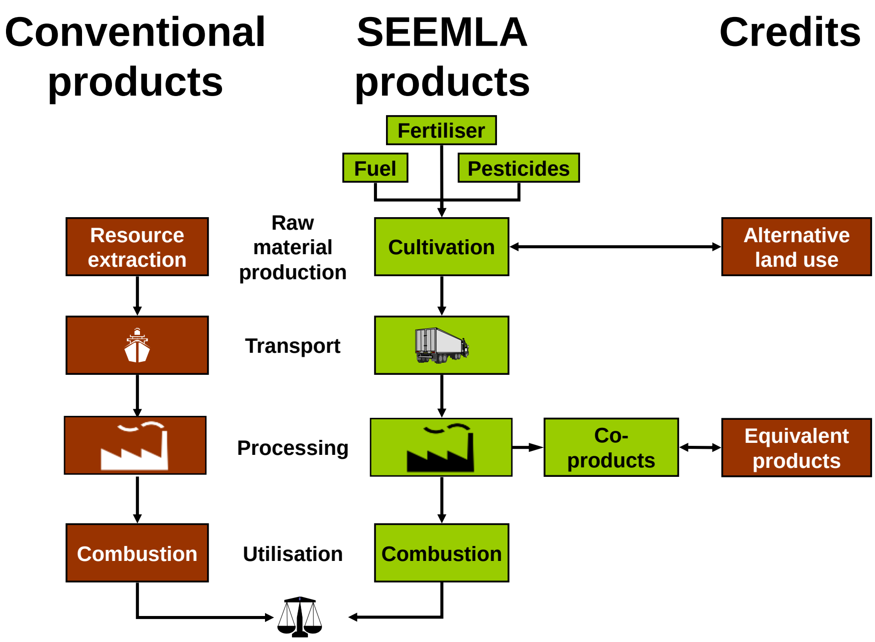

Fig. 1-4 Environmental and socio-economic assessment within the SEEMLA project: the SEEMLA products are compared to conventional reference products along the whole life cycle.

The performance of each product and co-product is compared to conventional reference products. All three pillars of sustainability will be analysed using methodologies that are based on life cycle thinking. Further details such as the credits related to alternative land use are explained in the following sections (see e.g. section 2.2.3 on alternative land use).

1.2.4 Importance of a common basis

Individual aspects of sustainability (environmental, economic and societal) are studied in separate tasks within WP 4. A prerequisite for the compatibility of results from these individual assessments is that the same systems are analysed and that the work is carried out on the basis of common definitions and settings.

The common definitions and settings are also relevant for the entire consortium because there are several interlinkages between this WP and partners from other WPs such as the definition of use options to be applied in WP 6 or the data which should be provided to WP 4 in compliance with the common settings and definitions. Therefore, the common settings and definitions need to be agreed upon all partners.

Another reason for discussing the definitions and settings with the whole consortium is the fact that they will affect the outcomes of the analyses regarding the main pillars of sustainability and hence are of high importance for the project.

1.3 This final report

This 'Final report of definitions and settings for WP 4' (Deliverable D 4.2) contains an update of the definitions and settings used in WP 4 and supersedes the earlier 'Interim report of definitions and settings' (Deliverable D 4.1) of December 13th, 2016 [Rettenmaier et al. 2016]. It is the final, consolidated version of a document which has continuously been updated until June 2018.

First results were gained at the 'Internal workshop on definitions and settings' which was conducted during the project meeting in Rome (Italy) on November 8th, 2016. Outcomes of this workshop and of communications with SEEMLA partners following the project meeting were compiled in an interim report (D 4.1). The definitions and settings were refined at the 'Internal workshop on interlinkages' in Lviv (Ukraine) on June 1st, 2017 and at a project meeting in Thessaloniki (Greece) on November 29th, 2017. The last adjustments were made at a project meeting in Copenhagen (Denmark) on May 15th, 2018.

2 Common definitions and settings

As described above in section 1.2.4, all elements of a sustainability assessment should be based on the same common definitions and settings in order to ensure consistency. These common definitions and settings are used in each of the subsequent analyses and are summarised in the following. For additional specific definitions, settings and methodological aspects of the environmental and socio-economic assessment, respectively, please refer to the respective detailed reports [Keller et al. 2018; Rettenmaier et al. 2018].

2.1 Goal definition

The comprehensiveness and depth of the sustainability assessment can differ considerably depending on its goal. This is similar to life cycle assessment (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 and the target audience(s).

Intended applications and goal questions

The environmental and socio-economic sustainability 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.

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 the following. Their purpose is to guide the environmental and socio-economic sustainability assessment in WP 4:

- Which implications on environment, economy and society 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 performance regarding the main pillars of sustainability than others?
- Do some use options show a better performance regarding the main pillars of sustainability than others?
- Are the production chains economically viable under the current political and economic framework conditions?
- 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?

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 and socio-economic sustainability 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 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 and socio-economic sustainability 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], the SETAC code of practice for life cycle costing [Swarr et al. 2011] and the UNEP / SETAC guidelines for social life cycle assessment [Andrews et al. 2009]. In an excursus on greenhouse gas (GHG) emissions, the calculation rules laid down in Annex V of the Renewable Energy Directive (RED) [European Parliament & Council of the European Union 2009] are applied in order to prove compliance with the stipulated minimum GHG emissions savings.

For the analysis of the SEEMLA systems, definitions and settings are necessary. They are used in the subsequent analyses (tasks) to guarantee the consistency between the different assessments of environmental and socio-economic 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 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 and socio-economic 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 and socio-economic sustainability 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 and socio-economic sustainability assessment within the SEEMLA project covers Europe. 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.

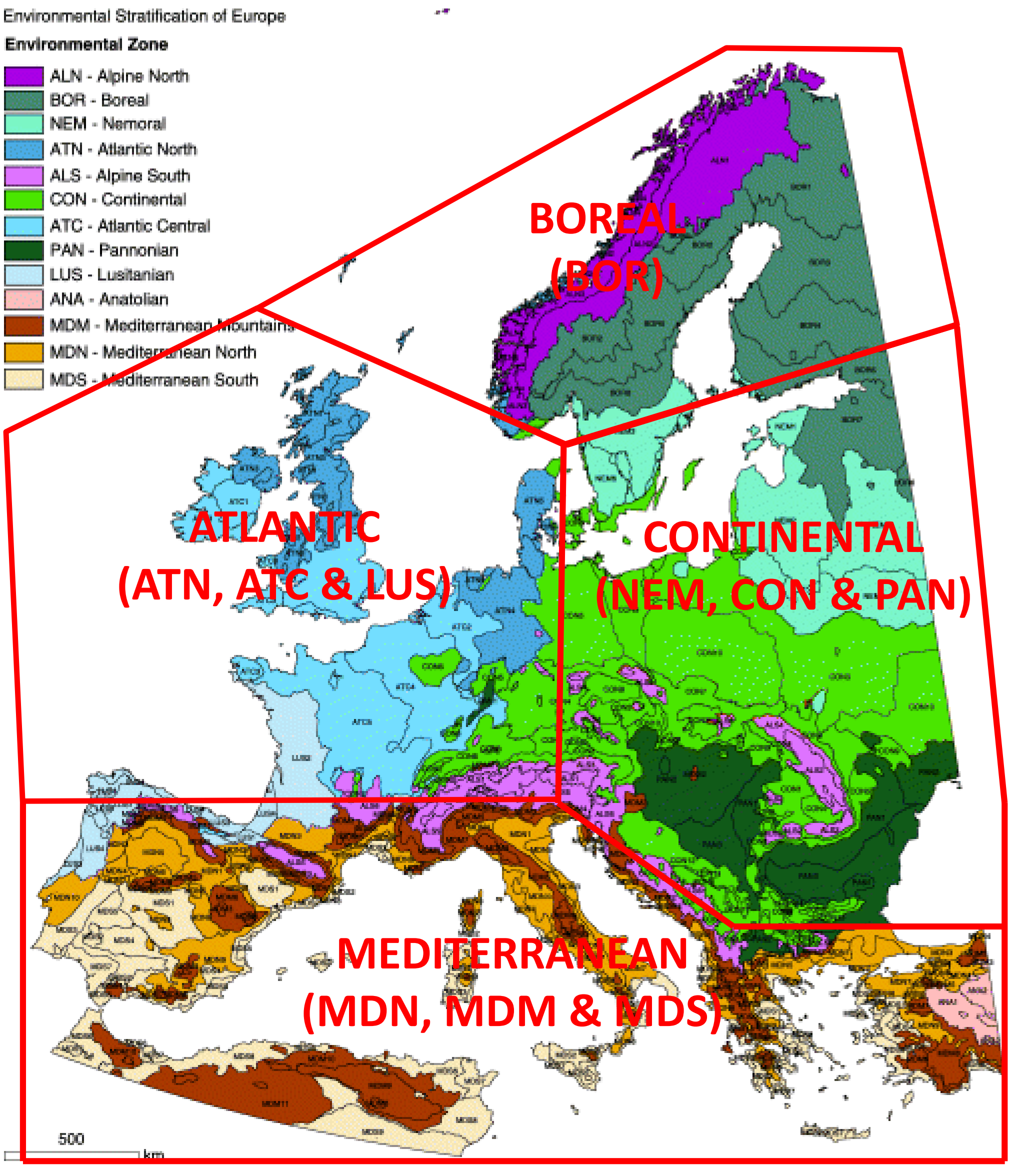

Fig. 2-1 Aggregated zones used for the environmental and socio-economic assessment within the SEEMLA project based on climatic zones of [Metzger et al. 2005].

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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 and socio-economic sustainability 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 3.1.4.1), including land use change effects and associated changes in carbon stocks. Also, for the equivalent conventional reference products (see section 3.1.4.2), the entire life cycle is taken into account.

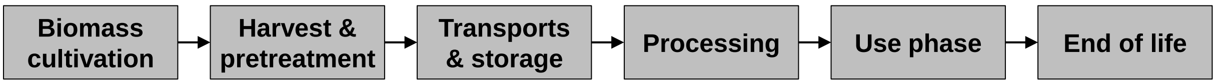

Fig. 2-2 System boundaries applied within the SEEMLA project.

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. 1-4 on page 11) in terms of associated environmental and socio-economic impacts. For a more detailed description see section 3.1.4.1.

2.2.4 Functional unit and reference unit

The key elements of any sustainability assessment are the system's function and functional unit. It is a reference to which the environmental and socio-economic 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 RED-related analyses, 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 and socio-economic sustainability 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].
- Data on all other biomass conversion processes were taken from IFEU's internal database [IFEU 2018] and supplemented with literature data.

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 The SEEMLA scenarios

In the following, the SEEMLA scenarios are qualitatively described. As indicated in section 1.2.3, the scenarios follow the principle of life cycle comparisons. 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 as well as related monetary flows and socio-economic impacts 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.

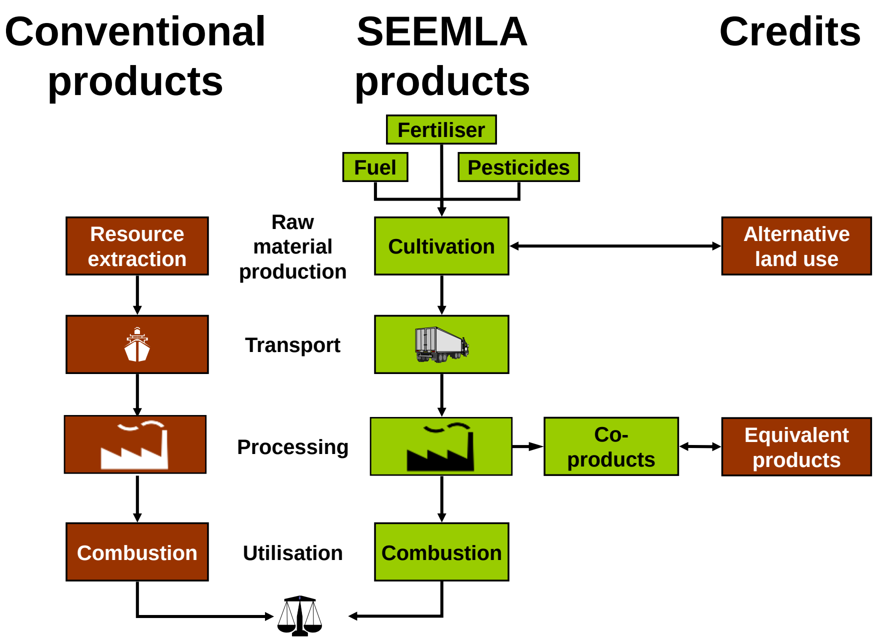

Fig. 3-1 Basic principle of life cycle comparison applied in WP 4.

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 crops as well as biomass residues are excluded.

As introduced in section 2.2.1, WP 4 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 and socio-economic sustainability 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 3.1.4.

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. Harvesting of the biomass including chopping or baling and transportation to a conditioning facility is treated in section 3.1.2. The cultivation of crops is compared to other use options for the same land (section 3.1.4.1). 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)*	*Robinia pseudoacacia* L.	X	X
	Black pine	*Pinus nigra* J.F.Arnold	X	X
	Calabrian pine** (aka Turkish pine)	*Pinus brutia* Ten.	X	X
	Basket willow	*Salix viminalis*.	X	X
	Poplar	*Populus spp.*	X	X
	Black locust (SRC)*	*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

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

** 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 environmental and socio-economic sustainability assessment within the SEEMLA project:

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

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 (see also section 2.2.1.1).

Due to differences in climatic suitability, not all of the perennial lignocellulosic crops listed in Table 3-1 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*.	–	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.

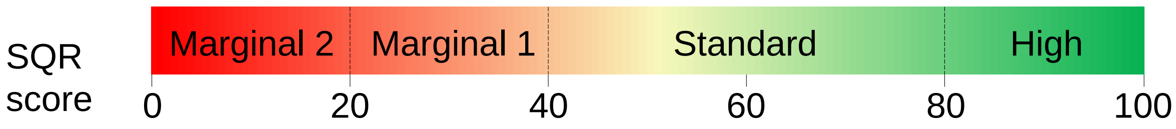

Fig. 3-2 Soil marginality classes.

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	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	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% Switchgrass: 15% Giant reed: 50%	15 / 25%* 15% 15%

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

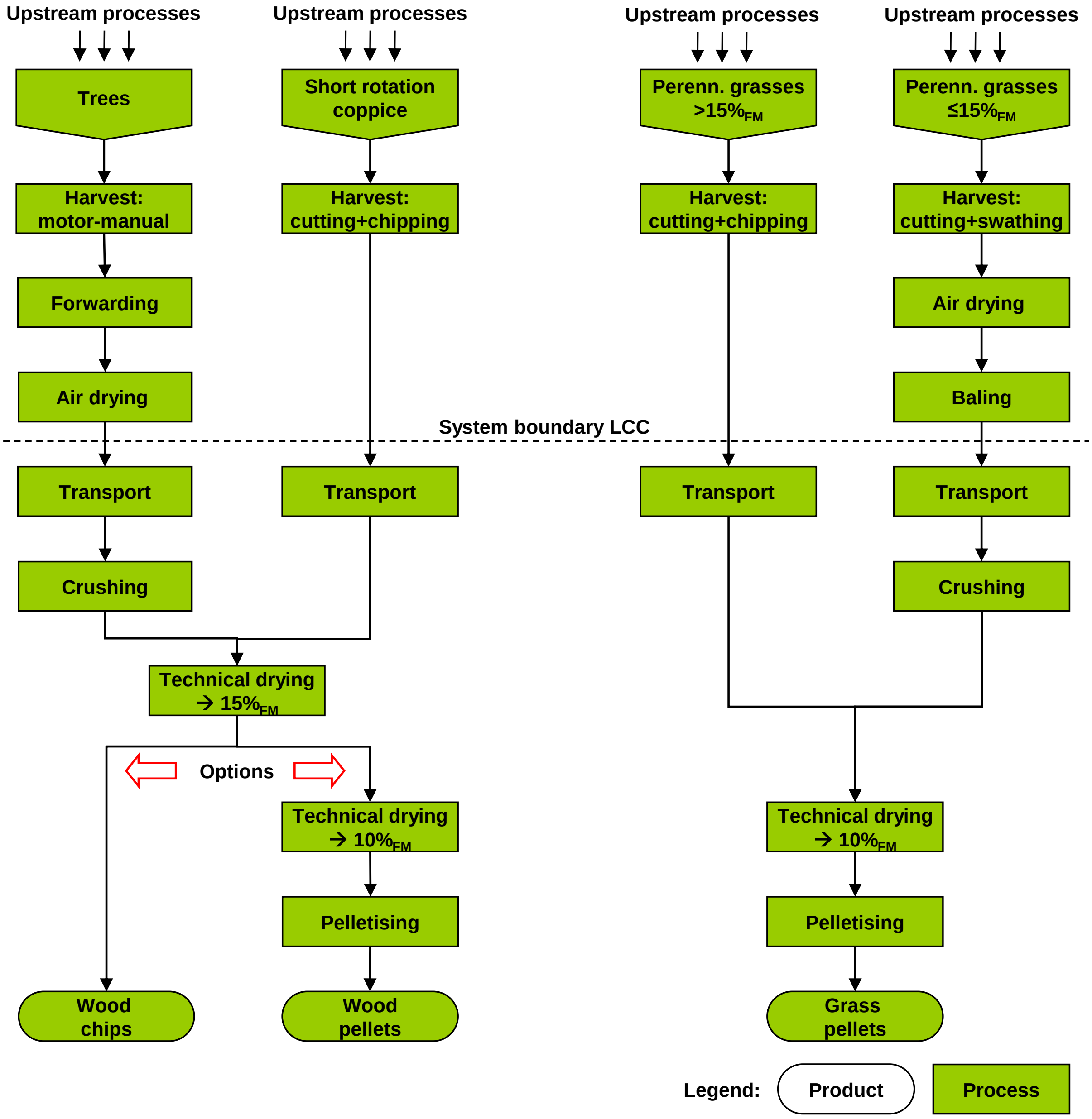

Fig. 3-3 Biomass harvesting, logistics and conditioning options investigated within the SEEMLA project.

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 (cut and chipped) and technically dried.

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

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 CHPs, 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 (see also Fig. 3-4):

- 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 plant (CHP).
- Production of 2nd generation ethanol for use in a passenger car.

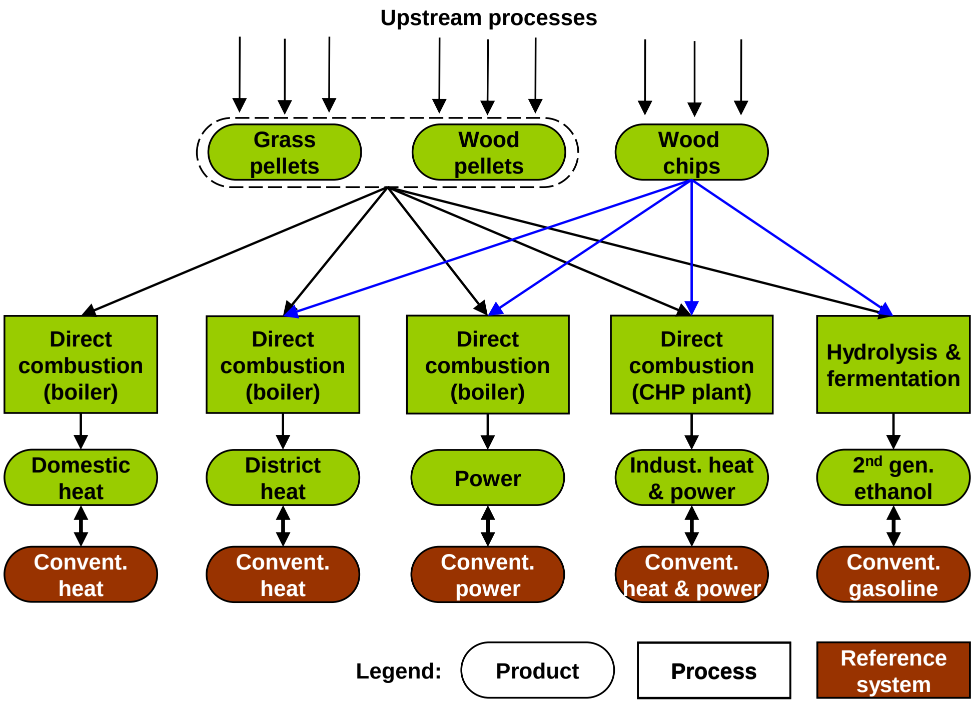

Fig. 3-4 Biomass conversion and use options investigated within the SEEMLA project.

In order to show the bandwidth of possible results of the environmental and socio-economic 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 3-8 (page 29)
	Replaced power mix	**Power mix** (from grid) | coal | natural gas

3.1.4 Reference systems

The bioenergy options are compared to so-called reference systems which include both the agricultural reference system (section 3.1.4.1) and the reference products (section 3.1.4.2).

3.1.4.1 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, land use changes (i.e. carbon stock changes) are not part of the main scenarios, but assessed in sensitivity analyses.

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

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, large uncertainties are related to the long-term effects of this process. For instance, clearing the planation after its life time in order to cultivate annual crops again significantly reduces long-term effects. For that reason, the relevance of such soil organic carbon accumulation 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 is 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]. Hence, carbon stock changes in the soil are not considered in the main scenarios. Still, in order to assess the parameter's influence on the environmental performance of the investigated perennial crops, carbon stock changes are subject of a sensitivity analysis.

Carbon stock changes in the vegetation
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. Carbon stock changes in the vegetation are not considered in the main scenarios. However, they are subject of a sensitivity analysis.

3.1.4.2 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 3-8 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 3-8 lists appropriate conventional reference systems to which the bioenergy systems are compared. In general, the conventional reference systems shall represent the marginal technology that would most likely be replaced first when 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 3-8 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

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 3-9).

Table 3-9 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 3-10. 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 and socio-economic sustainability 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 3-10.

Table 3-10 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 energetic 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 (German Railways, Welzow):
    - Cutting, crushing, transportation to storage and conditioning unit, technical drying, pelleting and transportation to the conversion unit (alternative A).
    - Cutting, crushing, transportation to the conversion (alternative B).
- Greece (Fillyra, Ismaros, Kalhantas): Cutting, trimming, transportation to storage and conditioning unit, final crushing and transportation to the conversion unit.
- Ukraine (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 summarized in Table 3-11. 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 3-11 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 (German Railways, Welzow):
  - local heating (alternative A).
  - combined heat and power plant (CHP) (alternative B).
- Greece (Fillyra, Ismaros, Kalhantas): local heating.
- Ukraine (Poltava, Vinnitsa, Volyn A–C, Lviv A–D):
  - Local heating (alternative A).
  - District heating network (alternative B).
  - CHP (alternative C).

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.

4 Abbreviations

CHP	Combined heat and power
dLUC	Direct land use change
DM	Dry matter
EC	European Commission
FM	Fresh matter
GHG	Greenhouse gas
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
MJ	Megajoule
MWh	Megawatt hour
RED	Renewable Energy Directive
SETAC	Society of Environmental Toxicology and Chemistry
SRC	Short rotation coppice
UN	United Nations
UNEP	United Nations Environment Programme
WP	Work package

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