ADVANCEFUEL

Innovative cropping schemes for lignocellulosic feedstock production

D2.2 Innovative crop rotation schemes

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ADVANCEFUEL at a glance

ADVANCEFUEL (www.ADVANCEFUEL.eu) aims to facilitate the commercialisation of renewable transport fuels by providing market stakeholders with new knowledge, tools, standards, and recommendations to help remove barriers to their uptake. The project will look into liquid advanced biofuels – defined as liquid fuels produced from lignocellulosic feedstocks from agriculture, forestry and waste – and liquid renewable alternative fuels produced from renewable hydrogen and CO2 streams.

In order to support commercial development of these fuels, the project will firstly develop a framework to monitor the current status, and future perspectives, of renewable fuels in Europe in order to better understand how to overcome barriers to their market roll-out. Following this, it will investigate individual barriers and advance new solutions for overcoming them.

The project will examine the challenges of biomass availability for second-generation biofuels, looking at non-food crops and residues, and how to improve supply chains from providers to converters. New and innovative conversion technologies will also be explored in order to see how they can be integrated into energy infrastructure.

Sustainability is a major concern for renewable fuels and ADVANCEFUEL will look at socio-economic and environmental sustainability across the entire value chain, providing sustainability criteria and policy-recommendations for ensuring that renewable fuels are truly sustainable fuels. A decision support tool will be created for policy-makers to enable a full value chain assessment of renewable fuels, as well as useful scenarios and sensitivity analysis on the future of these fuels.

Stakeholders will be addressed throughout the project to involve them in a dialogue on the future of renewable fuels and receive feedback on ADVANCEFUEL developments to ensure applicability to the end audience, validate results and ensure successful transfer and uptake of the project results. In this way, ADVANCEFUEL will contribute to the development of new transport fuel value chains that can contribute to the achievement of the EU's renewable energy targets, and reduce carbon emissions in the transport sector to 2030 and beyond.

To stay up to date with ADVANCEFUEL's stakeholder activities, sign up at: www.ADVANCEFUEL.eu/en/stakeholders

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Executive Summary

The overarching goal of the ADVANCEFUEL project is to facilitate the market roll-out of advanced liquid biofuels derived from lignocellulosic feedstocks, and other liquid renewable fuels from a non-biological origin (further jointly addressed as "RESfuels" in this report). The project specifically aims to facilitate change within the transportation sector between 2020 and 2030, with an outlook on post-2030 impacts. This report assesses fields of innovation in cropping lignocellulosic energy crops, while also evaluating these innovations. The evaluation focuses on: (a) the potential of these innovations to reduce biomass production costs, (b) the environmental impact of growing such crops, and (c) the willingness of farmers to grow lignocellulosic energy crops and public acceptance regarding post implementation of new cropping schemes.

In order to identify fields of innovation for lignocellulosic cropping, and to describe single innovations in these fields, the project utilised a two-fold approach that consisted of: (1) an organised workshop in order to receive inputs from several European projects with case studies on cropping on marginal lands and (2) the consortium carried-out an extensive literature review. The workshop provided useful information and rather subjective results (chapter 2) including the ranking of different impact factors. This was particularly relevant when considering the acceptance factor. There were some publications found through the literature review on single features that influence public acceptance after the implementation of innovative cropping scheme, however there were no results that had ranked these schemes. The thorough literature review (chapter 3) was therefore essential to describe the innovations and their impact on biomass production costs and the environment in detail in both a qualitative and quantitative way.

The fields of innovation considered in this study include agricultural management, breeding, crop selection, crop rotation, intercropping, multipurpose cropping, cropping on marginal land, and harvesting technology. Impacts of the described innovative cropping schemes were compared and evaluated from the economic, environmental, and acceptance perspectives (chapter 4). This chapter highlights that the different perspectives favour different innovations, but also that impacts of specific innovations are site specific and depend on various economic, environmental, and social settings.

In conclusion, all innovations resulting in sustainable yield increases are of economic and environmental interest. This increase of yield as a sum of several innovations is denoted as a "learning effect" in the literature. The learning effect includes, for example, the generation (breeding) and selection of new genotypes as well as improved agricultural management and logistics, but also knowledge exchange and training. The learning effect had higher potential to increase biomass yields per hectare and to reduce biomass production costs and GHG

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emissions compared to single innovations. Different measures are recommended in this report in order to accelerate the learning effect. One suggested measure is the establishment of a standardised assessment chart that could be applied systematically to all cases of lignocellulosic biomass cultivation. This would include the definition of a minimum set of parameters that could be assessed with standard methods and reported for all case studies. Such a standardised assessment chart would permit a better comparison of case studies and best practices. Furthermore, an open information policy in the EU is required for accelerating information flow and, hence, the learning effect. This should include the development of a communication strategy to enhance information accessibility and enhance the cooperation between stakeholders. Finally, to cope with the complexity of economic and environmental aspects as well as public acceptance, a tool is needed. This could be a decision support system on the EU level that would need to include standardised data on costs, sustainability, and social acceptance.

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Contents

Abbreviations

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DAP	Diammonium phosphate
DM	Dry matter
EUBCE	European Biomass Conference & Exhibition
FAO	Food and Agriculture Organization of the Unites Nations
GHG	Greenhouse gas
ILUC	Indirect land use change
NUTS	Nomenclature of Territorial Units for Statistics
ROI	Return on investment
SOC	Soil organic carbon
SRC	Short rotation coppice
TSP	Triple Super Phosphate
VAT	Value-added tax

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1. Introduction

ADVANCEFUEL aims to increase the share of renewable energy in the future energy mix by increasing the share of sustainable advanced biofuels and renewable alternative fuels in the final EU transportation energy consumption. A key barrier for increasing the share of advanced biofuels is the cost of feedstocks (see ADVANCEFUEL Deliverable 1.1). Therefore, one aim of ADVANCEFUEL is to explore cost reduction potentials from innovative cropping systems, while at the same time avoiding greenhouse gas (GHG) emissions by indirect land-use changes (ILUC), or other negative environmental or social impacts.

Several ideas are emerging regarding how biomass cropping for biofuel or industrial use can be innovated. The question is; "What are the most promising innovative cropping systems for different regions in Europe?". Next to the profitability of innovative cropping systems, the most viable innovations should be associated with positive or neutral environmental impacts on the global and local scale. The success of innovations in cropping systems is highly site specific. Local case studies have been elaborated in recent years all over Europe in order to collect numerous details on profitability and environmental impacts. These data are then used in the respective projects as inputs to other work packages that detail sustainable supply chains or life cycle assessments. The aim of this deliverable is to summarise existing case studies, highlight their key innovations, and evaluate them from different perspectives such as: economic, environmental, and acceptance aspects. The assessment will at this point, focus only on feedstocks from dedicated cropping, since these are expected to produce the largest share of feedstocks for advanced fuels (Deliverable 2.1, "Report on lignocellulosic feedstock availability, market status, and suitability for RESfuels"). The use of residues will be discussed later in Deliverable 2.3, "Technology roadmaps and upgrading strategies for lignocellulosic feedstock supply chains", which will become available in July 2020.

The approach to summarise existing case studies was two-fold. First, a workshop was organised that brought together different case studies of innovative cropping on marginal land in Europe (chapter 2). In an interactive session, the case studies were discussed regarding their economic, environmental, and social implications, while other related barriers were also addressed. Second, the identification and description of the different fields of innovations for lignocellulosic cropping from case studies was assessed from the literature review (chapter 3). This was followed by an evaluation of the different innovations from the economic, environmental, and social perspectives (chapter 4).

- The results from this deliverable will be used as inputs for several other tasks of ADVANCEFUEL: Input to upgrading of value chains (Task 2.3): Deliverable 2.3 considers innovations as the entry point of supply chain upgrading. The

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assessment of innovative cropping schemes from Deliverable 2.2 will be utilised to further investigate promising upgrading strategies for supply chains.

- Input to cost reduction potential (Task 6.2): D6.1 conducts an integrated analysis, where all feedstock relevant cost-supply data will be included into the model. Cost reduction potential due to promising innovative cropping approaches will be an important part of this analysis.
- Input to sustainability aspects (Task 4.3): This report facilitates the selection of relevant environmental impacts to be measured spatially explicit for lignocellulosic energy crops.
- Input to good practices and lessons to be transferred (Task 5.2): This report provides input to the validation, analysis, and optimisation of "Good Practices" within Vensim systems dynamics modelling as data concerning upstream biomass production and management
- Input to monitoring framework (D1.2): Progress in RESfuels and ADVANCEFUEL project is regularly monitored. As part of this monitoring framework promising solutions to overcome the previously identified barriers are presented. High costs of feedstocks were identified as one of the key barriers and this work will contribute to addressing this barrier.

Dissemination of the results of this deliverable will be realised as a presentation at the European Biomass Conference and Exhibition 2019 (EUBCE 2019) in Lisbon on 28 of May 2019.

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2. Workshop

To provide an overview of successful cropping innovations in Europe in particular on marginal land, a workshop was organised to bring together and receive inputs from different stakeholders.

2.1. Workshop scope and methods

The workshop was organised by ADVANCEFUEL as a joint event with the final event of the SEEMLA project taking place on 20-21 November 2018 in Brussels. Details on the workshop organisation and other sessions can be found in the ADVANCEFUEL Deliverable 7.2.

The workshop brought together a number of ongoing EU projects that put their focus on innovative cropping systems- mainly on marginal lands:

- **FORBIO** (Fostering sustainable feedstock production for advanced biofuels on underutilised land in Europe) aimed at fostering sustainable feedstock production for advanced biofuels on underutilised land in Europe at local, site-specific level. This includes the development of roadmaps for the removal of economic and non-economic barriers to the market uptake of advanced bioenergy.
- **MAGIC** (Marginal lands for growing industrial crops) aims to promote the sustainable development of resource-efficient and economically profitable industrial crops grown on marginal lands, considering that industrial crops can provide valuable resources for high added value products and bioenergy.
- **BECOOL** (Brazil-EU cooperation for development of advanced lignocellulosic biofuels) intends to develop advanced lignocellulosic biofuels in Europe and in Brazil, produced from sustainable agricultural value chains.
- **LIBBIO** (Lupinus mutabilis for increased biomass from marginal lands and value for biorefineries) seeks to develop consumer food, feed, non-food and bio-energy products from Andean lupine varieties (Lupinus mutabilis) adapted to European farming conditions by applying bio-refinery cascading principles for crop value creation and modern crop breeding technologies.
- **GRACE** (Growing advanced industrial crops on marginal lands for bio refineries) projects aims are to produce sustainable products with a strong market potential, to guarantee a reliable and affordable supply of sustainably produced biomass on marginal land, and to better link biomass producers with the processing industry.
- **SEEMLA** (Sustainable exploitation of biomass for bioenergy from marginal lands) projects main objective was 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 project promotes the reconversion of marginal lands for plantations of lignocellulosic crops.

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The relevant projects were briefly introduced during the workshop. As they had differing project durations (Figure 1), only two projects could present final results. The project presentations were followed by an interactive assessment of innovative cropping systems. During this session the workshop participants were asked to select a study case of innovative cropping from their projects and evaluate it based on four evaluation criteria according to the work package focus: feedstock costs, environmental sustainability, barriers to implementation, and social acceptance after implementation. In order to guide these study case evaluations, the participants received a set of cards with evaluation criteria, which they were asked to place on a poster. The poster was divided in four sections so that each of the evaluation criteria on the cards was attributed to one of these sections and ranked according to its impact or weight (Figure 2). For instance, if actual costs of comparable biomass are very low, that might be a high weight barrier for farmers to implement an innovation. The card "biomass cost" would then be placed near to the center of the poster at the "high weight" end of the arrow in the top-right quarter of the poster. For each section a set of cards with pre-printed attributes were provided in order to stimulate the discussion (Table 1). The attributes were selected on the basis of a rough literature review (costs, sustainability, social acceptance), AdvanceFuel Deliverable 1.1 (barriers), and internal brainstorming (social acceptance). The participants were not asked to use all of the cards and they also were given additional empty cards to add other attributes. The groups had 40 minutes to evaluate the case studies.

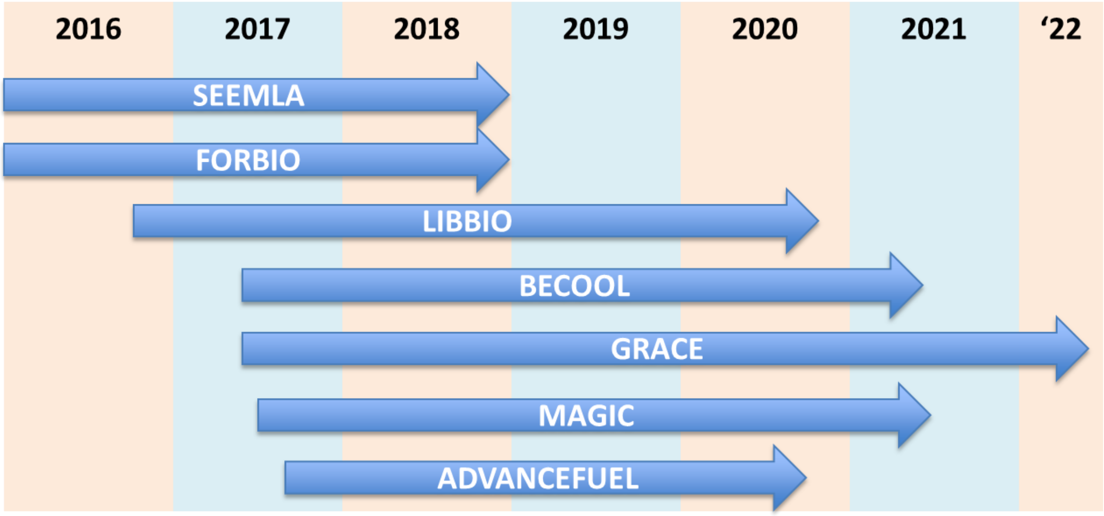

Figure 1: Project durations of the different projects that participated in the ADVANCEFUEL workshop.

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Table 1: For each evaluation criteria (cost, sustainability, barriers, social acceptance) attributes were pre-defined that possible have an impact on the respective criteria. These attributes were printed on the workshop cards.

Costs	Sustainability	Barriers	Social acceptance
• Land rental • New machinery • Work force • Pesticides, herbicides • Seeds, saplings • Irrigation system • Irrigation water • Fossil Fuel • Training and capacity development • Insurance	• GHG-emissions (Due to fossil fuels) • GHG-emissions (Due to land-use change) • Soil organic matter • Soil fertility • Soil erosion • Soil quality (other aspects) • Nutrient retention • Water availability • Water quality • Biodiversity	• Lack of knowledge (of environmental constraints) • Lack of standards and regulations1) • Cost of biomass • Consistent quality • Profitability of biomass production • Habits of farmers • Required investments	• Environmental values2) • Land ownership • Shared benefits • Shared costs • Lack of knowledge • Competing interests

1) Lack of harmonised regulations on sustainable farming practices for dedicated energy crops

2) Value as magnitude of preference or individual priority (Tadaki et al., 2017)

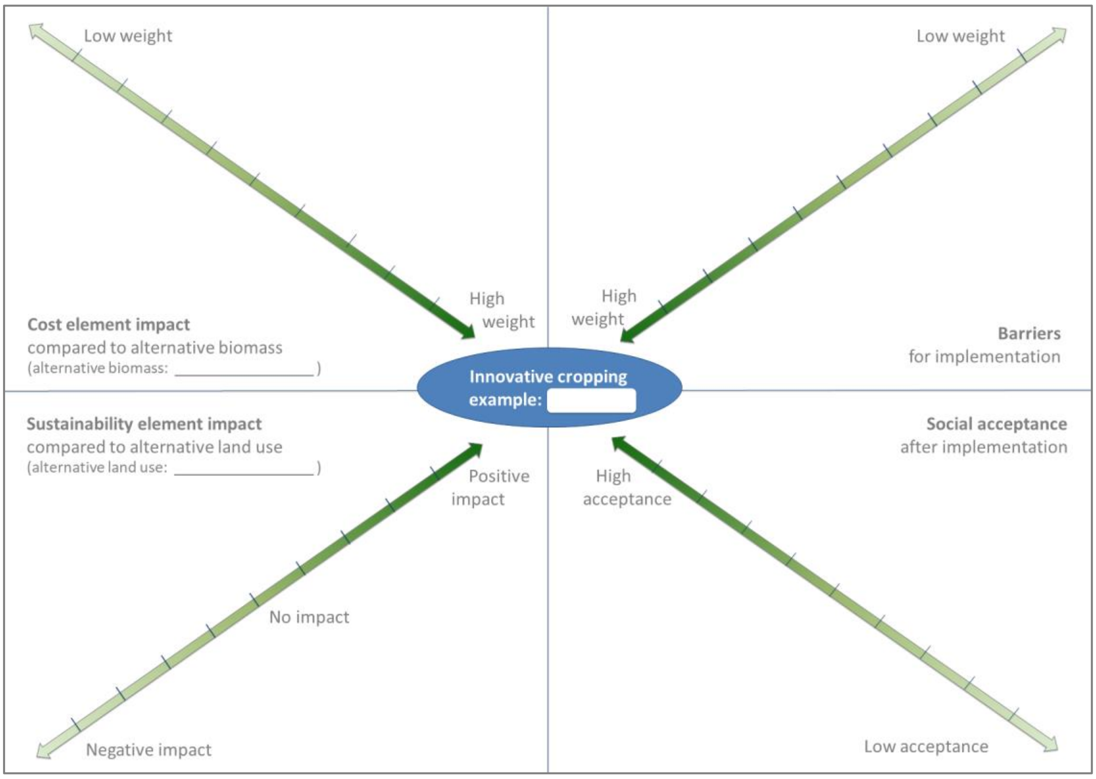

Figure 2: Poster used during the workshop for the evaluation of case studies of innovative cropping.

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The groups worked on five different case studies of innovative cropping (for details see results in chapter 2.2):

- Cropping black locust in short rotation coppice on marginal land (SEEMLA)
- Cropping Willow in short rotation coppice on marginal land (FORBIO)
- Introduction of Andean lupine cropping on marginal land in Europe (LIBBIO)
- Crop rotation system with sorghum or hemp in winter on conventional agricultural land (BECOOL)
- Cropping of Miscanthus on marginal land (MAGIC & GRACE)

The projects GRACE and MAGIC worked together as they selected very similar case studies. In the end of the workshop, each group presented their evaluation results.

2.2. Workshop results

For each project, results were presented for cost impact, sustainability impact, barriers for implementation and social acceptance after implementation. The results described below represent subjective evaluation of the respective impacts selected by the workshop participants. The aim was to learn from the participants' knowledge on specific case studies including information that was not assessed scientifically, but was observed during implementation of the case studies.

2.2.1. SEEMLA

This project discussed the study case of **cropping black locust in short rotation coppice on marginal land in Lusatia/Germany and Thrace/Greece**. Black locust (*robinia pseudoacacia*) was grown on 2 different types of marginal land: post-mining and abandoned land (grassland) in Germany and Greece, respectively.

Cost impact

In addition to labour costs, initial investments of new machinery and setup of an irrigation system (only in Greece irrigation was needed) were identified to have the highest impact on biomass production costs. The insurance for black locust SRC on marginal land was also expected to have high impact on feedstock production costs. Rather medium effects were attributed to fossil fuel consumption and monitoring as well as initial training and capacity development. Variable costs of irrigation water, pesticides, and herbicides had low impact on total biomass production costs.

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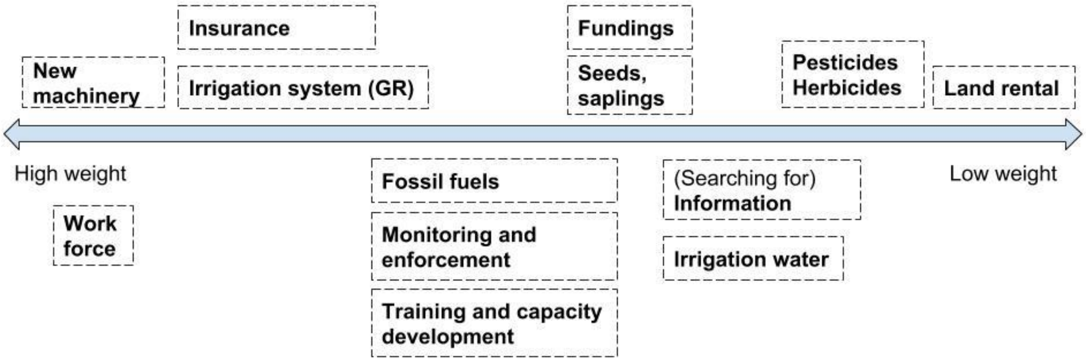

Figure 3: Cost impacts on black locust SRC on marginal land.

Environmental impact

Cropping black locust in short rotation on marginal land was expected to have a strong positive effect on soil fertility, in particular when planted on previous mining sites with very poor soil quality (Vítková et al., 2017). This is due to the easy access to atmospheric nitrogen by bacterial root symbionts and the input of organic matter due to root turnover and litter fall. Furthermore reduced soil erosion contributes to soil fertility. Black locust cropping on marginal land might negatively impact biodiversity, as natural succession is expected to lead to a more diverse landscape than SRC coppice monoculture. If black locust needs to be irrigated in order to produce promising yields, it might also have a negative impact on water availability if grown on large scale.

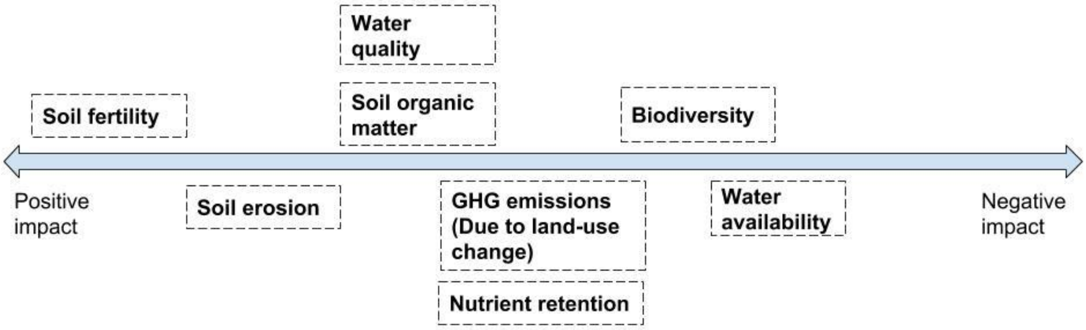

Figure 4: Environmental impacts of black locust SRC on marginal land.

Barriers

Profitability is a major barrier to extend black locust SRC on marginal land. Therefore, the availability of funding or shared use of machinery by several farmers might help to overcome this barrier (see cost section). The lack of standards and regulations of cropping black locust is also perceived as a high weight barrier, being in line with findings outlined in the ADVANCEFUEL Deliverable 1.1 "Barriers to advanced liquid biofuels & renewable liquid fuels

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of non-biological origin". Consistence of quality and the lack of knowledge on environmental constraints are regarded as barriers of lower weight. The invasiveness of black locust was not discussed during the workshop (no predefined card "invasiveness" was available), but the issue is discussed in the SEEMLA project Deliverable D4.3 "Final report on environmental assessment covering LCA & LC-EIA" (Rettenmaier et al., 2018). The report emphasizes that the spread of black locust to adjacent areas needs to be prevented. If a spread to adjacent forests can't be guaranteed, then it is recommended to use other tree species. Hence, the invasiveness could be a barrier for growing black locust on marginal land.

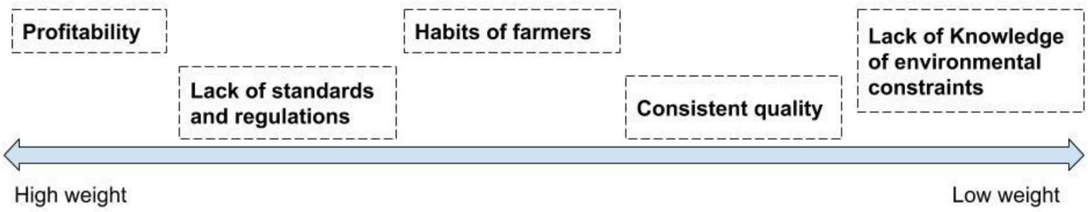

Figure 5: Barriers for implementation of black locust SRC on marginal land.

Social acceptance

Workshop participants expected positive environmental effects from cropping black locust SRC on marginal land. Hence, social acceptance was also assumed to be high, if the public judges environmental aspects to have high priority (environmental values). Shared benefits as increased job opportunities also were expected to lead to high social acceptance of established black locust SRC. In contrast, competing interest and lack of knowledge about this cropping system were expected to lead to low social acceptance.

Figure 6: Social acceptance after implementation of black locust SRC on marginal land.

2.2.2. FORBIO

The discussed study case during the workshop was **willow SRC cropping on degraded former agricultural land** in the Ivankiv region of Ukraine. Soil degradation was due to intensification of agriculture in this area after withdrawal of large areas from agricultural production after the Chernobyl disaster. The land was abandoned 15 years before the SRC establishment because of unsatisfying soil conditions and bad economic conditions in the region. The study fields were part of an industrial production of biomass.

Cost impact

In contrast to black locust, irrigation water costs bear the highest impact on total production costs of willow SRC biomass from marginal land in the Ukraine. This difference is most probably rather related to regional differences of the environmental setting than to differences of the crop. Initial investments in training and capacity development are also considered to have relative high impact on final costs. As for black locust, annual incurring costs for land rental, pesticides and herbicides, permissions, fossil fuel, and seeds/saplings have less impact on total production costs.

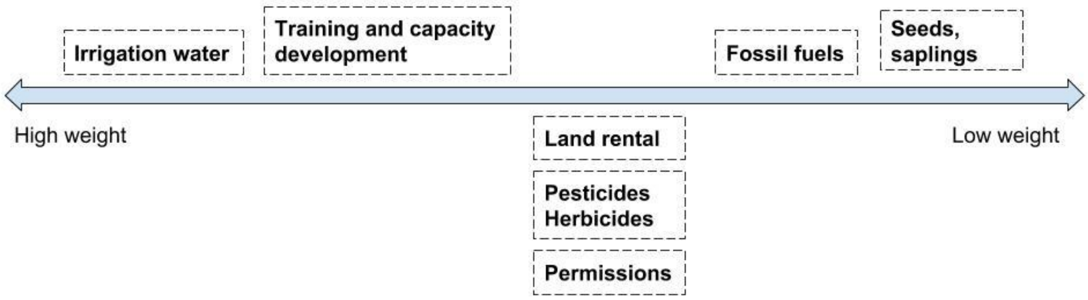

Figure 7: Cost impacts on willow SRC cropping on marginal land.

Environmental impact

As initial soil quality can be expected to be higher for this willow example than for SEEMLAs black locust example, the positive impact on soil organic matter, soil fertility, and soil quality was weaker . Instead soil erosion prevention was the most relevant positive effect for this study case. A very high positive environmental effect compared to common agricultural use (e.g. wheat cropping) can be expected for biodiversity as no pesticides are applied and herbicides are only applied before planting and during the first year of growth. No major negative environmental effects have been identified for willow cropping on marginal land.

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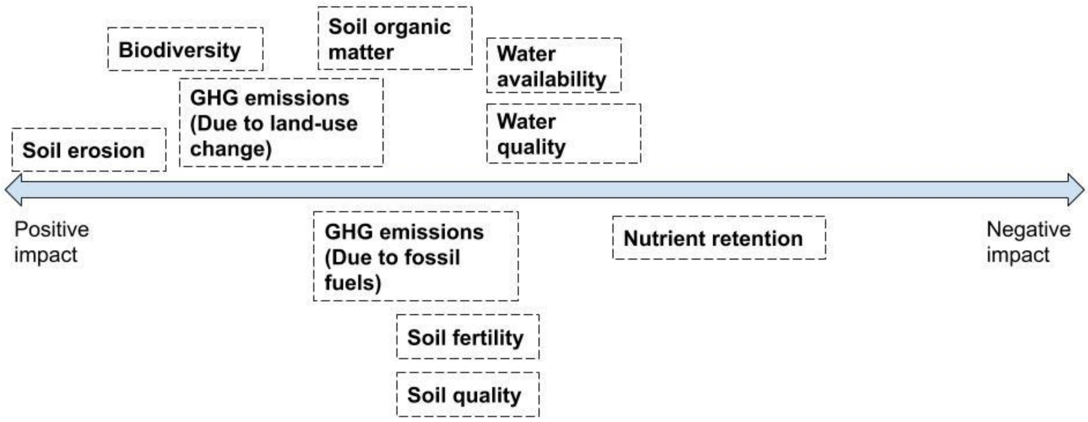

Figure 8: Environmental impact on willow SRC cropping on marginal land.

Barriers

The cost of produced biomass is regarded to be the most striking barrier for growing willow on marginal land followed by the lack of standards and regulation for cropping willow on abandoned arable land. Also required investments, habits of farmers and low profitability hamper willow SRC establishment on marginal land. As for black locust, also for willow SRC the lack of knowledge regarding environmental constraints and consistent quality of the biomass are regarded only as low weight barriers. Such an environmental constraint could be water availability.

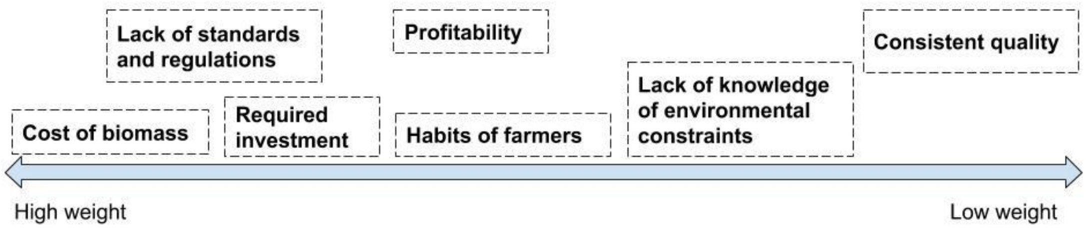

Figure 9: Barriers for implementation of willow SRC cropping on marginal land.

Social acceptance

As for black locust, environmental values (positive environmental effects) are expected to have a higher positive impact on social acceptance of willow SRC cropping on marginal land than shared benefits and costs. The highest impact on social acceptance is, however, related to the lack of knowledge about this type of land use. Land ownership and competing interests were regarded to have low weight on social acceptance of willow cropping, but again this might be rather an effect of regional setting than of the respective crop.

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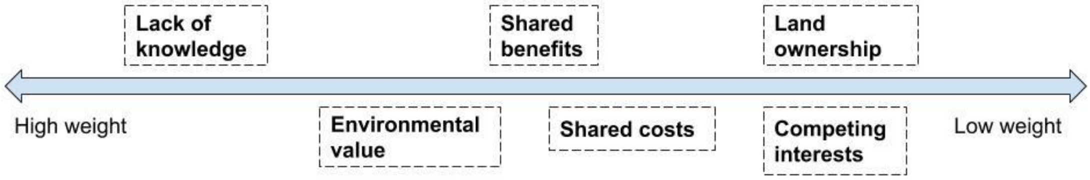

Figure 10: Social acceptance after implementation willow SRC cropping on marginal land. In contrast to the poster, the weight on acceptance instead of the level of acceptance (high and low) was assessed.

2.2.3. LIBBIO

This workshop example suggested **Andes lupine cropping in Europe as a new species with multiple potential uses**. Study sites were established in different European countries. No particular country was selected for the study case discussion during the workshop. This group didn't use the predefined attributes of table 1, but attributes were selected according to the discussion of this study case.

Cost impact

High positive impacts on the Andes lupine biomass production costs are expected to result from the multipurpose use of the crop and the possibility to use part of it for high added value products. But also for this case, biomass production costs are always yield dependent. This is due to relative constant fixed costs per hectare and, therefore, costs per tonne of biomass decrease with increasing yields.

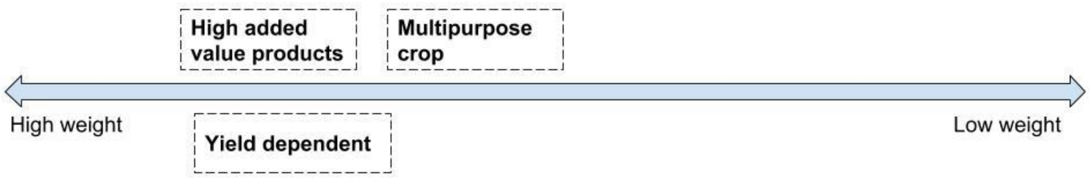

Figure 11: Cost impact on Andes Lupine cropping in Europe.

Environmental impact

The main innovation of this study case is the selection of a new crop to be grown in Europe. Nevertheless, the project also studies the feasibility of Andes lupine cropping on marginal low fertility land. Therefore, the symbiotically N_2-fixing plant is expected to have a positive impact on soil fertility and consequently also on soil organic matter content. The crop cover is expected to prevent soil erosion efficiently. The risk of this new plant being invasive might be considered a negative environmental impact, but further research is needed in order to confirm this concern.

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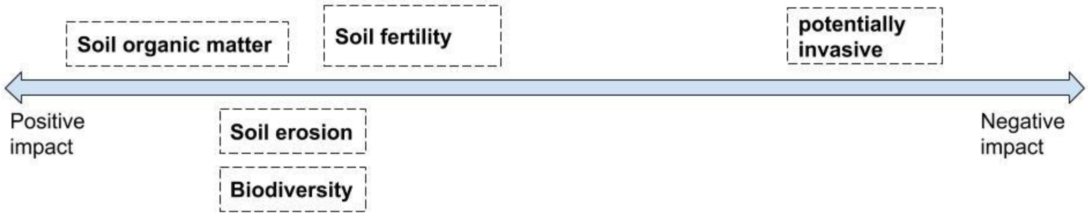

Figure 12: Environmental impacts of Andes Lupine cropping in Europe.

Barriers

The major barrier of introducing Andes lupine cropping in Europe is the fact that it is a novel food and feed to which neither farmers nor consumers are used to. For farmers this might include the factor "lack of knowledge of environmental constraints" mentioned by the other examples. But not only the consumer habits, but also the consumer protection was regarded as a high weight barrier. New species not endemic to the EU need to be added to the EU variety list and need to follow the Nagoya protocol (on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization to the Convention on Biological Diversity; https://www.cbd.int/abs/about/default.shtml/), but these are considered to be medium and low weight barriers for Andes lupine cropping in Europe.

Figure 13: Barriers for implementation of Andes Lupine cropping in Europe.

Social acceptance

In our workshop the most important factor for high social acceptance of Andes lupine cropping in Europe was the degree of naturalness of the end-products. The prime example is the preference of consumers to use lipsticks made by biobased lupine oil instead of mineral oil. The consumer acceptance also depends on the existence of concrete results regarding crop uses and how its cultivation impacts the environment.

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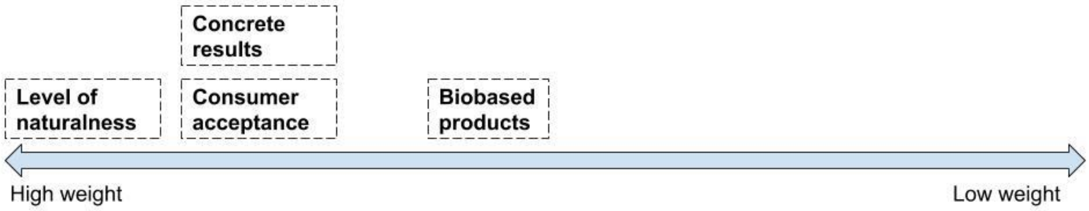

Figure 14: Factors influencing social acceptance after implementation of Andes Lupine cropping in Europe. In contrast to the poster, the weight on acceptance instead of the level of acceptance (high and low) was assessed.

2.2.4. BECOOL

BECOOL was only running since year by the workshop time and no final results were available yet. The project established **rotational cropping study sites with lignocellulosic crops** (sunn hemp, hemp, kenaf, and fiber sorghum) **after maize on agricultural land** in Italy, Spain and Greece. The case studies discussed during the workshop were fiber sorghum and hemp grown in rotation with maize or wheat in Italy.

Cost impact

The main additional cost that occur in rotational cropping with lignocellulosic crops as winter crops are those related to training and capacity development. This also includes the search of information on best practices and regulations. While fossil fuel has a high impact on increasing the costs, the availability of funds is regarded to have a high potential to reduce costs. Variable costs for irrigation water and pesticides are also regarded to have a relative high impact on biomass production costs. Additional work force is expected to have a lower impact for this example in Southern Europe.

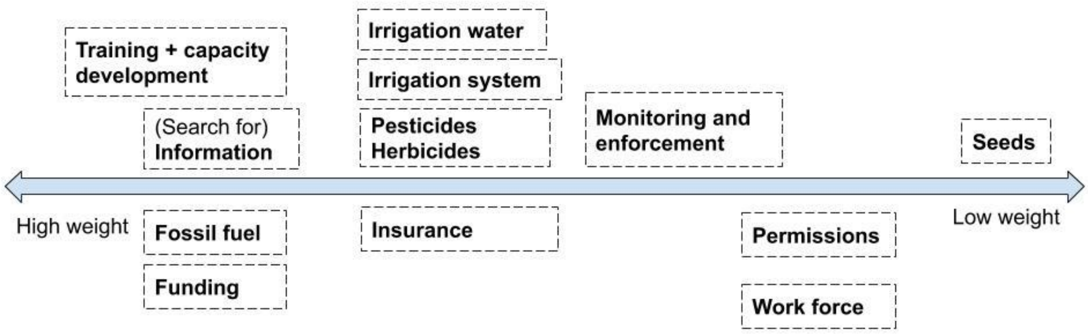

Figure 15: Cost impact of growing lignocellulosic biomass in crop rotation.

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Environmental impact

A slight positive impact of growing a lignocellulosic crop in winter in rotation with maize or wheat was attributed to nutrient retention and soil fertility. Compared to cropping on marginal land with degraded soil, however, the environmental impacts of this example are perceived to be rather on the negative impact side. The greatest negative environmental impact was expected to result from GHG emissions due to additional fossil fuel needed for seeding, crop management and harvest.

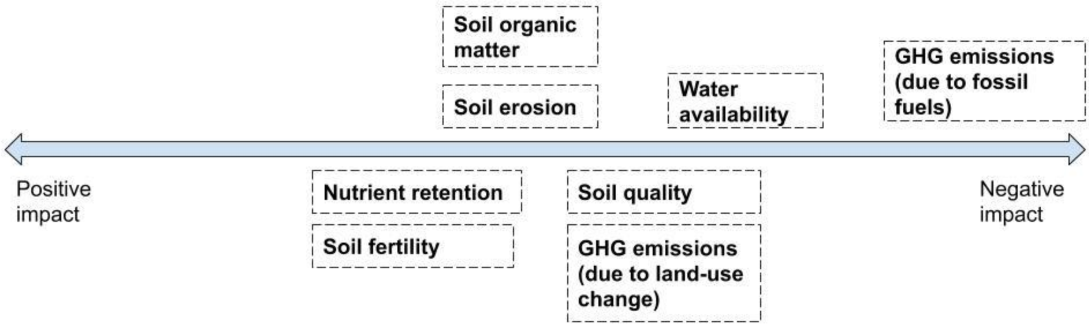

Figure 16: Environmental impact of growing lignocellulosic biomass in crop rotation.

Barriers

In contrast to cropping on marginal land, lack of standard and regulations is not relevant for rotational cropping with the selected lignocellulosic crops. Instead biophysical constraints (e.g. the length of the vegetation period), the lack of knowledge about environmental constraints and the lack of market are high weight barriers. Another barrier that hampers quick and large scale implementation of growing lignocellulosic biomass in crop rotation is the tendency attaching to traditional cultivation practices. In addition, require investments and biomass production costs lead to low profitability.

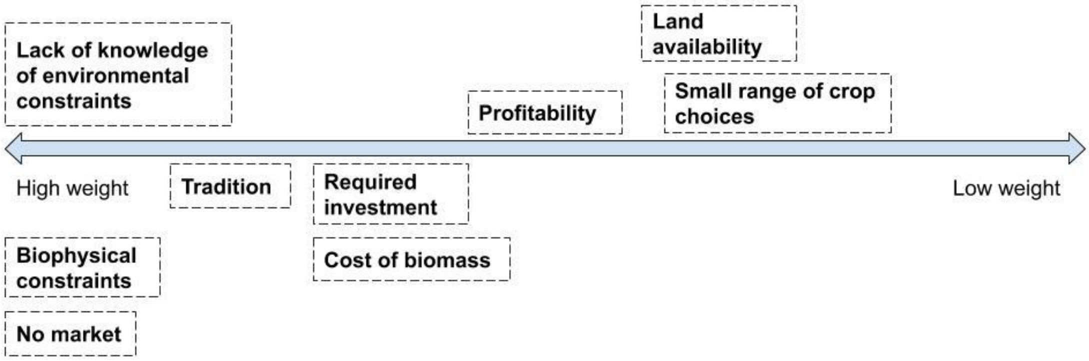

Figure 17: Barriers for implementation of growing lignocellulosic biomass in crop rotation.

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Social acceptance

As pointed out during the workshop, high acceptance of crop rotation with lignocellulosic crops can be achieved via shared benefits and environmental values since crop rotation with sorghum and hemp has the potential to improve soil quality and reduce the input of plant protection products (Annevelink et al., 2018). In contrast, the following factors were identified that lead to low social acceptance: competing interests, shared costs, and the lack of stakeholder awareness of this innovative cropping scheme and its benefits. Crop rotation competes with the interest of maximum yield of the main crop. If the main crop yields are not affected directly by crop rotation with lignocellulosic crops or indirectly by changes in soil quality, then the social acceptance should be high as additional products are being produced.

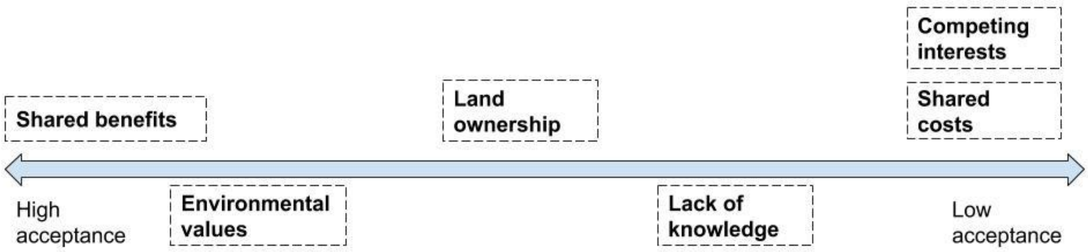

Figure 18: Social acceptance after implementation of growing lignocellulosic biomass in crop rotation.

2.2.5. MAGIC & GRACE

The projects MAGIC and GRACE had only completed the first year of their project duration and, hence, documented results were still not available at the time of the workshop. Both projects have case studies on **miscanthus cropping on marginal land** in altogether seven European countries. Part of this case studies were performed on degraded land.

Cost impact

In contrast to all other examples, for miscanthus the highest impact on biomass production costs results from rhizome costs as rhizomes are much more expensive than seeds. The search for information about best practices and insurance are expected to have relative high impact on the costs as well. As miscanthus cropping is not very widespread today, the impact of training and capacity development on total costs is still regarded to be relevant. If irrigation is needed, this can have a higher impact on total costs compared to other variable costs as pesticides, herbicides, fossil fuel and work force.

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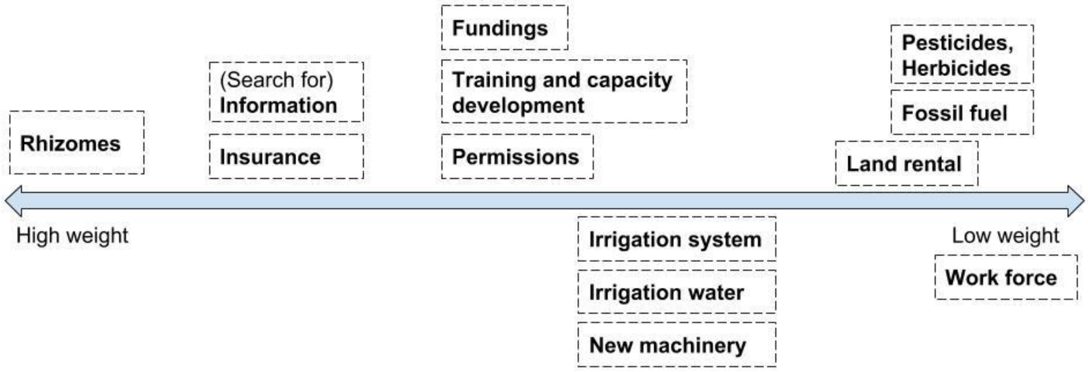

Figure 19: Cost impact of miscanthus cultivation on marginal land.

Environmental impact

Miscanthus cultivation on marginal land is regarded to have very positive effects on reducing soil erosion and, hence, overall stabilization of soil quality. This is consistence with the potential of this land use to increase soil organic matter and soil fertility. The effect on GHG emissions reduction due to substitution of fossil fuel was regarded to be quite high. This positive effect was, however, expected to be lowered by negative effects on GHG emissions due to land-use change.

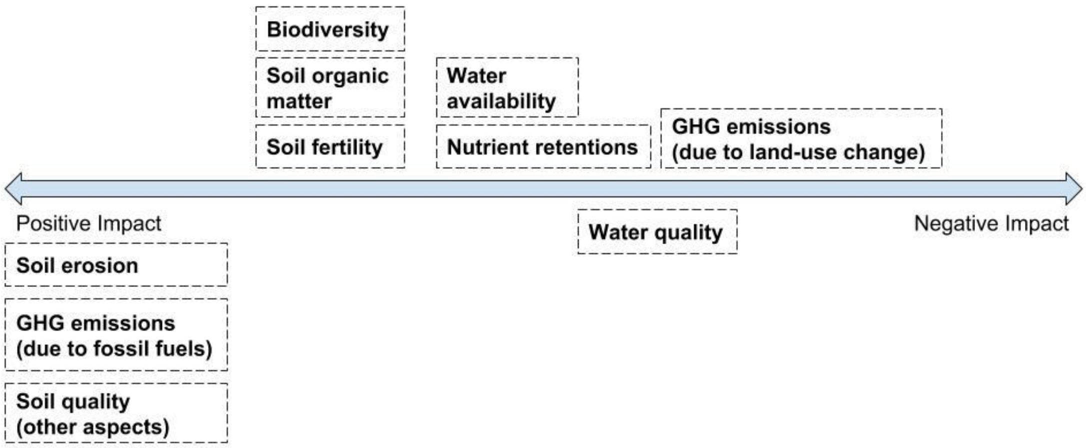

Figure 20: Environmental impact of miscanthus cultivation on marginal land.

Barriers

The main reasons for low adoption rates among farmers are the high investments needed for miscanthus establishment and a lack of knowledge related to environmental constraints. Such an environmental constraint could be frost resistance. The habits of farmers (traditions) and the high production cost of this feedstock hampers farmers to cultivate miscanthus on marginal land. The lack of standards and regulations and the profitability are regarded to be me-

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dium weight barriers. As for SRC on marginal land, the quality consistency of the produced biomass is rather perceived as a low weight barrier.

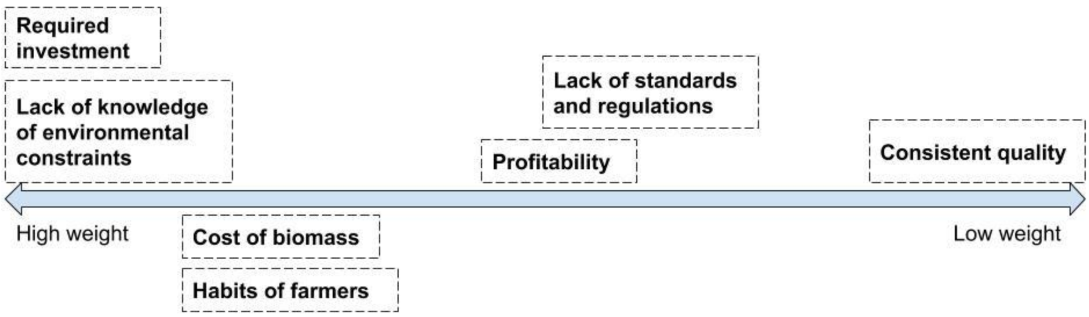

Figure 21: Barriers for implementation of miscanthus cultivation on marginal land.

Social acceptance

For the presented example, shared costs and benefits lead to highest impacts on social acceptance. While shared benefits increase social acceptance, shared costs, e.g. increased traffic of heavy vehicles, rather lead to rejection of this cropping alternative on marginal land. Land ownership and environmental values can also have a negative effect on social acceptance. During the workshop it was pointed out that large scale miscanthus fields can be perceived as huge walls (2 m high), which have the potential to significantly change the appearance of landscapes. In analogy, the media reported about the "cornification of arable land" as maize cultivation increased significantly due to biogas subsidies. Competing interests and lack of knowledge are regarded to have a lesser impact on social acceptance of miscanthus cropping on marginal land.

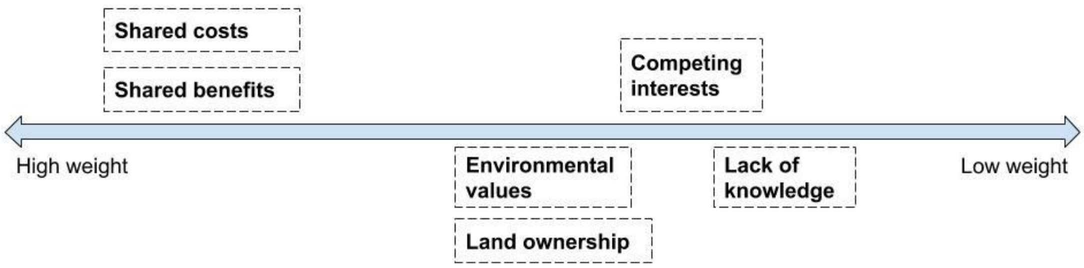

Figure 22: Social acceptance after implementation of miscanthus cultivation on marginal land. In contrast to the poster, the weight on acceptance instead of the level of acceptance (high and low) was assessed.

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3. Fields of innovation for lignocellulosic cropping

The innovation potential for feedstock production has been assessed for biomass from agriculture, forestry, waste and aquatic biomass by Baker et al. (Baker et al., 2017) with the aim to assess the research and innovation potential towards sustainable and low cost biomass availability. Complementary to this wide scope, our report focused on innovations that are related to dedicated crops and harvesting of lignocellulosic biomass. Innovations related to the supply chain beyond the field gate will be presented in the Deliverable 2.3, "Technology roadmaps and upgrading strategies for lignocellulosic feedstock supply chains".

Some innovative cropping schemes were presented during the workshop. In the following subsections, these schemes and other identified innovations related to lignocellulosic biomass cultivation and harvesting will be described from technical, environmental, economic and social perspectives. This description is based on examples found in the literature.

3.1. Agricultural management

Studies show that the first step of agricultural management is to choose suitable crops. This is followed by the operational management that includes water management, tillage and land preparation, liming and acidity control, fertiliser use, crop protection and harvesting.

3.1.1. Optimisation of planting density

One example of the improvement of agricultural management is the optimisation of planting density. The threefold increase in miscanthus planting density for an experimental site in Poland doubled yields (Borkowska and Molas, 2013). The value of gained yield exceeded the additional production costs, so that miscanthus production costs could be decreased by 7% (Borkowska and Molas, 2013).

3.1.2. Crop establishment improvements

Most of these management items have different effects on annualized costs for annual compared to perennial crops. Lignocellulosic perennial energy crops as miscanthus, switchgrass, giant reed or SRC only need to be planted once in 10 to 20 years. Therefore, the effect of improvements in crop establishment depends on the crops lifespan and the share of establishment costs compared to total production costs. This share of establishment costs was reported to be 2% for switchgrass, 11% for giant reed, 12% for miscanthus (Soldatos, 2015), and

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24% (median of several studies) for short rotation coppices (Hauk et al., 2014). Therefore, there is only little potential to reduce total production costs by improving establishment of switchgrass compared to giant reed, miscanthus and SRC. Such improvements of crop establishment can be related e.g. to reduced tillage, land preparation, liming and planting and after planting herbicide application and fertilisation. In contrast, water management (irrigation), pest control and in some cases fertilisation, generate production costs every year (e.g.- for giant reed on marginal land: fertiliser 13%, irrigation 20%, herbicide 2% (Soldatos, 2015)).

3.1.3. Fertilisation

While some studies show, that fertilisation is only needed during crop establishment, other studies report repeated fertilisation during the plantation lifespan (Felten et al., 2013; Heller et al., 2003). The frequency of fertilisation during the crop lifespan has a significant impact on total GHG emissions. For miscanthus, it was estimated that 67% of total GHG emissions were related to sewage sludge fertilisation (Felten et al., 2013). This estimation includes the emission of N_2O from soil of the fertilized fields. When sewage sludge is applied as fertiliser, adequate risk management strategies are needed to avoid health risks including a periodic monitoring of soil and crop properties (Maaß and Grundmann, 2018). Therefore, Maaß and Grundmann (2018) suggested that a proposal of EU common wastewater reuse criteria are needed.

Synthetic fertilisation of willow SRC accounted for 37% of total energy input to this cropping system. If fertilisation is done with synthetic fertilisers, the upstream emissions from the production of fertiliser adds a great share to total cropping GHG emissions. Therefore, reducing or substituting synthetic fertiliser can result in important environmental improvements (Kern and Don, 2018). The replacement of synthetic fertiliser with biosolids for Miscanthus production resulted in a reduction of the global warming potential by 23–33% and of energy demand by 12–18% (Murphy et al., 2013). On the other hand the substitution also increases the acidification and eutrophication potential by 290–400% and 258–300%, respectively. That makes clear that a holistic approach is needed to evaluate such a practice. In general, second generation crops were found to emit 40% to >99% less N_2O than conventional annual crops (Don et al., 2012). In addition, the lack of tillage during the perennial crop lifespan compared to annual crops can lead to decreased GHG emissions and increase of SOC.

3.2. Breeding

Breeding aims among others at increasing biomass yields and quality (pulping characteristics, ethanol yield, etc.) or in improving plant propagation. The effort of breeding to increase yields is part of conventional land use intensification. In order to increase yields, breeding aims to e.g. increase the growth speed, the leaf area index, and leaf area duration. Higher yields contribute to improved utilization of resources (area, fertiliser, work force, etc.) a higher produc-

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tivity of inputs and consequently to a decrease of the biomass production costs and GHG-emissions per ton of biomass. One of the largest threats to sustainable energy crop production are yield losses by pests or diseases (Karp and Shield, 2008). Therefore, another objective of breeding is to increase resistance of energy crops in order to achieve the maximum possible annual yields. This is sometimes called "closing the yield gap", which relates to the difference of maximal possible (potential) yield and actual yield (Allwright and Taylor, 2016). Also the resistance to abiotic stresses such as water limitation is a very important breeding target in order to reduce senescing, losing leaf area, and avoid mortality. Increasing the resistance of energy crops can also lead to the expansion of energy crop production into marginal land, as more resistant plants are able to grow in less suitable conditions (Baker et al., 2017) or enable the introduction of new species, that are originally not fully adapted to grow in the EU (e.g. Andes Lupine, see LIBBIO project). Increasing the nutrient use efficiency by breeding can contribute to reduce the fertiliser amounts and, hence, to reduce the GHG-emissions of lignocellulosic energy crops.

Breeding that aims at increasing biomass quality might at the same time lead to yield decreases. Breeding decreased yields by more than 23-43% when pulping characteristics were improved (Leplé et al., 2007) and by 16-24% as ethanol yields were enhanced (Van Acker et al., 2014). The increase in ethanol yields per gram of dry wood were outweighed by the overall yield penalty (Van Acker et al., 2014). For later stages of the supply chain (transport, storage) however, a decrease of biomass amount without reducing the quality (ethanol yields per hectare) might still be advantageous.

The last major focus of breeding concerns improvements of plant propagation. The cheapest way of propagation is direct sowing by seed. As common clones are sterile, miscanthus is commonly propagated by vegetative reproduction using rhizomes. A relative big area is, however, required to cultivate miscanthus for rhizome production and harvesting below-ground rhizomes can account for 1,904-3,006 EUR/ha (Xue et al., 2015). Therefore, breeding efforts focus on the establishment of seed based miscanthus hybrids. Planting of seed based miscanthus can be done by seed-plugs that are first established in a glasshouse for 8 weeks, before they are planted in the field or by direct seed propagation (Clifton-Brown et al., 2017). Hastings at al. (2017) pointed out that at a minimum cut of one year regarding the breakeven point (breakeven points ranged between 3-6 years) is possible when establishing miscanthus through direct seeding or seed-based plugs instead of rhizome propagation. Propagation by seed-plugs has the additional advantage of reducing the establishment time by a year compared to rhizome based propagation (Clifton-Brown et al., 2017). According to the author group around Clifton-Brown (2017), most barriers for upscaling miscanthus cultivation have been removed and the method for hybrid seed production has been established. Seed based propagation has a large multiplication factor, which is a precondition of upscaling miscanthus cropping. In the next 20 years, focus is expected to be on establishment of seed-based plug propagation, while it is still not foreseeable if direct seeding will be possible and reasonable in

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future (Moritz Wagner, personal communication, March 2019). Direct seed sown propagation and seed-based plug propagation account for 900 GBP/ha and 1500 GBP/ha instead of 2000 GBP/ha for intensive rhizome establishment (Hastings et al., 2017). The establishment of aboveground stem-segments costs 810 EUR/ha instead of 1703 EUR/ha by rhizomes (O'Loughlin et al., 2018).

The effect on GHG-emissions for the different propagation technics still needs to be studied and assessed and compared in future studies. Currently two Horizon 2020 projects are dealing with innovations to miscanthus cropping. While the GRACE project focuses on the upscaling of Miscanthus cropping, the MAGIC project focuses on cropping on marginal land with miscanthus and other lignocellulosic energy crops.

3.3. Crop selection

Crop selection might focus on cultivar selection of already used species and hybrid species or on selection of new species. The precondition of hybrid selection is the availability of a range of hybrids that resulted from previous breeding efforts (see sec. 3.4). The selection of adapted cultivars is part of learning process for farmers resulting in steady average yield increases on a regional scale and, hence, biomass production cost reduction. The learning process might be accelerated by compiling trial results from different crops including detailed information on selected species and hybrids, on agricultural management and on site characteristics. For instance, in a former mining area in Spain it was found that willow biomass yield can range from 1.3 to 8.6 tonnes DM/ha between genotypes (Castaño-Díaz, María et al., 2018). The water and nutrient use efficiency also varies between genotypes (Bloemen et al., 2017; Toillon et al., 2016). A comparison of 56 poplar genotypes for their yield, nitrogen-use efficiency and nitrogen export rate revealed that the studied parameters vary widely between studied genotypes. The genotypes with relative efficient nitrogen use were also responsible for the highest nitrogen exports during harvest, which is not desirable (Toillon et al., 2016). Therefore, contradicting interests related to yield maximization and nutrient retention in the soil needed to be considered before crop genotype selection.
Crop selection of new species includes the selection of endemic species and of newly introduced species from other parts of the world. An example is the suggestion to grow birch in short rotation coppices on marginal land in Belgium, as after 4 years of growth birch was found to be well adapted to grow on marginal land compared to poplar and willow (Vande Walle et al., 2007). While yields from birch are lower than for poplar and willow, birch plantations are established by sowing instead of planting and rotation cycles are longer. This leads to lower costs over the plantation lifespan, but the cost effectiveness has not been assessed yet (Vande Walle et al., 2007).

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The introduction of new exotic species in Europe, in contrast, is more complex. Beside the agronomic and economic feasibility, new species need to be registered to the plant variety catalogue as a precondition for the certification of seeds and the Nagoya protocol needs to be implemented. From the environmental perspective it is important to assess both, potential environmental positive impacts as increased belowground carbon sequestration, but also possible negative impacts of new species (e.g. invasiveness). An example is the use of Andes Lupine in Europe for biomass production, which is studied on industrial scale in the Horizon 2020 project LIBBIO. The acceptance of new species in society can be related to the perception of its potential impacts, positive and negative, by different actors. Main concerns are related to the uncontrolled propagation of new species and cultivation in monocultures that may lead to the displacement of endemic species (Jørgensen, 2011; Vítková et al., 2017).

3.4. Crop rotation

Growing lignocellulosic energy crops as catch crop in crop rotation system can be regarded as "temporal intensification of land use". Only annual lignocellulosic energy crops as sorghum, hemp, kenaf, and sun hemp can be used for common crop rotations. Traditional food crops that are used as dedicated energy crops fit well in conventional crop rotations, but little knowledge exists on the management of new lignocellulosic energy crops as mentioned above (Zegada-Lizarazu and Monti, 2011). The cost reduction potential of growing lignocellulosic energy crops in crop rotation needs to consider cost impacts on both crops grown in rotation rather than the energy crop only. This is because crop rotation can reduce soil erosion and improve soil quality and it has the potential to reduce external input through nutrient recycling, maintain productivity, avoid pest accumulation associated with monoculture as summarized by Zegada-Lizarazu and Monti (2011). All these factors can lead to yield increase of the main crop and, hence, cost and GHG-emission reductions on annual field level in addition to savings related to reduced inputs. It is also possible that both crops are used for bioenergy production, e.g. because the field is very close to the conversion plant. BECOOL pointed at the fact that farmers are simply not used to grow two crops per year. However, some farmers already added a second crop per field and year to their crop rotation which they mulch in order to maintain the soil organic carbon balance. One promoted solution to maintain soil organic carbon and harvest the catch crop for advanced fuel production comes from research on energetic utilization of straw, the so-called "sustainable limits of crop residual harvest" (Searle and Bitnere, n.d.; Zhao et al., 2015). This approach ensures that the straw amount needed to maintain the soil organic balance remains on the fields, while only the rest is used for bioenergy. Furthermore, sequential cropping might lead to yield decreases of the main crop if the duration of cultivation of this crop is reduced, but total biomass production on the field is increased if a second crop is cultivated in the winter in addition to the main crop. This has been

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reported for rotational cropping of maize and triticale versus mono-cropping of maize for biogas production in Italy by Peters et al. (2016).
Another positive environmental effect of crop rotation is that it can increase the belowground microbial diversity with positive effects on soil organic matter and soil fertility (Tiemann et al., 2015). In order to describe and quantify the beneficial effect of growing lignocellulosic energy crops in crop rotational systems the Horizon 2020 project BECOOL established several trials in Italy, Spain and Greece. Results from these trials are, however, not available yet.

3.5. Intercropping

The main impacts of intercropping documented in the literature include the reduction of negative environmental effects (erosion, leaching) and the reduction of synthetic nitrogen fertiliser usage in order to decrease the global warming potential, but biomass yield increases were not always observed. For instance, intercropping of poplar SRC with a legume had no effect on yield compared to poplar monoculture, but the intercropping plantation had higher soil NO_3 content due to the legume and higher soil water content as the mulch of cut cover crops decreased evaporation from soil (Silvestri et al., 2018). In addition, the intercropping of SRC was weed free at the first harvest and N content of poplar wood was higher. During the second rotation the poplar canopy closed quickly, however, so that the cover crop did not thrive again. Positive environmental effects and cost savings of reducing synthetic fertiliser are still to be compared to the negative effects of increased fuel consumption and soil compaction during seeding and later mulching. This comparison gets even more complex if the effect of intercropping on soil organic carbon is assessed. Tree-based intercropping in Ontario Canada assessed the effect of willow SRC in-between rows of old established willow trees compared to willow SRC monoculture (Cardinael et al., 2012). SRC intercropping led to higher soil organic carbon content and a yield increase of 17% compared to SRC monoculture. The underlying yield of intercropping SRC was, however, only related to the area of SRC but not of the rows of old trees. In regard to social acceptance, woody crops in an agricultural landscape mainly faced positive reactions. Part of the population is, however, still sceptical towards SRC. This scepticism can be overcome by taking social preferences into consideration and by an open information policy in the respective region (Reppin and Augenstein, 2018). Intercropping trials have also been performed for lignocellulosic grasses. In a switchgrass and legume intercropping systems Ashworth et al. (2015) determined environmental effects of displacing synthetic-N with legumes in the USA. They found that legume intercropping could reduce the global warming potential by 5% and reduce groundwater acidification by 27%. This option of feedstock production still requires energy based input. According to the authors the aim should be to optimize management and synthetic fertiliser usage. It had been shown before, that the economically breakeven point of fertiliser application for switchgrass is 67 kg N/ha, indicating

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that higher applications are economically not reasonable (Mooney et al., 2009). Another study compared intercropping of sorghum and Andes lupine with sorghum monocropping (Busch et al., 2018). While under optimal conditions concerning water and nutrient supply the monocropping resulted in better yields, deficiency of water, P and N supply resulted in no significant yield differences between treatments. Therefore, intercropping might be a promising option to reduce synthetic fertiliser usage and increase soil quality when cropping on marginal land. This may also have a positive effect on the balance of GHG emissions of such cropping systems.

3.6. Multi-purpose cropping

Multi-purpose cropping can refer to the use of different parts of one crop for different purposes or it can point to the production of a crop and at the same time avoid negative or generate positive environmental effects. The use of crop residues for bioenergy was the focus of the Horizon 2020 project S2Biom, where cost supply curves and biomass potentials have been compiled for all EU28 countries, Western Balkans, Moldova, Turkey and Ukraine. Orr et al. (2015) suggested that dual-purpose sorghum (food and energy) provides a promising alternative to continuous maize cropping with respect to soil health indicators. The Horizon 2020 project BECOOL is currently performing trials with sorghum and kenaf as dual-purpose crops.

The irrigation of energy crops with wastewater is another aspect of multi-purpose cropping. It has been shown that growing willow SRC on wastewater irrigated fields in Estonia could reduce N and P concentrations efficiently (Holm and Heinsoo, 2013). At the same time the irrigation with wastewater increased wood yield by 41%. In an economic assessment the cost reduction potential for biomass production in willow SRC by irrigation with wastewater or by adding sewage sludge was calculated (Dimitriou and Rosenqvist, 2011). With the wastewater irrigation biomass production cost reduction potentials of 25% and 30% were estimated for Sweden and Southern European countries, respectively. The cost reduction potential was based on estimated yield increase of 30% and 60% for Sweden and Southern Europe. Yield increases were expected to be higher for Southern European countries where water is a clear limiting factor. Irrigation with wastewater was also tested for perennial grasses. While perennial grasses can also effectively remove nutrients from wastewater, no yield increases were found for Arundo donax in Italy or switchgrass in Southwest USA when irrigated with wastewater compared to freshwater (Ganjegunte et al., 2017; Zema et al., 2012). The same is valid for urban wastewater irrigation compared to drainage water irrigation for giant reed in Italy (Borin et al., 2013). In practice, however, the use of wastewater has environmental and social concerns due to harmful substances, which need to be addressed when designing and managing such systems (Barbosa et al., 2015).

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The second purpose in addition to biomass production can also be the purification of soil water from agricultural fields and ditches to mitigate groundwater N pollution. Bioenergy buffer strips planted along ditches of an agricultural field in Italy removed mineral N efficiently and willow performed better than miscanthus (Ferrarini et al., 2017). The cultivation of willow SRC in Central Illinois (USA) was found to be unlikely to provide positive revenues because of high land rental costs, but as a conservation practice cost per unit of N removed at a watershed scale, the net cost were comparable to other conservation practices (Ssegane et al., 2016).

Phytoremediation, that is the efficient use of plants to remove, detoxify ofr immobilise environmental contaminates, can also be a secondary purpose of growing energy crops. In a review study, Pandey et al. (2016) concluded, that linking phytoremediation with energy crops is a feasible and sustainable approach for economic return during remediation of contaminated land. The authors, however, also point out, that the fate of the accumulate pollutants should be studied before using the biomass for various aspects to ensure the sustainability of this approach.

3.7. Cropping on marginal land

Dedicated cropping for biomass feedstock on marginal land in Europe can be regarded as "spatial intensification of land use". In ADVANCEFUEL Deliverable 1.3, "Marginal land" was defined as, "Land on which cost-effective food and feed production is not possible under given site conditions and cultivation techniques" (Wicke, 2011). Currently, there is no standardised or generally accepted definition of marginal land in the EU, which hampers the comparison of general findings between different studies performed on marginal land. In addition, the reasons for marginality can be very diverse: land unsuitable for food production; ambiguous lower quality land; or economically marginal land (Shortall, 2013).

Wagner et al. (2019) assesses the economic feasibility of miscanthus cultivation on marginal land for biogas production and comes to the conclusion that profitability can indeed be achieved depending on the individual case. But, the authors identified the biomass yield as the limiting factor of the economic attractiveness of cultivating miscanthus on marginal land, which is in line with previous studies (LfULG, 2014; Searle and Malins, 2014; Soldatos, 2015). Yields of at least 11 tonnes DM/ha are necessary to be economically competitive to maize silage. Biomass production costs per tonne depend very much on the achieved yields per hectare, which depends on the reason for marginality. Yields from some relative fertile marginal land can equal that of agricultural land. This was, for example, the case for willow SRC on abandoned farmland in Canada (Labrecque and Teodorescu, 2003) or for grass on very dry sites or sites prone to flooding compared to the control site in Ireland (Meehan et al., 2017). But in general yields are lower on poor-quality marginal land compared to agricultural land (Searle and Malins, 2014). As agricultural land is primarily dedicated for food and feed pro-

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duction, cost estimates need to be based on energy crop yields found for commercial scale fields on unused marginal land. Aylott et al. (2010) successfully developed a GIS-based modelling approach for making informed decisions for the identification of economic suitable and sustainable marginal sites for energy cropping. Another decision support tool for biomass selection on marginal land was developed and validated for diverse sites in France, Romania and Sweden (Andersson-Sköld et al., 2014). There is however no assessment on the biomass production cost reduction potential by using these systems.

Positive environmental effects of biomass cropping on marginal land are associated in relation to soil organic carbon (SOC), biodiversity, soil erosion, or soil hydrologic characteristics. Wicke (2011), however, stated: "The proposition of using degraded and marginal land for bioenergy production is based on presumed positive social and environmental impacts." Several environment impacts of SRC of different clones (on agricultural land) depend mainly on their biomass yields (Bacenetti et al., 2016). For instance, SOC increases relative to the annual input amount of organic matter. Therefore, clones with higher yield have a higher potential to increase SOC. Correspondingly, degraded land with low SOC content has also a relative high potential for SOC increases through dedicated biomass cropping as reviewed by Blanco-Canqui (2010). Even though several studies mention the possibility to increase SOC by growing lignocellulosic energy crops, only few studies have assessed the effect in the field. Walter et al. (2015) sampled 21 SRCs in Europe and found that there is no general pattern of carbon sequestration in the soil. With an average SRC age of 18 years, most of these trials were probably not established on marginal sites. But sites for which the topsoil SOC content in cropland was low had higher SOC content changes from cropland to SRC and none of the sites with more than 51 tonnes C/ha in croplands showed increases of SOC from cropland to SRC (Figure 23). A positive example was reported for giant reed cultivation on marginal land prone to erosion in Italy with an increase of 13 tonnes C/ha within 8 years starting from a topsoil carbon content of 36 tonnes C/ha (Fagnano et al., 2015). But the existence of positive examples does not preclude that SOC increases through biomass cropping can be expected for all types of marginal land especially not for those with high initial topsoil carbon content.

Despite SOC increase also other positive environmental effects can result from growing lignocellulosic energy crops on degraded soils. For instance, the cultivation of switchgrass was recommended on degraded soils with impermeable surface or near-surface soil layers as it can enhance water infiltration, reduce surface runoff and decrease duration of saturated soil conditions compared to soybean as row crop treatment (Zaibon et al., 2017).

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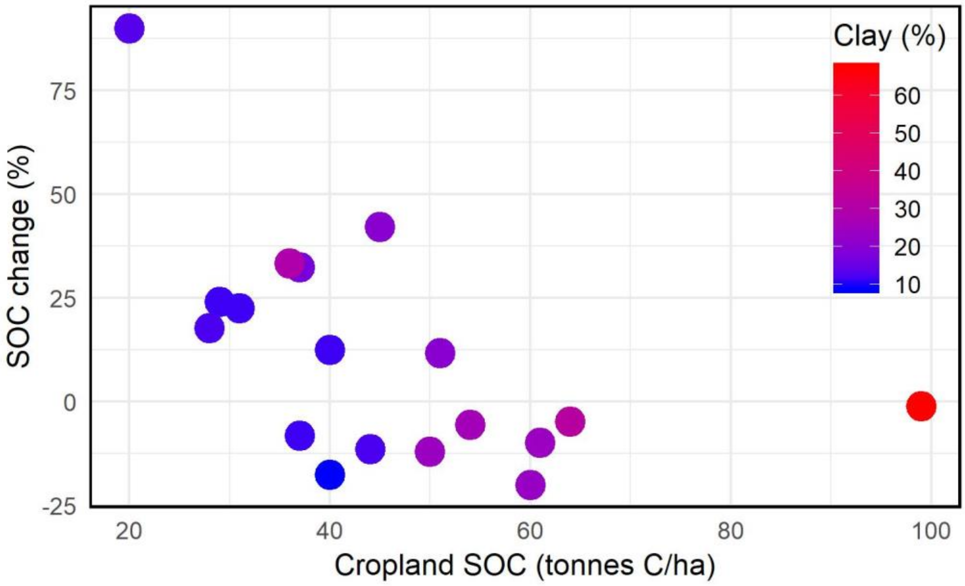

Figure 23: Soil organic carbon (SOC) changes in the topsoil of short rotation coppices in relation to SOC content of adjacent croplands, which is assumed to equal SOC content before SRC establishment. Cropland SOC depends on top soil clay content (data source: Walter et al. (2015)).

Negative environmental effects associated with biomass cropping on marginal land are related to fertiliser consumption. As degraded marginal soils are often depleted in plant essential nutrients, the feasibility of growing energy crops without or with minimal fertiliser input needs to be assessed. In particular N-fertiliser production is a major energy consumer in the agricultural sector and it accounts for one third of total energy input to crop production in the USA (Gellings, 2009). Hofmann-Schielle et al. (1999) tested SRC of poplar, willow, and aspen on former arable land, which was no marginal land. They found that only balsam poplar didn't need any fertilisation or herbicides. For a willow short rotation coppice trial in a former mining area in Northern Spain, fertilisation and weed control were found to be important management operations that are always necessary in marginal land of low soil fertility. Without fertilisation and weed control in the first two years of this willow trial over 80% less yield was obtained. A promising option in order to reduce or even to avoid fertiliser application is the selection of symbiotically N_2-fixing tree species such as black locust or alder. For a short rotation coppice of grey alder, it was found that after the fifth year 147 kg N/ha were accumulated in the top 20 cm soil layer (Uri et al., 2002). Biological N-fixation also contributed to the N-demand of miscanthus as revealed by a crop growth modelling study and verified by nitrogenase activity tests (Davis et al., 2010).

Cropping on marginal land can have a positive effect on biodiversity. For instance, weed biomass and invertebrate abundance were consistently greater for miscanthus and willow SRC compared to fallow land and cereal crop fields, respectively (Haughton et al., 2016). In contrast, Wagner et al. (2019) highlighted that "areas with high biodiversity or marginal sites that

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provide habitats for species worthy of protection should be excluded from biomass cultivation".

By using a yield prediction model and landscape planning data with detailed information on conservation values and land-use-related functional deficits, fields of one region in Germany were classified for their Miscanthus production suitability (Harvolk et al., 2014). The authors found that overall yields were not reduced when only suitable fields were selected for Miscanthus cultivation and that using 10% of the study area (or 50% of all suitable fields) for growing Miscanthus would provide thermal energy for 20% of all households (286 households) of this region.

3.8. Harvesting technology

Energy crops can be harvested by machinery for grain harvest and straw collection that are commonly part of farmer machinery pools. Depending on the machinery, this requires two to three passes for mulching, windrowing and baling. Substantial expansion of the area cropped with lignocellulosic energy crops and shared use of the machinery by neighbouring farmers will promote the production and use of specialized harvesting machinery as suggested for single-pass harvesting of giant reed and switchgrass (Martelli, Bentini, & Monti, 2015). The use of such machinery will reduce costs and GHG emissions due to reduced fuel consumption. Taking values of CO_2 eq. emissions of miscanthus production (Felten et al., 2013), the difference of single pass to double pass leads to differences of less than 1% of total emissions and fuel consumption during 16 years including all field establishment and management activities.

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4. Evaluation of innovative cropping

For the evaluation of innovative cropping fields, innovations will be compared from different perspectives: economic, environmental, and social. Wherever applicable, the field of innovation in which single innovations have been described in detail will be provided in **bold** font.

4.1. Biomass production costs

In D1.1 "Barriers to advanced liquid biofuels & renewable liquid fuels of non-biological origin", the lack of profitability in regard to the cultivation of dedicated crops is mentioned as one of various economic barriers in regard to feedstock supply. Key aspects of economically competitive lignocellulosic biomass are low production costs linked with high biomass yields. The selling prices are generally calculated to lay between 65-100 EUR/tonne DM (Hastings et al., 2017; Mergner et al., 2017; Soldatos, 2015; Styles et al., 2008). For the biomass producers one can assume that it is decisive to reach profit margins high enough to cover variable and fixed costs as well as to meet their profit expectations. Assuming constant prices for biomass, higher profit margins can be realized either by

1.) Decreased production costs, or
2.) Higher biomass yields, if production costs remain stable and costs per unit of biomass decline.

Selected innovative cropping schemes stated in chapter 3 have the ability to target both of these aspects. Production costs and yields have been documented in a number of studies focusing on sequential cropping (**crop rotation**) (Peters et al., 2016; Schievano et al., 2015), miscanthus cultivation (**breeding**) (Hastings et al., 2017; Lewandowski et al., 2016; Mergner et al., 2017; Styles et al., 2008) and willow cultivation (**cropping on marginal land)** (Mulè, 2017; Styles et al., 2008; Zheliezna et al., 2016).

To establish an economic perspective, this subchapter (1) discusses the importance of identifying leverage points for effective cost reduction, (2) discusses the role of multi-purposed crop rotation and market changes, (3) illustrates cost reduction potentials of selected innovations, (4) addresses the role of upscaling, and (5) gives an outlook of production cost reduction potentials until 2030 and 2050.

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Table 2: Lignocellulosic biomass production costs and yields of selected cases comparing cropping on arable and marginal land

Reference	Land type	Crop	Country	Yield (tonnes DM / ha*yr)	Production costs (EUR/tonne DM*yr)
(Soldatos, 2015)	Arable land	Giant reed	South Europe	25	46
(Soldatos, 2015)	Marginal land, but not specified	Giant reed	South Europe	16	54
(Soldatos, 2015)	Arable land	Switchgrass	South Europe	16	57
(Soldatos, 2015)	Marginal land, but not specified	Switchgrass	South Europe	9	63
(Soldatos, 2015)	Arable land	Miscanthus	South Europe	20	59
(Soldatos, 2015)	Marginal land, but not specified	Miscanthus	South Europe	13	65
(LfULG, 2014)	Arable land	Miscanthus	Methau, Germany	15	37
	Arable land	Miscanthus	Spröda, Germany	11	50
	Arable land	Miscanthus	Kalkreuth, Germany	20	27
	Arable land	Miscanthus	Roda, Germany	27	20
	Arable land	Miscanthus	Baruth, Germany	9	61
	Arable land	Miscanthus	Pommritz, Germany	14	39
	Arable land	Miscanthus	Average from six sites above	16	34
	Marginal land, post-mining	Miscanthus	Zwenkau, Germany	11	50

4.1.1. Importance of identifying leverage points (ValueLinks)

Leverage points are the spots in a supply chain, when accurately targeted, already minor twists can lead to major efficiency gains. Identifying these points is the entrance of developing improvement strategies (Springer-Heinze, 2008). One example for such a minor twist is the change of propagation practices, in the miscanthus example (**breeding**) we have shown that high establishment costs justify intensive innovation efforts, since the miscanthus establishment costs account for approximately 30% of total miscanthus production costs. It also needs to be considered that variables of production costs vary according to the country, region, and biophysical conditions. A study on giant reed, miscanthus, and switchgrass has shown that ir-

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rigation costs in the northern part of Mediterranean Europe are much lower while yields are exceeding the performance in the south. In the south of Mediterranean Europe, irrigation can account for 20% of total production costs, which makes cost reduction efforts worthwhile (Soldatos, 2015). Also the innovation of irrigation with sewage sludge (**multi-purpose crops**) generates the biggest effects on cost reduction where irrigation is an essential as well as costly part of production inputs (Dimitriou and Rosenqvist, 2011). The method performed in the second ADVANCEFUEL workshop (subchapter 2.2), illustrates one option how these leverage points can be identified. The cost impact attributes which were ranked by the participants to have a "high weight", also show the highest shares of production costs (Table 2) and, hence, represent the leverage points of the given examples. The closer the elements are to "low weight", the less efficient it gets to target them when developing cost reduction strategies.

Table 3: Leverage points that were ranked as having "high weight" impacts on biomass production cost during the ADVANCEFUEL workshop (subchapter 2.2).

Innovative cropping scheme	**Leverage points (High weight economic cost element)**
Crop rotation (BECOOL)	Fossil fuel, funding, land rental, training and capacity development, (search for) information
Willow SRC (FORBIO)	Irrigation water
Andean Lupine (LIBBIO)	Yield dependent
Miscanthus (MAGIC & GRACE)	Rhizomes
Robinia (SEEMLA)	New machinery, work force

However, it also needs to be considered that not all cost elements can be influenced by cost reduction strategies. For instance, regarding crop rotation cost elements actors do not have an influence on the fossil fuel price, funding, or land rental price. Thus, these aspects cannot be addressed by R&D, innovation, or business model efforts.

4.1.2. Flexibility - Advantage and disadvantage

Smart business models are often characterized by a high level of flexibility, which enables the farmer to react to changing external circumstances. These changing circumstances could be linked to bio-physical changes which require resilient crop management, or market price fluctuations. Annual *multi-purpose crops* enable the farmer to add certain flexibility to his marketing strategy, if he is not bound to a long-term contract. For instance in Italy farmers cultivate maize silage as fodder and add triticale as a catch crop to their crop rotation for biogas production. Both crops can be supplemented with one another for either feed or biogas feedstock (Peters et al., (2016). This flexibility due to the linkage of **crop rotation** and **multi-purpose crops** increases farmers' willingness to grow the respective crop, since the innovative approach promises additional revenues without the risk of lacking sufficient fodder units (Pe-

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ters et al., 2016). In contrast, SRC (**intercropping**) decrease farmers' flexibility, due to their long life span. There are two sides of the medal, when it comes to the flexibility of perennials. On the one hand, in years of low biomass market prices, the farmer can decide to postpone harvest to the following year. On the other hand, SRC require high upfront investments and are characterized by long return on investments (ROIs) (8 years; Zeller et al., 2009). Thus, in case of low profitability, it takes a long time for the farmer until his revenues break-even. For miscanthus cultivation on a former sewage field (hypothetical case calculated with marginal land potential of 1,140 ha; **marginal land**), a total investment of 684,480 EUR without VAT would be needed based on the calculation of a 10 years payback time (Mergner et al., 2017).

4.1.3. Cost reduction potentials of cropping innovations

In this report, economical attractive innovations are identified on the basis of the calculated biomass production cost reduction potentials (Table 4), and the reduced production costs through biomass yield increase (Table 5).The method being followed, in order to calculate cost reduction potentials are shown in Box 1.

Table 4: Biomass production cost reduction potentials [%] for different innovations (negative reduction = increase of costs).

Crop	Innovation					Other effect	
	Breeding (propagation by seeds)	Propagation by above-ground stem segments (not rhizomes)	Planting density increase by 3 times	Sewage sludge application	Cropping on marginal land	Upscaling	Learning effects
Miscanthus	7-16[1]	9[1]	7[1]		-11[4], -44[5]		
Switchgrass					-10[4]		
Willow SRC						10[3]	25[3]
Giant Reed					-17[4]		
SRC				7[2]			

Data source: [1] method described in Box 1 below[2] (Dimitriou and Rosenqvist, 2011) [3] Sweden (Rosenqvist et al., 2013) , [4] (Soldatos, 2015), [5] former mining site compared to average of 6 agricultural sites (LfULG, 2014)

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Box 1: *Method how cost reduction potentials of different options for miscanthus establishment and increased planting density* were calculated

*Miscanthus Propagation (**breeding and above-ground stem segments**):*

Total production costs of miscanthus were used from LfULG (2014) as presented in Table 4. These costs are listed separately for the different cost impact attributes (establishment, fertiliser, plant protection products, etc.). Hastings et al (2017) states an establishment cost reduction potential of seed-based plug propagation accounting for 25%, and direct sown seed propagation accounting for 55%. Consequently, this share was subtracted from the establishment costs in the LfULG data and the percentage of reduced total production costs (7-16%) was calculated. For the stem segment propagation, it was calculated using establishment costs of 810 EUR/ha, instead of 1703 EUR/ha for rhizome planting (O'Loughlin et al. 2018).

*Planting density (**agricultural management**)*

*Borkowska and Molas (2013) furthermore compared the economics of conventional planting density (10,000 plants/ha) with high planting densities (30,000 plants/ha). Conventional establishment costs of 3,232 EUR/ha*yr consequently grow up to 7,952 EUR/ha*yr. The calculated production costs potential of 7% results from the doubled yield amounts from 16.1 tonnes DM/ha to 32.5 tonnes DM/ha Borkowska and Molas (2013).*

Table 5: Yield change potentials [%] or expected changes (+: increase, -: decrease) for different innovations.

Crop	Innovation				Other effect	
	Breeding for yield increase	Breeding for quality increase	Irrigation with wastewater	Cropping on marginal compared to agricultural land	Cropping on large compared to small scale[3]	Learning effects
Miscanthus	+	-		-70[3], -37[5], -31[4]	-80	+
Switchgrass	+	-		-31[3], -42[4]	-74	50[6]
Willow SRC	+	-		0[3]	-38	+
Poplar SRC	+	-16-24, >-30[1]		-39[3]	-91	+
Giant Reed	+	-		-37[4]	-	+
SRC			25, 30[2]			

Data source: [1] 23-43% yield decrease when pulping characteristics were improved (Leplé et al., 2007) and 16-24% yield decrease as ethanol yields were enhanced (Van Acker et al., 2014) [2]calculated with a yield increase from 9 tonnes DM/ha up to12 tonnes DM/ha; increase from 9 tonnes DM/ha up to 15 tonnes DM/ha (Dimitriou and Rosenqvist, 2011), [3] changes of maximum yield; decrease from 44 to 13, from 13 to 9, and from 18 to 11 tonnes DM/ha for miscanthus, switchgrass and poplar, respectively, while for willow maximum yields were 15 tonnes DM/ha on marginal and agricultural land (Searle and Malins, 2014) , [4] changes of average yield as stated in Table 2 (Soldatos, 2015), [5] 11.1 tonnes DM/ha yield from former mining site compared to 16.1 tonnes DM/ha (average of 6 agricultural sites) (LfULG, 2014), [6] for study case in the USA, no yields given (Karp and Shield, 2008)

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In order to answer the question of the most economic attractive innovations, one could point at those with the highest cost reduction potentials (Table 4). However, due to the high number of influencing factors regarding those innovations, technological readiness levels (TRLs), and environmental complexity, no single innovation can be pointed out as the one solution which cuts costs under all circumstances and enhances the market roll-out of RESfuels. This study identified a few of those single innovations. For instance, focusing on miscanthus, planting density increase by three times (**agricultural management**) with a reduction cost potential of 7% seems promising, since their time scope does not lie in the far future as i.e. seed-based propagation. This innovation can already be implemented. Furthermore, the full influence of diffusion stays with the farmer, not with external factors like breeding progress. However, it cannot be considered as most promising compared to other solutions, because firstly so far only one relevant study by Borkowska and Molas (2013) has been found on this matter, and secondly we cannot guarantee that density increase by three times always generates the same cost reduction levels. The illustrated aboveground stem-based propagation cost reduction potentials of 9% are based on O'Loughlin et al. (2018) who finds stem-based propagation -originating from a rhizome-based generation- a cheaper alternative compared to rhizome-based propagation. In contrast, Xue et al. (2015) determine stem-derived propagation with total costs of 4,241 EUR/ha more expensive than planting accounting for 3,376 EUR/ha. Although seed-based propagation promises higher cost reduction potentials (7-16%), it is considered less favourable, since its implementation time-scope lies in the future (2050) and could lead to uncontrolled spreading of miscanthus seeds (Jørgensen, 2011). Another high ranked innovation with a cost reduction potential of 7% is irrigation with sewage sludge (**multi-purpose cropping**), which is partially dependent on the farmer's willingness to implement it and partially on the availability of the sludge, which is higher in urban areas. However, this innovation has a rather narrow geographical scope in the EU. Economies of scale was ranked low, since the expansion of willow SRC is not solely dependent on the farmers' willingness to adopt the crop, but also on political will and arising positive market trends.

Intercropping and **cropping on marginal land** (-44 to -10%) occur to be the least economical innovations irrespective of their time-frame or their dependence on internal or external factors. As mentioned in subchapter 3.7. "cropping on marginal land", the financial benefit also depends on the input level. Soldatos (2015) distinguishes between high (75 kg N/ha) and low (50 kg N/ha) inputs. Giant reed was most profitable on marginal land in combination with high inputs equal to 63 EUR/tonne DM. Higher inputs are not aligned with sustainable agricultural management practices. **Intercropping** was already introduced as a sustainability-driven approach, rather than a market price-driven one. When cropping two crops simultaneously on one piece of land, one crop most likely always promises higher revenues than the other. This means that space of a higher-value crop is being sacrificed for the other, for the sake of sustainability. A restructuring of EU subsidies and consequently the agricultural sector would make biodiversity-driven agriculture more lucrative, since price-driven agriculture leads

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to monocultures, as shown in the past. Di Lucia & Woods (2018) developed a landscape design approach which enhances multifunctionality and promotes sustainable outcomes. **Intercropping** and **crop rotation,** however, both have the potential to decrease fertiliser inputs per produced crop unit. The results need to be embedded into their context: After reducing production costs via implementing an innovation, some crops might still be more expensive than their alternatives. Focusing on Table 2, compared to giant reed and switchgrass, miscanthus entails the highest production costs (Soldatos, 2015). However, even if an estimation of a 16% cost reduction is considered (**breeding**), miscanthus production costs would account for approximately 50 EUR/tonne DM. Consequently, miscanthus is more price competitive than switchgrass (57 EUR/tonne DM), but still more expensive than giant reed (46 EUR/tonne DM). Cropping on large compared to small scale (-91% to -38%), cannot be regarded as an innovation, but rather a signal for potential risks that the farmer should take into consideration when selecting a new crop, this is further explained in sub-section 4.1.4.

The improvement of **agricultural management** mainly targets sustainable agricultural practices linked with higher input efficiency, e.g. through precision agriculture. Thus, improvements of agricultural management are often considered economically attractive. From the perspective of providing ecosystem services such as purifying water by plants (**multi-purpose cropping**), farmers do (often) not get paid for the provision of such positive externalities. By externalities it is referred to those environmental impacts in Figure 25 which do not generate a direct economic impact.

Improved **harvesting technologies** generally targets decreased production costs by logistic improvements, however as already stated in chapter 3.8 "Harvesting technology" the reduced fuel consumption of e.g. single-pass machinery accounts for only 1%, thus effects of this innovation field can be ranked as low.

Crop selections can lead to higher yields, higher resistance and lower production inputs. However, they are often linked with uncertainties and risks, which is why farmers first implement new crops on rather small trials, to assess the interaction of soil quality and yield generation. New crops can bring new business opportunities for the farmer.

The overarching and probably most promising cost reduction tool presented in this chapter is "learning effect" with a cost reduction potential of 25%, since it is a combination of all available innovations and their selection based on gained knowledge and growing experience on the specific crop. This learning effect can be related to all innovations introduced in this report and innovations beyond our scope, but is not regarded as an innovation itself. Through knowledge exchange, training, trial and error etc., practitioners will identify those innovations or innovation combinations which are most suitable to their economic, environmental, and social circumstances.

The likelihood of innovation implementation depends on the reduction potential it would generate in the respective country. Except for irrigation innovations (**agricultural management**), the described innovations would lead to an improved economic situation throughout

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Europe. However, they would show different weights. For instance, innovations which target specific cost impact attributes will only generate similar cost reduction potentials when applied to countries with similar production cost levels and cost element weights. Thus, the calculated potentials regarding miscanthus propagation are only applicable to Belgium, Germany, and the UK. In other countries these innovations would still be profitable, but they would weight differently due to e.g. lower labour costs, or additional irrigation costs. Irrigation with wastewater only leads to cost reduction if it substitutes common irrigation which is already in place. It can still generate positive effects due to increased yields, but it is most likely to be implemented in the south of Europe where irrigation plays a more important role. The cost reduction potential of plant density increase (**agricultural management**) by three times (7%), economy of scale (10%), learning effect (25%), **cropping on marginal land** (-44% to -10%), **breeding** for yield increase, **breeding** for quality increase (-30% to -16%), and cropping on large compared to small scale (-91% to -38%) have a potential to realize same levels of cost reduction potential as illustrated irrespective of the country, since they address ratios and total production costs, instead of single components.

4.1.4. Upscaling - Why size does matter

Although, it cannot be considered as an innovation, economies of scale that result from spatial upscaling of growing lignocellulosic crops can lead to production cost reduction. The upscaling of lignocellulosic biomass cultivation spreads stable production costs due to i.e. fully utilised machine capacities, across larger yield amounts, which results in reduced costs per produced unit. Rosenqvist et al. (2013) assigned a 10% costs reduction potential to willow upscaling. However, it has been controversially discussed in scientific literature if cost reductions resulting from spatial upscaling of the cropped area and related economies of scale may be offset by lower yields, as e.g. small SRC plots in Sweden achieved twice as high yields as large plots (Dimitriou and Mola-Yudego, 2017). The according numbers are shown in Table 5 under "Cropping on small compared to large scale" (Searle and Malins, 2014). In North America, small plot yields were 4-7 times higher for poplar compared to those of large commercial plantations. Another study on miscanthus, switchgrass, poplar, willow, and eucalyptus has shown similar results as achieving respectable yields of up to 40 tonnes/ha yr on a field trial scale, while on a semi-commercial scale yields were significantly lower. This shows that small field trials overestimate yield potentials under real life conditions. The explanation given by the experts is based on higher yield at field edges, inefficiencies in the drying and harvesting process which leads to biomass losses and are unavoidable at a commercial scale (Searle and Malins, 2014).

4.1.5. Cost reduction outlook until 2030/2050

This sub-section solely focuses on cost reduction potentials demonstrated in Table 4 and projects their implementation time-scope until 2030/2050. The method being followed is described in Box 2. For all suggested cropping innovations, biomass production costs decrease

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until 2030. In the following paragraph, the cost reduction potentials until 2030 of the different innovative cropping schemes are described on the basis of the NUT2 case DE1 which can be found in the respective Tables in Annex I.

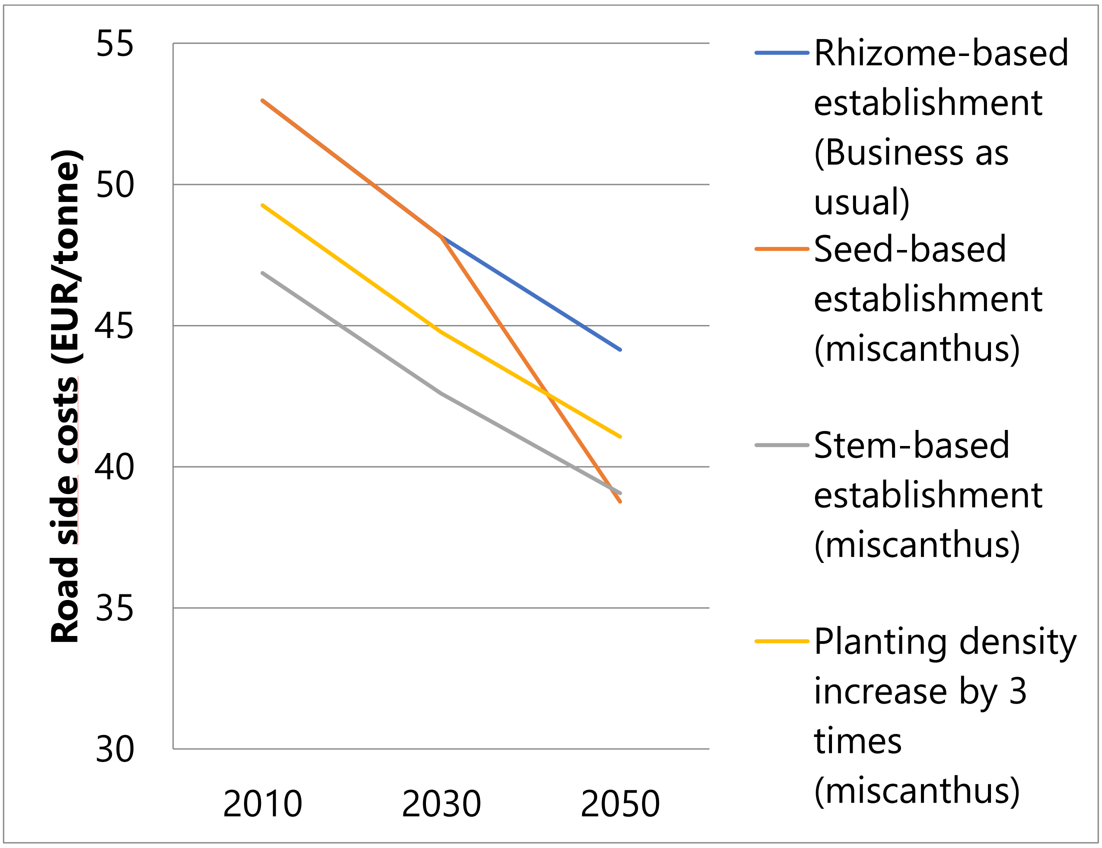

Figure 24: Outlook of the cost reduction potential until 2030/2050 on the basis of the NUT2 case DE1 illustrated in the Biomass Policy Project Deliverable 2.3.

Miscanthus production costs decrease by 17% until 2050 when planted by rhizomes. In comparison, with the implementation of seed-based establishment in 2050, costs decrease by 27% as shown in Table 8 (Annex I). Aboveground stem-based propagation can however decrease costs today by 9% (Table 4) and by 17% until 2050 (Table 9, Annex I). Planting density increase is introduced as another innovation which can be implemented ASAP and reduce costs by 17% (Table 10, Annex I). Both economies of scale, by upscaling the cultivated area substantially, and learning effects that might include some aspects of the mentioned innovations, together have the potential to reduce production costs of willow SRC by 25% (Table 11, Annex I) and 38% (Table 12, Annex I) by 2050.

These results must be perceived as a rather liberal outlook, since it is strongly simplified and does not address the future developments of production input costs. According to (Alexandratos and Bruinsma, 2012), there will be a global slowdown in the annual increase of fertiliser consumption from 31.6 kg N/tonne produced cereal in 2005/2007 to 30.4 kg N/tonne pro-

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duced cereal in 2050 and of the irrigation water withdrawal from the current (2012) 2,760 km^3/yr to 2,926 km^3/yr in 2050. This can be explained by higher fertiliser application efficient technologies with decreased nutrient loss, environmental concerns, and increased irrigation efficiency (Alexandratos and Bruinsma, 2012). The World Bank (2016) accounts for a decrease in Diammonium phosphate (DAP) fertiliser from 419 USD/tonne to 353 USD/tonne costs until 2025. Also other fertiliser costs like posphate rock, potassium chloride, Triple Super Phosphate (TSP), and urea are expected to decrease (World Bank, 2016). To summarise, consumption is predicted to decrease, but prices will most likely increase due to resource scarcity (e.g. water and crude oil). But, will resource scarcity have the same impact on agricultural production in 2050 as it has today or will the sector be fossil-fuel independent by then? A profound analysis regarding net production cost developments of all cost elements (e.g. labour, fertiliser, plant protection products, establishment, insurance etc.) is needed.

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Box 2: *Steps being followed for calculating the outlook of production cost developments until 2030/2050 as shown by the tables in Annex I.*

1. *Step: Calculating cost reduction potential as shown in Table 4*
2. *Step: Assigning cost reduction potential to the year the innovation enters the market*

   The innovations illustrated in table 4 have different temporal relevance. For instance while some innovations like propagation by stem segments (**breeding**) *of miscanthus and* planting density increase by 3 times (**agricultural management**) *can be realised asap, other innovations will take more time to enter the market. For example* seed-based establishment (**breeding**) *is still in the "development phase".* So in the first step it is important to think of the timeframe when the innovation and thus its cost reduction potential will be probably effective. The temporal timeframe was considered as follows:

   Table 6: Innovation time-frame for the calculated cost reduction potentials shown in Table 4

Innovation time-frame	Unit	today (2015)	2030	2050
Breeding (propagation by seeds)	%	0	0	x
Propagation by stem segments (not rhizomes)	%	x	0	0
Planting density increase by 3 times	%	x	0	0
Upscaling	%	0	0	x
Learning Effects	%	0	0	x

3. *Step: Formulating assumptions*

   For a realistic future projection regarding cost reduction potentials until 2030/2050, the different cost elements of various lingocellulosic crops and their future developments would need to be separately investigated upon. For instance how will fertiliser prices look like in 2030/2050? Will farmers have the same fertiliser demand per ha and crop as they currently do etc.? However, this projections are strongly simplified possible cost and demand effects according to the following list:

- ***Assumptions:***

- *Production costs remain the same. Current production cost data will be extracted from D2.3 Biomass Policy Project (Elbersen et al., 2015)*
- *Yields increase by annually 0.5% (Elbersen et al., 2015). Current yield data will be extracted from D2.3 Biomass Policy Project (Elbersen et al., 2015)*

  Consequently, even without innovations there would be a yield-based production cost

4. *Step: Country selection*

   Some innovation cost reduction potentials can be equally applied to all EU member states, i.e. ***economy of scale*** *and* ***learning effects.*** *Whereas cost reduction potentials derived from literature (Hastings et. al 2017; LfULG 2014; O'Loughlin et al. 2018), which targets only single cost elements (in this case establishment costs), can only be applied to countries with similar production cost levels and cost element weights in regard to the total production costs. Consequently, all innovations referring to miscanthus applications have only been applied to the countries Germany, UK, and Belgium, since the derived numbers for the calculation have been extracted from studies which conducted field trials in the respective countries.*

5. *Step: Putting everything together*

   The innovation cost reduction potential of the selected countries was added to the respective year (step 2) on top of the yield-based production cost reduction (step 3)

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4.2. Environmental sustainability

All fields of innovation that were presented in Chapter 3 have an impact on the environment, but not always the same aspects are changed by the innovations and, hence, different environmental impact features are affected (Figure 25). The two central environmental impact features are (1) changes in the soil organic carbon (SOC) balance and (2) the GHG emissions (excluding soil emissions). Some other environmental impact features exist that are not directly part of the GHG balance of the cropping systems: erosion, biodiversity, water quality, water availability and soil fertility (excluding SOC content). Erosion leads to organic rich topsoil loss and has, therefore, a negative impact on SOC influencing indirectly the GHG balance. The following cropping system aspects have an impact on production costs in addition to their environmental impacts: biomass yield, management (including inputs as fuel, fertiliser, herbicide, and pesticide), nutrient use efficiency, and water use efficiency.

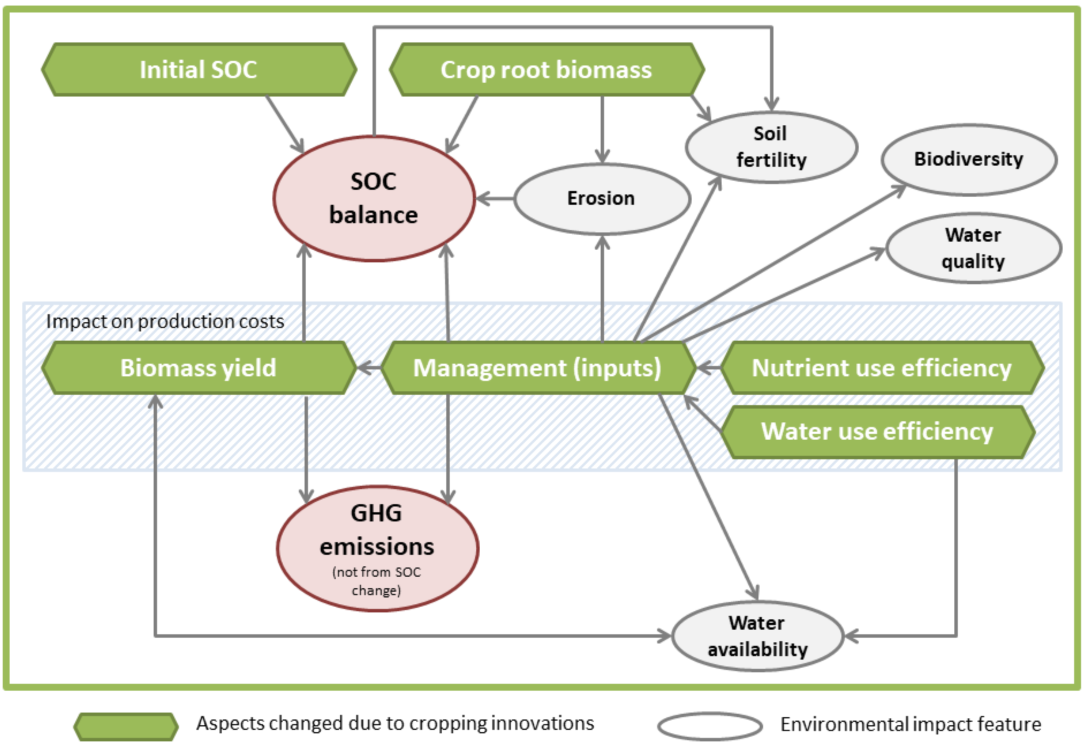

Figure 25: Scheme of main aspects that are changed due to lignocellulosic cropping innovations and their environmental impacts.

<u>*Soil organic carbon*</u>

The SOC content is an important part of the GHG balance of cropping systems. The soil can be a source or a sink of CO_2 emissions depending of the change of SOC. The emissions can range from -3.9 to 2.8 tonnes CO_2/ha yr (negative and positive values indicate C sequestration

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and emission, respectively) after land-use change from cropland to SRC (subchapter 3.7; Walter et al., 2015). The potential to sequester CO_2 by soil depends largely on the initial SOC content as SOC content can only be increased up to a new equilibrium of increased biomass input and decomposition rate (Figure 25). Therefore, it is essential to assess the SOC content, before assumptions about the potential of carbon sequestration are drawn. In general, SOC increases and, hence carbon sequestration is possible, if biomass input by lignocellulosic crops exceeds the input by the vegetation cover of the previous land use. This might be in particular the case for degraded **marginal land**. To maximize biomass input, **crops selection** might focus on crops with high yields or high root biomass or at the combination of such crops in **intercropping** or **multi-purpose cropping** can also be an option. In addition to sequestration, cropping systems can also reduce soil CO_2 emissions by omission of tillage during several years due to cultivation of perennial instead of annual corps (**agricultural management, crop selection**). The potential to sequester carbon in soil is always bound to a timeframe. For instance, land-use change from degraded land to lignocellulosic cropping can sequester carbon in soil, but once cropping stops the land can degrade again and, hence, release SOC. And for extrapolations of GHG-emission balances into future, it also needs to be considered that carbon sequestration into soil is very slow while carbon loss from soils is very fast. A review of temporal dynamics of SOC found that grassland establishment or afforestation from cropland increased SOC, but no equilibrium was reached within 120 years (Poeplau et al., 2011). The same review reports that deforestation and grassland conversion to cropland lead to rapid SOC losses with a new equilibrium reached already after only 2 decades. Therefore, on global scale net carbon sequestration seems only to be achievable if land use conversion from forest and grassland to cropland is stopped.

<u>GHG emissions</u> (not from SOC change) depend on fuel and fertiliser use. This affects all innovation fields (Table 7). For instance, low soil fertility (**marginal land**) requires fertiliser application even for lignocellulosic crop cultivation. Other innovation fields can be linked to the growth of crops with high nutrient use efficiency (**crop selection**, **breeding**, **crop rotation**, **intercropping**, and **multipurpose crops**). And finally, a farmer might opt to substitute synthetic with organic fertiliser (**agricultural management),** which has the potential to reduce GHG emissions by 28% (subchapter 3.1; Murphy et al., 2013). As in particular N-fertiliser production has a high impact on total cropping emissions, those cropping innovations can be considered as interesting alternative, which do not rely on or can minimize N-fertiliser application, e.g. symbiotically N_2-fixing species as black locust and alder in SRC or as miscanthus (**agricultural management**, **crop selection**). Reduction of fertiliser application and increased nitrogen use efficiency can lead to an N_2O-emission reduction of 40% to >99% for 2nd generation energy crops compared to conventional annual crops (Don et al., 2012). Every **agricultural** soil **management** item that can be avoided, has, in addition, the potential to reduce fuel consumption and, hence GHG emissions. But for the reduction of passes through fields at

harvest (**harvest technology**), the potential to save fossil fuel and GHG emissions is, however, very small (1%; chapter 3.8; Felten et al., 2013).

GHG emissions from innovative cropping schemes can be related to emissions per hectare or per ton of yield. Almost all innovation fields (except harvest technology) can have an impact on biomass yield and, hence, on GHG emissions. The relationship between biomass yield and GHG emissions of biomass production needs to be assessed for lignocellulosic crops. This relationship is not linear, because increasing yield also requires increased machine operation for harvesting. For instance, breeding for feedstock quality or cropping on marginal land can reduce yields per hectare by up to 30% and 70%, respectively (Table 4). This would translate to at least the same percentages of GHG emission increases per ton of biomass. In contrast, irrigation with wastewater (**multi-purpose cropping**) and learning effects (**sum of several innovations**) might increase yields to 30% and 50% and, hence, decrease GHG-emissions by a slightly lower percentage, respectively (see chapter 4.1, Table 5).

Erosion leads to the loss of carbon rich and fertile topsoil. Therefore, innovative crop schemes that help to avoid erosion are desirable. Erosion can be reduced by the establishment of dense crop root mats (**marginal land**, **crop selection**), a permanent vegetative cover (**crop selection**, **crop rotation**), or by reduced tillage (**agricultural management**). In addition, **intercropping** of annual crops with tree alleys perpendicular to the main wind direction can reduce wind erosion.

Table 7: Relevance of cropping innovation fields (chapter 3) in relation to environmental impact features (Figure 25).Impacts can be positive or negative depending on specific innovations within each cropping innovation field.

Cropping innovation fields	Environmental impact features						
	SOC change	GHG emissions	Erosion	Soil fertility	Biodiversity	Water quality	Water availability
Agricultural management							
Breeding							
Crop selection							
Crop rotation							
Intercropping							
Multi-purpose cropping							
Cropping on marginal land							
Harvest technology							

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Soil fertility increases with increasing SOC content. As all innovation fields can affect the SOC content, they may also have an indirect impact on soil fertility. A direct effect on soil fertility can be expected from decomposing roots if symbiotically N_2-fixing crop species are used as lignocellulosic crops (**crop selection**, **breeding**, **crop rotation**, **intercropping**, **multi-purpose cropping**, **marginal land**).

As for SOC, the impact of lignocellulosic biomass cropping on biodiversity depends on the starting point. For intensively used agricultural land with low biodiversity, the land use change to perennial biomass production can have positive effects on biodiversity (subchapter 3.7, Haughton et al., 2016). But land-use change of **marginal land** with high biodiversity or being a habitat for protected species, would have a negative effect on biodiversity and should be avoided (Wagner et al., 2019). As biodiversity can be expected to be higher at field margins compared to the center of crop fields (Stanley and Stout, 2013), **intercropping** annual crops with lignocellulosic crops can have a positive effect on biodiversity (**multi-purpose cropping**). In contrast, large scale monoculture that might result from upscaling lignocellulosic cropping (chapter 4.1) can have a negative effect on biodiversity compared to intercropping, but it might still be better compared to biodiversity levels of large scale monoculture of annual crops. Rotational cropping can, in contrast, increase belowground biodiversity (subchapter 3.4, Tiemann et al., 2015). Invasive species are a threat to biodiversity. Therefore, it is questionable if miscanthus propagation by seed will ever be implemented in Europe, as the undesired spread of seeds into natural areas can hardly be controlled (Jørgensen, 2011).

Water quality is mainly impacted by **agricultural management** that should aim at minimizing nitrate leaching. Therefore, innovative cropping schemes that do not rely on fertilisation should be preferred. Growing pest resistant crop genotypes so that pesticide application can be minimized also can help to protect groundwater from pollution (**crop selection**, **breeding**). **Multipurpose crops** might be used for additional wastewater treatment before the water is reintroduced to rivers, but this aspect is only of minor relevance compared to fertilisation practices.

Water availability depends on achieved biomass yields and vice-versa. The higher the plants biomass is, the higher is also their transpiration and interception of rainfall and, hence, their evaporation (**breeding**, **crop selection**, **crop rotation**, **intercropping**, **multi-purpose**, **marginal land**). Crops with high water use efficiency can have a positive effect on water availability as they use less water for a unit biomass (**crop selection**, **breeding**), but water use needs to be compared to alternative land use which might consume still less water. **Crop rotation** instead of only growing one crop per year might increase water use and, hence, can have negative effect on water availability. Biomass yield also depends very much on water availability. Irrigation might be essential in order to produce profitable biomass as it can increase yields substantially. For such cases, in particular for large scale cropping, the impact on water availability for food production and other uses needs to be assessed (see subchapter 4.3.2).

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Life cycle assessments of lignocellulosic crop production mainly focus on GHG emissions, but the other environmental aspects are also important. European projects (e.g. SEEMLA) have assessed environmental aspects such as erosion, soil fertility, water quality and availability, and biodiversity from a potential risk perspective. As most case studies still are on the stage of testing the agronomic and economic feasibility of lignocellulosic cropping schemes, they did not study yet the aforementioned environmental impacts. As the implementation of cropping case studies are expensive and work intensive, future study case results should be collected in a centralized database and case studies should report quantitatively or qualitatively on the environmental impact features (Fig. 24).

4.3. Acceptance by farmers and the public

Several results of the ADVANCEFUEL project show that social implications of RESfuel supply chains may be decisive for its successful rollout. D2.3 provides upgrading strategies for lignocellulosic supply chains with a view on social aspects. D4.4 contains a socio-economic assessment of RESfuel supply chains, and also strives upon the social dimension assessing the social performance at multiple layers of selected European good practice biorefineries. This report describes the social dimension of innovative cropping schemes.

It is important to differentiate between social acceptance as a "Barrier before implementation" and "Social acceptance after implementation". The first is mainly related to:

1. *Farmer's willingness* to implement a new cropping scheme on their fields, while the latter refers mainly to
2. *Public acceptance*.

This distinction is not meant to be strict, since farmers may also reject a new crop after its implementation due to e.g. low profits or negative impacts on soil quality. Also the (non-) acceptance of local actors can already play a role before the implementation phase takes place. However, that would require a highly engaged public who is aware of the future cropping plans of regional farmers.

In the EU, renewable energies face generally increasing local resistance in regard to additional production. Wüstenhagen et al. (2007), explains the decreasing social acceptance by the decentralised nature of renewable energies: Renewable energy plants have a higher visibility than conventional energy plants, since they require higher numbers of systems and are more likely to operate above ground, compared to below ground resource extraction of nuclear or fossil fuels. Thus, a successful uptake of innovative lignocellulosic cropping schemes requires an integration of social perception during an early stage, especially when the innovation depends on public support e.g. tax money (Petursdottir and Aradottir, 2000).

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In this section the strongest hurdles regarding (1) farmers' acceptance and (2) social acceptance as well as how they are influenced by the respective innovations will be further discussed. Furthermore, (3) action recommendations for acceptance creation will be given.

4.3.1. Cropping innovations and their contribution to farmers' acceptance

The workshop results (chapter 2.2) regarding "Farmer's willingness" to implement a new cropping scheme on his fields clearly circles around the economic aspects such as profitability (SEEMLA), cost of biomass (FORBIO), lack of markets (BECOOL), and high investments (MAGIC & GRACE).

Profitability is also a major cause for low farmers' acceptance identified by (Glithero et al., 2013). Consequently, we arrive at the conclusion that in the first step, the question of profitability should be answered before further barriers are addressed. And since, **intercropping** and **cropping on marginal land** were identified as the least economic attractive innovative cropping schemes, it can also be assumed that the farmers' willingness to implement them are respectively low. According to Pulighe et al. (2019) **cropping on marginal land** is related to high risks and uncertainties for the farmers. One way to overcome these risks are long-term contracts with fixed prices (Keutmann et al., 2016; Pulighe et al., 2019). Regarding **intercropping**, agricultural land is often rented, thus landlords need to give their approval for the cultivation of fast growing trees on their property which is often considered a hurdle (Böhm and Veste, 2018). Furthermore, the legal framework does not always allow the cultivation of SRC on specific land areas, or their harvest (Böhm and Veste, 2018). Innovations on **harvesting technologies** are pivotal since "lack of appropriate machinery" is often mentioned as a major barrier regarding dedicated energy crops (Uslu et al., 2018). However, profitability of a new machine depends on the purchase price, the scale of cultivation, full capacity utilization, and crop profitability. The workshop results show that new machinery is the biggest cost factor when implementing black locust. Thus, it definitely does not count as a low hanging fruit and, therefore, faces low farmers' acceptance. Money is, however, not always the convincing argument, since high investment costs were identified as the biggest obstacle for farmers to cultivate miscanthus. Establishment innovations (**breeding**) , can lead to a reduction of these costs (Chapter 4.1). Xue et al. (2015), however, claims that direct rhizome planting is the farmers' most preferred option compared to other establishment innovations. Stem-based propagation, for example, is still at an early development stage and appropriate harvest machinery and storage options without high propagation efficiency losses need to be developed (Xue et al., 2015). Also the geographical scope plays a role when considering acceptance creation measures, i.e. irrigation with wastewater (**multi-purpose cropping**) could face high social acceptance, only, however, in south European countries, where cost reduction potentials have a significant impact. Thus, it is rather a niche innovation due to its narrow implications. Furthermore, contamination leading to negative environmental and health impacts is a hurdle for social acceptance. Acceptance of wastewater irrigation depends on awareness of present or

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future water scarcity, educational level, costs and benefits, level of real or perceived health risks, and aesthetic attributes of the water (D'Andrea et al., 2015) as well as transaction costs and social capital (Maaß and Grundmann, 2018). Marginal land (**cropping on marginal land**) in Europe on the contrary, accounts for 220 Mha (Galatsidas et al., 2018). A rejection of this approach causes major potential losses for the cultivation of biomass for RESfuels. The selection of new species (**Crop selection**) is a double-sided sword. On the one hand, it promises the opportunity of higher feedstock quantity and quality, but on the other hand it could entail invasiveness risks. In order to prevent invasiveness of black locust, Crosti et al. (2016) suggests to implement buffer zones.

The acceptance to implement **crop rotations** is negatively influenced by biophysical constraints. For instance, Sweden has much shorter vegetation periods which makes sequential cropping much more challenging than e.g. in Italy (Peters et al., 2016). Additionally, high social acceptance of **crop rotations** depends on the context. For instance, the case study described by Peters et al. (2016) appears promising because it describes (A) a prosumer (all biomass is produced and utilised on-farm), (B) triticale and maize silage can be used for feed as well as food and easily substitute one another, and (C) the expansive extraction of single components for the conversion process is not required, since the entire plant is used for the gasification process. Opposed circumstances might have led to low farmers' acceptance. Lowering SOC contents will most likely present a barrier for farmers who already grow catch crops which they mulch, since they have a particular interest in maintaining their SOC levels. Other high ranked barriers of farmers' willingness to implement the respective cropping schemes such as lack of knowledge regarding environmental constraints (LIBBIO, BECOOL, MAGIC & GRACE), and lack of markets (BECOOL) are not directly impacted by the respective innovations, since they require organizational innovations.

4.3.2. Creating legitimacy among the wider public by implementing innovative cropping schemes

Regarding acceptance of the wider public, a variety of factors influence social acceptance, such as perceived benefits, perceived costs, trust towards the operators, information received (Soland et al., 2013), complementation of place-related values (De Groot and Bailey, 2016), as well as the aesthetical value and people's visual perception of landscape changes (Petursdottir and Aradottir, 2000). In the ADVANCEFUEL workshop, shared benefits and environmental values were mentioned in various examples as influencing factors of high public acceptance, while lack of knowledge, competing interest and shared costs were perceived to cause low social acceptance. Factors being observed in the LIBBIO project were level of naturalness, consumer acceptance, and the articulation of concrete results.

Shared benefits, lack of knowledge, and the articulation of clear results require different or complementary (organizational and social) innovations than the technical innovations addressed by this report. The most critically perceived innovations we identified are those which

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influence aesthetical value negatively or cause visual landscape changes e.g. through high growth of short rotation coppices (**intercropping**) or miscanthus (**breeding**) on a large scale, since they prevent the view in the distance which is desired.

Environmental values are expected to be positively addressed by those innovation fields that diversify the agricultural landscape and promote sustainable management. Those include **agricultural management** (e.g. tillage, and organic fertiliser), **crop rotation**, and **intercropping**. Also Fiorese et al. (2013) identified competing interests among food and fuel production as a main social barrier. The experts they interviewed suggested an integrated system that produces both products from the same land as a mechanism to overcome this obstacle. This approach could be realized by a **crop rotation**, and **multi-purpose cropping**. Other alternatives to mitigate land pressure are **cropping on marginal land**. However, **multi-purpose crops**, without being linked to other innovations like **crop rotation** or **intercropping**, would appear as a monoculture. Since the public is not directly affected by business costs and revenue structures, shared costs of innovative cropping schemes translate mainly into negative externalities. Negative externalities could be e.g. increase of heavy vehicle traffic (Upham and Shackley, 2006), due to an additional business line of the farmer. Single-pass harvesting (**harvesting technology**) and seed-based miscanthus propagation (**breeding**) could mitigate these costs, since a decreased volume of plant material translates into less transport frequency. Furthermore, seed-based plugs (**breeding**) cultivated in greenhouses could lead to job creation in the region. However, greenhouses follow a trend to accumulate on one geographical spot as so called "greenhouse parks", since it enables actors to reduce production costs through shared energy, water, and gas facilities. Such greenhouse parks face high social rejections. Thus, stem-segment propagation (**breeding**) is expected as the innovation with the highest social acceptance (Rogge et al., 2008). Another workshop outcome was that the *degree of naturalness* is ranked as the most influential determinant of high social acceptance regarding Andes lupine cultivation (**crop selection**). LIBBIO catches the attention of the broader audience by using red vegan lipsticks produced from lupine as their figurehead in order to communicate project matters. The wide range of plant-based products LIBBIO and the GRACE project offer are on the pulse of time and according to them increase consumer acceptance. But, in order for Andes Lupine to be added to the plant variety catalogue and to be cultivated in Europe, its distinctness, uniformity, stability, and its value for cultivation and use as an agricultural crop need to be proven (European Commission, 2019). On other terms the preferred degree of naturalness can also lead to low social acceptance towards the selected innovations. For instance, Petursdottir and Aradottir (2000) found that "natural" landscapes are preferred by the public. When focusing on the cultivation of un-utilised marginal land compared to cropped marginal land, the public might have a clear preference towards the first option. Also Boll et al. (2014) argue that social acceptance of biomass **cropping on marginal land** depends on the uniqueness of the landscape, and the impact on the visual landscape. The authors conclude that in general land use changes are best accepted for intensively farmed agri-

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cultural landscapes and that people prefer diversity among landscapes. Thus, it is important to take previous land use into consideration. One innovation in favour of increased naturalness on fields is **crop rotation**, since it avoids fallows.

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5. Conclusion and recommendations

The study aims to explore promising innovative cropping systems to produce feedstocks for advanced biofuels in different regions in Europe. It assesses the cost reduction potentials by innovative cropping systems, while avoiding greenhouse gas (GHG) emissions, and other negative environmental and social impacts. The assessment uses information and data from a workshop, case studies, and analyses of previous relevant studies and literature. The cases reviewed include: (1) the cropping of black locust in short rotation coppice on marginal land in Germany and Greece; (2) the cropping of willow SRC on degraded former agricultural land in the Ukraine; (3) cultivating Andes lupine in Europe as a new species with multiple potential uses; (4) rotational cropping with lignocellulosic crops (sun hemp, hemp, kenaf, and figer sorghum) after maize on agricultural land in Italy, Spain, and Greece; and (5) growing miscanthus on marginal land in seven European countries. The fields of innovation considered in this study mostly range from agricultural management to breeding, crops selection, crop rotation, intercropping, multipurpose cropping, cropping on marginal land, and harvesting technology. The assessment of the innovations and cases of promising innovative cropping schemes is carried out from an economic, environmental, and acceptance perspective, while also taking into account geographical and temporal variations of the assessment criteria.

From an economic perspective, not a single innovation identified can be selected as the most promising because its success might not be transferable throughout the EU. , e.g. increasing the planting density might not increase yields in dry regions. It is the gained knowledge in respect to a combination of several innovations which will bring the market roll-out of RESfuels forward from an agricultural point of view – stated within the report as the "Learning effect". This "Learning effect" can lead to cost reduction potentials of 25% (Rosenqvist et al., 2013). Moreover, intercropping and cropping on marginal land were found to be the least profitable innovations. The results show that cost reduction potentials in cropping systems do not necessarily lead to a higher relative attractiveness of one crop to another.

The two main environmental impacts considered for assessing innovative cropping systems were: (1) changes in the soil organic carbon (SOC) balance; and (2) the GHG emissions (excluding changes in SOC). Cropping on marginal land of low initial SOC and on land with low biodiversity is a promising choice for carbon sequestration, fertility increase, and positive effect on biodiversity and erosion avoidance. However, in order to achieve low GHG emissions per ton of biomass, adequate yields need to be achieved with minimal fertiliser application and without negative effects on quality of groundwater or water availability. This precludes that selected crops should have high nutrient use efficiency (depending on climate) and high

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water use efficiency. Learning effects resulting from breeding, crop selection, and agricultural management, are expected to increase yields by 50% (Karp and Shield, 2008), but this still needs to be confirmed in future studies on marginal lands.

The farmers' and general public acceptance varies across different cases and types of innovation. The farmers' acceptance of innovations depends on the profitability and the legal framework, access to appropriate equipment, conflicting traditions, and the invasiveness of the respective crops. High public acceptance is influenced by perceived benefits and costs, environmental externalities, low land pressure, aesthetical values, and general public visual perception of landscape changes.

The findings in this study show substantial opportunities and challenges in improving innovative cropping systems dedicated to produce feedstocks, for advanced biofuels in different regions in Europe (Tab. 8). Based on the findings, our recommendations revolve around cost reduction potentials, improvements of SOC, reduction of GHG emissions, profitability for the farmers, and integration of the public during early stages. Some major shortcomings and challenges when assessing the potentials exist, whereas a specific example is the lack of data availability, which makes comparisons between case studies less efficient. There is also a lack of information in reports and scientific articles on initial SOC content, and the lack of a definition regarding the precise marginal land type in various case studies (Li et al., 2018). All this information should be generated by default for all case studies including values on achieved yields and applied fertiliser. This would enable future reviews to assess whether sufficient yields can be generated on marginal land with almost no fertiliser applications. At present, only a few information sources can be found in the relevant literature on actual cases of innovative cropping systems for feedstock production utilising advanced biofuels. Results are often not comparable because the cases are too heterogeneous in terms of geographical location, biophysical conditions (i.e. countries, land types, and scales), and assessed parameters. Many studies on road side costs and yields do not mention the respective size of cropping area, even though this information on scales has significant implications for costs. Therefore, these circumstances hinder the transferability and extrapolation of the results. Furthermore, regional specifics make the comparison between production costs and yield performances rather difficult (Soldatos, 2015). Systematic experimental studies taking into consideration biophysical and socioeconomic gradients would be needed for analysing comprehensive nationwide cost reduction potentials for cropping systems. A standardised assessment chart applied systematically to all cases of lignocellulosic biomass cultivation is suggested for deriving exhaustive as well as area specific recommendations.

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Table 8: Summary of opportunities and challenges resulting from innovations in lignocellulosic cropping.

Opportunities	**Challenges**
Crop selection promises: • higher feedstock quality • higher biomass yield • better water and nutrient use efficiency These crop improvements could enable advanced fuels to meet sustainability requirements (COM (2010)11). They could also help to achieve the set target of 14% renewable energy in the transport sector by 2030 (RED II 2009/EC/28), and other regulation targets which create opportunities for lignocellulosic crops as stated in Alternative Fuels Infrastructure Directive (2014/94/EEU), Biofuel Directive (2003/30), and Energy Efficiency Directive (Dir 2012/27/EU). In addition, increased nutrient use efficiency can decrease fertilisation inputs (Nitrates Directive 91 / 676 /EEC).	• New species not endemic to the EU need to be added to the EU variety list and need to follow the Nagoya protocol. • Advanced biofuel feedstocks are only classified as such, if they are listed in RED II (2009/EC/28) under Annex IX. • Knowledge on economic and environmental effects per crop as well as public acceptance of crops and genotypes need to be communicated to farmers and decision makers. • A central consultancy body should be available for all European stakeholders in order to guarantee fast dissemination of knowledge and equal opportunities.
Growing dedicated energy crops can increase SOC levels. This leads to carbon sequestration and, hence, a decrease of GHG emissions in order to meet the Greenhouse gas savings thresholds of 50% for transport biofuels in RED II. This is also in line with the aim described in the ILUC Directive (EU) 2015/13 to move towards more second generation dedicated energy crops.	• Stakeholders dealing with European case studies on lignocellulosic copping need to agree upon a minimum set of parameters that should be assessed and reported by all project and a common method for data collection. This would allow in future estimating the potential to sequester carbon in soil. Such a dataset would need to include data on initial SOC content and previous land use.

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Opportunities	Challenges
Cropping on marginal land has the potential to avoid land pressure and, hence, indirect land-use change. This meets the target of the ILUC Directive (EU) 2015/1513 in avoiding the competition with the food production.	• A European definition is required for "marginal land", including different types of marginal land and their potential use. • For each case study, types of marginal land need to be defined in reports and scientific publications. • The potential use of marginal land types should be related to achievable yields as well as required quantity of fertiliser application and irrigation.
Increasing the area used in a region for dedicated energy copping has the potential to decrease biomass production costs. Furthermore, it increases local production favoured by the ILUC Directive (EU) 2015/1513.	• Achievable yields for large scale farming need to be estimated carefully to guarantee success. The fact that yields on small plots are generally higher than on large plots needs to be considered. • A critical review on modelled biomass yields and reached yields in case studies is required in order to facilitate future yield estimates. Such a review needs to include data on field size, fertiliser application and irrigation.
Seed-based instead of rhizome-based miscanthus establishment has the potential to reduce biomass production costs significantly.	• A solution is needed in order to avoid undesired spread of seeds into natural areas in Europe.[1)]
Stem-based instead of rhizome-based miscanthus establishment has the potential to reduce biomass production costs.	• Development of appropriate harvesting machinery for miscanthus stem segments is needed[2)] • Development of storage facilities without high propagation efficiency losses is needed[2)]

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Opportunities	Challenges
Sewage sludge and wastewater application for a sustainable waste management decreases the groundwater use for irrigation and, hence, increase water availability as targeted by the Water Framework Directive (2008/98/EC) and the Urban Waste Water Treatment Directive. It also saves fertilisation Nitrates Directive (91 / 676 /EEC) and irrigation costs as well as foster plant growth.	• Adequate risk management strategies are needed to avoid health risks[3)] • Periodic monitoring of soil and crop properties[3)] • Proposal of EU common wastewater reuse criteria[3)]
Breeding has the potential to increase biomass yield, water and nutrient use efficiency and feedstock quality and, hence, reduces biomass production costs and GHG emissions. These impacts address a number of targets set by RED II, Water Framework Directive (2008/98/EC) and Nitrates Directive (91 / 676 /EEC), ILUC Directive (2015/1513).	• More long-term R&D is needed for perennial lignocellulosic crops in order to generate resistant hybrids with high yields. • Results from breeding programs for different hybrids should be publicly accessible and free of charge in order to facilitate information flow and the implementation of innovations.
Innovations in the field of crop rotation and multi-purpose crops can lead to the efficient use of resources (Water Framework Directive (2008/98/EC); Nitrates Directive (91 / 676 /EEC); EU Common Agricultural Policy), and diversification of farmer's business model portfolio.	• Establishment of a platform reporting on actual business models regarding dedicated energy crops is needed. • This platform should highlight best practice cases to foster experience and knowledge exchange among agricultural entrepreneurs.
Diversification of landscapes via intercropping (SRC stripes + main crop) can increase biodiversity and increase the soil organic matter which is supported by CAP Pillar I Direct Payments (Crop Diversification).	• Raising awareness among landlords, since they need to give their approval for the cultivation of fast growing trees on their property which is often considered a hurdle. • A legal framework needs to be adapted in favour of SRC cultivation and harvest on specific land areas (e.g. along drainage ditches).

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<table>
<tr><th>Opportunities</th><th>Challenges</th></tr>
<tr><td>The learning effect as a combination of different innovations has the potential to significantly increase biomass yields (RED II 2009/EC/28) and decrease biomass production costs. But, the testing phase of a variety of innovations is time and cost intensive.
There are, however, a few enabling programmes in place to promote innovations on the ground:
Horizon 2020, the Innovation Fund, the NER200 programme, and the regional development funds from European Investment Bank.</td><td>Different measures need to be taken in order to accelerate the learning effect for cost effective and sustainable lignocellulosic biomass production in the EU, while also considering factors affecting the acceptance by farmers and the public (summary of underlined points above):
A standardised assessment chart applied systematically to all cases of lignocellulosic biomass cultivation. This includes:
Definition of a “minimum set of parameters” that should be assessed and reported for all case studies.
Standard methods to collect data.
Open information policy in the respective region is required. This should include:
Development of a communication strategy
Enhancement of cooperation among stakeholders
To cope with the complexity of economic, environmental aspects as well as acceptance a tool is needed. This could be a decision support system on EU level that would need to include standardized data on costs, sustainability and social acceptance.</td></tr>
</table>

[1] (Jørgensen, 2011), [2] (Xue et al., 2015), [3] (Maaß and Grundmann, 2018)

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Annex I

Table 6: Seed-based establishment (miscanthus). Outlook of cost reduction potential until 2030/50. Assumed temporal relevance of the innovation: 2050; Geographical relevance: Belgium, Germany, UK.

Unit	Average yield tonnes DM/ha	Road side costs EUR/tonnes DM*yr	Road side costs EUR/tonnes DM*yr	Road side costs EUR/tonnes DM*yr
NUT2	2010 (Elbersen)	2010(Elbersen)	2030	2050
BE10	13.059	55.38	50.36	40.48
BE21	13.183	54.86	49.88	40.1
BE22	13.188	54.84	49.84	40.07
BE23	13.028	55.51	50.47	40.58
BE24	13.167	54.93	49.95	40.15
BE25	12.898	56.07	50.96	40.98
BE31	13.17	54.91	49.91	40.14
BE32	13.329	54.26	49.33	39.67
BE33	12.879	56.15	51.03	41.05
BE34	12.74	56.77	51.62	41.49
BE35	13.006	55.6	50.53	40.63
DE1	13.752	52.97	48.15	38.76
DE2	11.165	65.24	59.32	47.73
DE3	12.458	58.47	53.17	42.78
DE4	14.496	50.25	45.67	36.76
DE5	12.978	56.12	51	41.07
DE6	12.978	56.12	51	41.07
DE7	14.053	51.78	47.07	37.89
DE8	12.374	58.87	53.52	43.07
DE9	12.627	57.69	52.44	42.22
DEA	13.015	55.97	50.87	40.95
DEB	13.23	55.06	50.06	40.27
DEC	14.276	51.03	46.4	37.34
DED	13.416	54.3	49.36	39.73
DEE	13.202	55.18	50.17	40.38
DEF	11.108	65.58	59.61	47.98
DEG	12.477	58.38	53.09	42.72
UKD1	6.806	92.2	83.78	65.93
UKD3	6.806	92.2	83.78	65.93
UKD4	6.806	92.2	83.78	65.93
UKD6	6.806	92.2	83.78	65.93
UKD7	6.806	92.2	83.78	65.93
UKE1	7.696	81.54	74.09	58.3
UKE2	7.696	81.54	74.09	58.3
UKE3	7.696	81.54	74.09	58.3

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UKE4	7.696	81.54	74.09	58.3
UKF1	9.95	63.07	57.31	45.11
UKF2	9.95	63.07	57.31	45.11
UKF3	9.95	63.07	57.31	45.11
UKG1	9.269	67.7	61.52	48.44
UKG2	9.269	67.7	61.52	48.44
UKG3	9.269	67.7	61.52	48.44
UKH1	10.989	57.11	51.91	40.84
UKH2	10.989	57.11	51.91	40.84
UKH3	10.989	57.11	51.91	40.84
UKI1	8.636	72.67	66.06	52
UKI2	8.636	72.67	66.06	52
UKJ1	11.183	56.12	51.02	40.14
UKJ2	11.183	56.12	51.02	40.14
UKJ3	11.183	56.12	51.02	40.14
UKJ4	11.183	56.12	51.02	40.14
UKK1	9.799	64.04	58.21	45.8
UKK2	9.799	64.04	58.21	45.8
UKK3	9.799	64.04	58.21	45.8
UKK4	9.799	64.04	58.21	45.8
UKL1	7.913	79.3	72.13	56.7
UKL2	7.913	79.3	72.13	56.7

Table 7: Stem-based establishment (miscanthus). Outlook of cost reduction potential until 2030/50. Assumed temporal relevance of the innovation: asap; Geographical relevance: Germany & UK.

	Average yield	Road side costs (before innovation implementation)	New road side costs (after innovation implementation)	Road side costs	Road side costs
Unit	tonnes DM/ha	EUR/tonnes DM*yr	EUR/tonnes DM*yr	EUR/tonnes DM*yr	EUR/tonnes DM*yr
NUT2	2010 (Elbersen)	2010 (Elbersen)	2010	2030	2050
DE1	13.752	52.97	46.86	42.59	39.06
DE2	11.165	65.24	57.71	52.47	48.08
DE3	12.458	58.47	51.72	47.03	43.1
DE4	14.496	50.25	44.45	40.4	37.03
DE5	12.978	56.12	49.65	45.12	41.38
DE6	12.978	56.12	49.65	45.12	41.38
DE7	14.053	51.78	45.8	41.63	38.17
DE8	12.374	58.87	52.08	47.35	43.4
DE9	12.627	57.69	51.03	46.39	42.53
DEA	13.015	55.97	49.51	45	41.25
DEB	13.23	55.06	48.71	44.29	40.58
DEC	14.276	51.03	45.14	41.05	37.62
DED	13.416	54.3	48.04	43.67	40.03

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DEE	13.202	55.18	48.82	44.39	40.69
DEF	11.108	65.58	58.01	52.73	48.34
DEG	12.477	58.38	51.65	46.97	43.05
UKD1	6.806	92.2	79.85	72.56	66.52
UKD3	6.806	92.2	79.85	72.56	66.52
UKD4	6.806	92.2	79.85	72.56	66.52
UKD6	6.806	92.2	79.85	72.56	66.52
UKD7	6.806	92.2	79.85	72.56	66.52
UKE1	7.696	81.54	70.62	64.17	58.82
UKE2	7.696	81.54	70.62	64.17	58.82
UKE3	7.696	81.54	70.62	64.17	58.82
UKE4	7.696	81.54	70.62	64.17	58.82
UKF1	9.95	63.07	54.62	49.63	45.52
UKF2	9.95	63.07	54.62	49.63	45.52
UKF3	9.95	63.07	54.62	49.63	45.52
UKG1	9.269	67.7	58.63	53.28	48.87
UKG2	9.269	67.7	58.63	53.28	48.87
UKG3	9.269	67.7	58.63	53.28	48.87
UKH1	10.989	57.11	49.46	44.96	41.21
UKH2	10.989	57.11	49.46	44.96	41.21
UKH3	10.989	57.11	49.46	44.96	41.21
UKI1	8.636	72.67	62.94	57.22	52.47
UKI2	8.636	72.67	62.94	57.22	52.47
UKJ1	11.183	56.12	48.61	44.2	40.51
UKJ2	11.183	56.12	48.61	44.2	40.51
UKJ3	11.183	56.12	48.61	44.2	40.51
UKJ4	11.183	56.12	48.61	44.2	40.51
UKK1	9.799	64.04	55.46	50.41	46.21
UKK2	9.799	64.04	55.46	50.41	46.21
UKK3	9.799	64.04	55.46	50.41	46.21
UKK4	9.799	64.04	55.46	50.41	46.21
UKL1	7.913	79.3	68.68	62.47	57.21
UKL2	7.913	79.3	68.68	62.47	57.21

Table 8: Planting density increase by 3 times (miscanthus). Outlook of cost reduction potential until 2030/50. Assumed temporal relevance of the innovation: asap; Geographical relevance: EU wide.

	Average yield	Road side costs (before innovation implementation)	New road side costs (after innovation implementation)	Road side costs	Road side costs
Unit	tonnes DM/ha	EUR/tonnes DM*yr	EUR/tonnes DM*yr	EUR/tonnes DM*yr	EUR/tonnes DM*yr
NUT2	2010 (Elbersen)	2010 (Elbersen)	2010	2030	2050
AT11	17.277	32.37	30.1	27.37	25.09

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AT12	15.221	37.13	34.53	31.4	28.77
AT13	10.095	55.98	52.06	47.35	43.4
AT21	10.001	56.52	52.56	47.79	43.8
AT22	13.424	42.1	39.15	35.58	32.62
AT31	11.978	47.19	43.89	39.89	36.58
AT32	8.768	64.46	59.95	54.53	49.97
AT33	6.307	89.62	83.35	75.75	69.44
BE10	13.059	55.38	51.5	46.83	42.92
BE21	13.183	54.86	51.02	46.39	42.52
BE22	13.188	54.84	51	46.35	42.49
BE23	13.028	55.51	51.62	46.93	43.03
BE24	13.167	54.93	51.08	46.45	42.57
BE25	12.898	56.07	52.15	47.4	43.45
BE31	13.17	54.91	51.07	46.42	42.57
BE32	13.329	54.26	50.46	45.88	42.06
BE33	12.879	56.15	52.22	47.46	43.53
BE34	12.74	56.77	52.8	48.01	43.99
BE35	13.006	55.6	51.71	47	43.08
BG31	18.045	16.24	15.1	13.73	12.59
BG32	18.446	15.9	14.79	13.45	12.32
BG33	16.69	16.69	15.52	14.11	12.93
BG34	15.185	18.75	17.44	15.86	14.54
BG41	16.092	17.44	16.22	14.75	13.52
BG42	15.28	17.71	16.47	14.97	13.72
CY00	10.913	32.28	30.02	27.3	25.01
CZ01	13.327	21.62	20.11	18.28	16.76
CZ02	13.45	21.42	19.92	18.1	16.6
CZ03	12.871	22.38	20.81	18.92	17.34
CZ04	12.845	22.43	20.86	18.96	17.39
CZ05	13.572	21.22	19.73	17.94	16.44
CZ06	15.013	19.19	17.85	16.23	14.87
CZ07	14.83	19.42	18.06	16.42	15.05
CZ08	13.932	20.68	19.23	17.48	16.02
DE1	13.752	52.97	49.26	44.77	41.06
DE2	11.165	65.24	60.67	55.16	50.55
DE3	12.458	58.47	54.38	49.45	45.32
DE4	14.496	50.25	46.73	42.47	38.93
DE5	12.978	56.12	52.19	47.43	43.5
DE6	12.978	56.12	52.19	47.43	43.5
DE7	14.053	51.78	48.16	43.78	40.14
DE8	12.374	58.87	54.75	49.78	45.62
DE9	12.627	57.69	53.65	48.77	44.72
DEA	13.015	55.97	52.05	47.31	43.37
DEB	13.23	55.06	51.21	46.56	42.66
DEC	14.276	51.03	47.46	43.16	39.55
DED	13.416	54.3	50.5	45.9	42.08

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DEE	13.202	55.18	51.32	46.66	42.77
DEF	11.108	65.58	60.99	55.44	50.82
DEG	12.477	58.38	54.29	49.37	45.25
DK01	9.39	104.15	96.86	88.05	80.7
DK02	9.39	104.15	96.86	88.05	80.7
DK03	9.39	104.15	96.86	88.05	80.7
DK04	9.39	104.15	96.86	88.05	80.7
DK05	9.39	104.15	96.86	88.05	80.7
EL11	14.279	39.82	37.03	33.66	30.87
EL12	13.42	42.09	39.14	35.59	32.62
EL13	11.171	49.6	46.13	41.93	38.43
EL14	11.025	48.71	45.3	41.17	37.75
EL21	10.83	49.96	46.46	42.25	38.7
EL22	11.414	46.02	42.8	38.89	35.66
EL23	10.287	50.96	47.39	43.07	39.51
EL24	9.472	54.15	50.36	45.78	41.95
EL25	9.396	54.35	50.55	45.94	42.11
EL30	9.623	55.06	51.21	46.53	42.67
EL41	9.309	54.78	50.95	46.32	42.46
EL42	10.856	49.99	46.49	42.27	38.73
EL43	10.785	50.14	46.63	42.4	38.86
ES11	12.975	49.47	46.01	41.83	38.34
ES12	11.04	58.4	54.31	49.39	45.25
ES13	12.661	51.04	47.47	43.15	39.57
ES21	13.704	46.9	43.62	39.67	36.36
ES22	13.513	46.91	43.63	39.67	36.35
ES23	11.616	51.83	48.2	43.81	40.16
ES24	12.406	47.61	44.28	40.24	36.89
ES30	10.238	53.53	49.78	45.26	41.47
ES41	10.716	54.4	50.59	45.98	42.16
ES42	10.861	50.41	46.88	42.61	39.08
ES43	11.196	48.44	45.05	40.94	37.53
ES51	13.095	45.22	42.05	38.24	35.05
ES52	12.4	44.88	41.74	37.95	34.78
ES53	14.328	39.9	37.11	33.74	30.93
ES61	11.696	46.64	43.38	39.42	36.14
ES62	11.534	47.16	43.86	39.86	36.55
ES63	12.124	47.99	44.63	40.56	37.19
ES64	12.124	47.99	44.63	40.56	37.19
ES70	12.124	47.99	44.63	40.56	37.19
FR10	14.928	46.55	43.29	39.36	36.08
FR21	14.503	47.86	44.51	40.47	37.1
FR22	14.333	49.36	45.9	41.72	38.25
FR23	13.873	51	47.43	43.12	39.52
FR24	15.226	44.55	41.43	37.66	34.53
FR25	13.796	51.28	47.69	43.34	39.73

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FR26	15.552	44.17	41.08	37.34	34.24
FR30	13.298	53.2	49.48	44.98	41.23
FR41	14.525	48.71	45.3	41.18	37.75
FR42	14.168	49.93	46.43	42.22	38.7
FR43	14.434	49.01	45.58	41.43	37.98
FR51	15.533	43.92	40.85	37.13	34.04
FR52	14.455	48.94	45.51	41.37	37.92
FR53	14.946	43.69	40.63	36.94	33.85
FR61	16.481	40.38	37.55	34.13	31.29
FR62	14.715	44.96	41.81	38	34.84
FR63	15.668	43.53	40.48	36.81	33.74
FR71	13.197	51.43	47.83	43.47	39.85
FR72	15.164	45.31	42.14	38.31	35.11
FR81	12.924	47.67	44.33	40.29	36.94
FR82	11.049	55.29	51.42	46.76	42.85
FR83	11.687	49.67	46.19	41.98	38.5
FR91	14.293	47.07	43.78	39.81	36.49
FR92	14.293	47.07	43.78	39.81	36.49
FR93	14.293	47.07	43.78	39.81	36.49
FR94	14.293	47.07	43.78	39.81	36.49
HR03	16.623	15.75	14.65	13.31	12.21
HR04	16.623	15.75	14.65	13.31	12.21
HU10	16.366	16.38	15.23	13.85	12.69
HU21	16.1	16.63	15.47	14.06	12.89
HU22	16.971	16.23	15.09	13.72	12.57
HU23	15.924	16.64	15.48	14.07	12.9
HU31	17.498	16.09	14.96	13.6	12.47
HU32	17.62	15.76	14.66	13.33	12.22
HU33	16.923	15.74	14.64	13.31	12.2
ITC1	12.219	71.62	66.61	60.56	55.52
ITC2	7.629	123.92	115.25	104.8	96.09
ITC3	13.839	58.18	54.11	49.2	45.08
ITC4	13.586	66.01	61.39	55.83	51.17
ITH1	9.157	103.24	96.01	87.3	80
ITH3	15.199	60.62	56.38	51.25	46.98
ITH4	15.447	61.2	56.92	51.75	47.42
ITH5	16.615	51.13	47.55	43.22	39.62
ITI1	15.112	53.78	50.02	45.48	41.69
ITI2	14.667	55.65	51.75	47.06	43.13
ITI3	15.695	52.29	48.63	44.22	40.53
ITI4	14.625	54.46	50.65	46.04	42.21
ITF1	14.464	56.24	52.3	47.55	43.58
ITF2	14.93	53.74	49.98	45.44	41.64
ITF3	14.825	53.33	49.6	45.08	41.33
ITF4	16.229	48.34	44.96	40.88	37.48
ITF5	15.299	51.34	47.75	43.41	39.79

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ITF6	15.22	50.45	46.92	42.66	39.11
ITG1	15.57	49.85	46.36	42.14	38.64
ITG2	13.036	57.1	53.1	48.27	44.26
LU00	13.059	42.36	39.39	35.82	32.83
MT00	14.168	24.56	22.84	20.77	19.04
NL11	11.832	93.18	86.66	78.75	72.21
NL12	11.583	95.17	88.51	80.47	73.76
NL13	11.81	93.34	86.81	78.92	72.35
NL21	12.723	86.65	80.58	73.23	67.14
NL22	13.095	84.18	78.29	71.2	65.26
NL23	12.094	91.15	84.77	77.08	70.66
NL31	12.797	86.15	80.12	72.82	66.75
NL32	11.676	94.42	87.81	79.85	73.18
NL33	12.473	88.38	82.19	74.72	68.48
NL34	12.773	86.31	80.27	72.97	66.88
NL41	12.931	85.25	79.28	72.09	66.05
NL42	13.152	83.83	77.96	70.86	64.98
PL11	14.494	38.22	35.54	32.32	29.62
PL12	14.302	38.73	36.02	32.75	30.02
PL21	13.596	40.74	37.89	34.44	31.57
PL22	13.523	40.96	38.09	34.62	31.74
PL31	14.942	37.07	34.48	31.34	28.73
PL32	14.729	37.61	34.98	31.8	29.16
PL33	14.378	38.53	35.83	32.56	29.86
PL34	13.22	41.9	38.97	35.43	32.48
PL41	14.469	38.29	35.61	32.36	29.68
PL42	12.778	43.35	40.32	36.64	33.61
PL43	14.386	38.06	35.4	32.19	29.51
PL51	13.999	39.57	36.8	33.45	30.66
PL52	14.405	38.45	35.76	32.5	29.79
PL61	13.601	40.73	37.88	34.44	31.57
PL62	12.508	44.29	41.19	37.44	34.32
PL63	11.371	48.71	45.3	41.18	37.74
PT11	11.468	36.56	34	30.92	28.34
PT15	10.684	35.14	32.68	29.71	27.23
PT16	11.935	33.74	31.38	28.52	26.15
PT17	14.403	28.07	26.11	23.74	21.76
PT18	12.074	31.96	29.72	27.02	24.76
PT20	12.074	31.96	29.72	27.02	24.76
PT30	12.074	31.96	29.72	27.02	24.76
RO11	17.014	15.4	14.32	13.01	11.93
RO12	17.671	13.93	12.95	11.77	10.79
RO21	18.261	13.89	12.92	11.74	10.77
RO22	18.341	14.07	13.09	11.9	10.91
RO31	18.062	14.36	13.35	12.14	11.13
RO32	16.153	16.46	15.31	13.92	12.76

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RO41	15.652	16.99	15.8	14.36	13.17
RO42	18.664	13.65	12.69	11.54	10.57
SI01	16.82	14.8	13.76	12.51	11.47
SI02	16.82	14.8	13.76	12.51	11.47
SK01	15.617	15.24	14.17	12.88	11.81
SK02	15.934	15.27	14.2	12.91	11.83
SK03	14.573	17.13	15.93	14.48	13.27
SK04	15.153	31.82	29.59	26.9	24.66
UKD1	6.806	92.2	85.75	77.92	71.43
UKD3	6.806	92.2	85.75	77.92	71.43
UKD4	6.806	92.2	85.75	77.92	71.43
UKD6	6.806	92.2	85.75	77.92	71.43
UKD7	6.806	92.2	85.75	77.92	71.43
UKE1	7.696	81.54	75.83	68.9	63.16
UKE2	7.696	81.54	75.83	68.9	63.16
UKE3	7.696	81.54	75.83	68.9	63.16
UKE4	7.696	81.54	75.83	68.9	63.16
UKF1	9.95	63.07	58.66	53.3	48.88
UKF2	9.95	63.07	58.66	53.3	48.88
UKF3	9.95	63.07	58.66	53.3	48.88
UKG1	9.269	67.7	62.96	57.21	52.48
UKG2	9.269	67.7	62.96	57.21	52.48
UKG3	9.269	67.7	62.96	57.21	52.48
UKH1	10.989	57.11	53.11	48.27	44.25
UKH2	10.989	57.11	53.11	48.27	44.25
UKH3	10.989	57.11	53.11	48.27	44.25
UKI1	8.636	72.67	67.58	61.43	56.33
UKI2	8.636	72.67	67.58	61.43	56.33
UKJ1	11.183	56.12	52.19	47.45	43.49
UKJ2	11.183	56.12	52.19	47.45	43.49
UKJ3	11.183	56.12	52.19	47.45	43.49
UKJ4	11.183	56.12	52.19	47.45	43.49
UKK1	9.799	64.04	59.56	54.14	49.63
UKK2	9.799	64.04	59.56	54.14	49.63
UKK3	9.799	64.04	59.56	54.14	49.63
UKK4	9.799	64.04	59.56	54.14	49.63
UKL1	7.913	79.3	73.75	67.08	61.43
UKL2	7.913	79.3	73.75	67.08	61.43

Table 9: Upscaling (Willow SRC). Outlook of cost reduction potential until 2030/50. Assumed temporal relevance of the innovation: 2050; Geographical relevance: EU wide.

	Average yield	Road side costs	Road side costs	Road side costs
Unit	tonnes DM/ha	EUR/tonnes DM*yr	EUR/tonnes DM*yr	EUR/tonnes DM*yr
NUT2	2010 (Elbersen)	2010 (Elbersen)	2030	2050

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AT11	11.075	45.31	41.2	33.98
AT12	10.446	48.55	44.14	36.4
AT13	10.647	47.64	43.32	35.72
AT21	11.154	45.47	41.33	34.11
AT22	10.901	46.52	42.29	34.89
AT31	9.646	52.58	47.8	39.42
AT32	11.78	43.05	39.13	32.28
AT33	9.752	52.01	47.27	39.02
AT34	10.341	49.04	44.56	36.78
BE10	11.992	55.41	50.38	41.56
BE21	9.809	67.74	61.58	50.81
BE22	11.878	55.94	50.84	41.97
BE23	10.893	61	55.46	45.76
BE24	13.142	50.56	45.95	37.92
BE25	11.246	59.09	53.72	44.3
BE31	13.06	50.88	46.24	38.16
BE32	13.125	50.63	46.02	37.97
BE33	11.997	55.39	50.34	41.53
BE34	11.795	56.34	51.24	42.27
BE35	12.973	51.22	46.56	38.41
BG31	10.963	22	20	16.49
BG32	10.21	23.63	21.48	17.73
BG33	9.015	25.41	23.09	19.05
BG34	8.516	27.49	24.98	20.62
BG41	8.431	27.38	24.9	20.53
BG42	7.527	29.56	26.87	22.18
CZ01	8.825	26.46	24.05	19.85
CZ02	8.659	26.97	24.53	20.23
CZ03	8.67	26.93	24.47	20.21
CZ04	8.744	26.71	24.28	20.04
CZ05	9.067	25.76	23.43	19.32
CZ06	8.951	26.09	23.71	19.57
CZ07	10.416	22.42	20.38	16.81
CZ08	9.928	23.52	21.38	17.65
DE1	10.696	62.58	56.87	46.92
DE2	10.893	61.45	55.87	46.09
DE3	10.794	62.01	56.39	46.52
DE4	7.572	88.39	80.35	66.27
DE5	9.75	68.65	62.38	51.49
DE6	9.75	68.65	62.38	51.49
DE7	11.558	57.86	52.62	43.39
DE8	7.498	89.28	81.14	66.94
DE9	9.291	72.04	65.49	54.03
DEA	12.085	55.39	50.37	41.55
DEB	11.218	59.67	54.24	44.76
DEC	11.896	56.27	51.14	42.19

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DED	9.347	71.61	65.11	53.69
DEE	8.535	78.43	71.29	58.83
DEF	7.162	93.46	84.94	70.13
DEG	8.908	75.14	68.3	56.35
DK01	7.128	127.88	116.27	95.95
DK02	7.128	127.88	116.27	95.95
DK03	7.128	127.88	116.27	95.95
DK04	7.128	127.88	116.27	95.95
DK05	7.128	127.88	116.27	95.95
EE00	6.991	31.98	29.07	23.98
ES11	9.442	62.43	56.73	46.82
ES12	9.18	64.5	58.62	48.36
ES13	9.365	63.38	57.63	47.53
ES21	9.571	61.67	56.05	46.23
FI19	4.269	91.67	83.26	68.79
FI1B	4.547	86.08	78.28	64.52
FI1C	3.55	110.25	100.1	82.69
FI20	0.893	438.1	399.2	329.06
FR10	12.365	51.57	46.89	38.67
FR21	10.921	58.32	53.03	43.72
FR22	11.338	57.26	52.06	42.93
FR23	12.828	50.61	46.01	37.97
FR24	10.836	57.44	52.22	43.09
FR25	14.341	45.27	41.14	33.95
FR26	11.615	54.27	49.32	40.7
FR30	12.278	52.88	48.06	39.67
FR41	11.668	55.64	50.6	41.73
FR42	11.397	56.96	51.77	42.71
FR43	12.88	50.41	45.82	37.8
FR51	12.281	50.97	46.33	38.22
FR52	12.984	50	45.46	37.5
FR53	10.895	54.99	50.01	41.26
FR61	11.645	52.44	47.67	39.34
FR63	12.535	49.93	45.39	37.45
FR72	10.757	58.61	53.29	43.95
FR91	11.974	53.07	48.25	39.8
FR92	11.974	53.07	48.25	39.8
FR93	11.974	53.07	48.25	39.8
FR94	11.974	53.07	48.25	39.8
HR03	9.11	22.42	20.38	16.82
HR04	9.11	22.42	20.38	16.82
HU10	9.367	23.26	21.15	17.45
HU21	8.389	25.93	23.57	19.44
HU22	10.268	21.8	19.83	16.35
HU23	9.076	23.71	21.56	17.78
HU31	11.62	19.68	17.89	14.76

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HU32	9.3	24.26	22.05	18.2
HU33	8.578	25.23	22.93	18.93
IE01	9.267	54.76	49.8	41.07
IE02	9.267	54.76	49.8	41.07
LT00	8.806	20.12	18.28	15.09
LU00	11.992	41.21	37.47	30.91
LV00	8.403	21.8	19.83	16.36
ME00	9.11		0	0
NL11	7.258	143.49	130.51	107.61
NL12	8.183	127.27	115.72	95.45
NL13	7.397	140.79	127.94	105.55
NL21	8.395	124.05	112.83	93.07
NL22	10.56	98.62	89.62	73.98
NL23	8.174	127.41	115.85	95.55
NL31	11.238	92.67	84.26	69.48
NL32	9.06	114.94	104.45	86.22
NL33	9.728	107.05	97.33	80.31
NL34	8.369	124.43	113.07	93.35
NL41	9.135	114	103.62	85.52
NL42	11.324	91.96	83.58	68.96
PL11	8.787	56.84	51.65	42.65
PL12	8.213	60.81	55.31	45.59
PL21	9.242	54.04	49.11	40.53
PL22	9.83	50.8	46.19	38.09
PL31	9.703	51.47	46.81	38.61
PL32	9.749	51.23	46.59	38.42
PL33	10.478	47.66	43.31	35.76
PL34	8.365	59.7	54.28	44.77
PL41	7.945	62.86	57.14	47.16
PL42	8.744	57.11	51.91	42.84
PL43	8.178	60.35	54.84	45.28
PL51	8.883	56.22	51.12	42.16
PL52	9.293	53.74	48.87	40.31
PL61	8.241	60.6	55.06	45.45
PL62	8.475	58.93	53.59	44.2
PL63	7.972	62.64	56.94	46.96
PT11	8.351	44.62	40.55	33.47
PT16	7.403	48.28	43.91	36.23
PT17	7.403	48.28	43.91	36.23
PT20	7.403	48.28	43.91	36.23
PT30	7.403	48.28	43.91	36.23
RO11	10.907	19.19	17.44	14.39
RO12	9.02	21.78	19.8	16.34
RO21	10.276	19.71	17.92	14.78
RO22	11.059	18.64	16.95	13.98
RO31	10.8	19.19	17.45	14.39

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RO32	12.098	17.57	15.97	13.18
RO41	11.661	18.23	16.57	13.68
RO42	11.303	18	16.37	13.5
SE11	8.547	84.8	77.11	63.58
SE12	7.888	91.88	83.5	68.88
SE21	8.841	81.98	74.49	61.48
SE22	4.785	151.46	137.78	113.64
SE23	0.602	1203.06	1097.33	905.3
SE32	8.277	87.57	79.65	65.69
SE33	8.089	89.61	81.44	67.19
SI01	12.889	15.19	13.81	11.39
SI02	12.889	15.19	13.81	11.39
SK01	9.117	20.44	18.58	15.33
SK02	9.768	19.5	17.74	14.63
SK03	10.747	18.19	16.54	13.64
SK04	11.332	37.74	34.3	28.3
UKC1	6.799	83.43	75.83	62.56
UKC2	6.799	83.43	75.83	62.56
UKD1	6.799	83.43	75.83	62.56
UKD3	6.799	83.43	75.83	62.56
UKD4	6.799	83.43	75.83	62.56
UKD6	6.799	83.43	75.83	62.56
UKD7	6.799	83.43	75.83	62.56
UKE1	7.228	78.48	71.35	58.88
UKE2	7.228	78.48	71.35	58.88
UKE3	7.228	78.48	71.35	58.88
UKE4	7.228	78.48	71.35	58.88
UKF1	8.157	69.54	63.24	52.15
UKF2	8.157	69.54	63.24	52.15
UKF3	8.157	69.54	63.24	52.15
UKG1	10.235	55.42	50.37	41.57
UKG2	10.235	55.42	50.37	41.57
UKG3	10.235	55.42	50.37	41.57
UKH1	9.802	57.87	52.62	43.41
UKH2	9.802	57.87	52.62	43.41
UKH3	9.802	57.87	52.62	43.41
UKI1	8.194	69.23	62.96	51.94
UKI2	8.194	69.23	62.96	51.94
UKJ1	11.394	49.79	45.28	37.35
UKJ2	11.394	49.79	45.28	37.35
UKJ3	11.394	49.79	45.28	37.35
UKJ4	11.394	49.79	45.28	37.35
UKK1	11.282	50.28	45.71	37.71
UKK2	11.282	50.28	45.71	37.71
UKK3	11.282	50.28	45.71	37.71
UKK4	11.282	50.28	45.71	37.71

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UKL1	9.241	61.38	55.77	46.03
UKL2	9.241	61.38	55.77	46.03
UKM2	8.993	63.08	57.36	47.32
UKM3	8.993	63.08	57.36	47.32
UKM5	8.993	63.08	57.36	47.32
UKM6	8.993	63.08	57.36	47.32
UKN0	8.993	63.08	57.36	47.32

Table 10: Learning Effect (Willow SRC). Outlook of cost reduction potential until 2030/50. Assumed temporal relevance of the innovation: 2050; Geographical relevance: EU wide.

Unit NUT2	Average yield tonnes DM/ha 2010 (Elbersen)	Road side costs EUR/tonnes DM*yr 2010(Elbersen)	Road side costs EUR/tonnes DM*yr 2030	Road side costs EUR/tonnes DM*yr 2050
AT11	11.075	45.31	41.2	28.32
AT12	10.446	48.55	44.14	30.33
AT13	10.647	47.64	43.32	29.77
AT21	11.154	45.47	41.33	28.43
AT22	10.901	46.52	42.29	29.08
AT31	9.646	52.58	47.8	32.85
AT32	11.78	43.05	39.13	26.9
AT33	9.752	52.01	47.27	32.51
AT34	10.341	49.04	44.56	30.65
BE10	11.992	55.41	50.38	34.63
BE21	9.809	67.74	61.58	42.34
BE22	11.878	55.94	50.84	34.97
BE23	10.893	61	55.46	38.13
BE24	13.142	50.56	45.95	31.6
BE25	11.246	59.09	53.72	36.92
BE31	13.06	50.88	46.24	31.8
BE32	13.125	50.63	46.02	31.64
BE33	11.997	55.39	50.34	34.61
BE34	11.795	56.34	51.24	35.22
BE35	12.973	51.22	46.56	32.01
BG31	10.963	22	20	13.75
BG32	10.21	23.63	21.48	14.77
BG33	9.015	25.41	23.09	15.88
BG34	8.516	27.49	24.98	17.18
BG41	8.431	27.38	24.9	17.11
BG42	7.527	29.56	26.87	18.48
CZ01	8.825	26.46	24.05	16.54
CZ02	8.659	26.97	24.53	16.86
CZ03	8.67	26.93	24.47	16.84
CZ04	8.744	26.71	24.28	16.7
CZ05	9.067	25.76	23.43	16.1

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CZ06	8.951	26.09	23.71	16.31
CZ07	10.416	22.42	20.38	14.01
CZ08	9.928	23.52	21.38	14.7
DE1	10.696	62.58	56.87	39.1
DE2	10.893	61.45	55.87	38.41
DE3	10.794	62.01	56.39	38.76
DE4	7.572	88.39	80.35	55.22
DE5	9.75	68.65	62.38	42.91
DE6	9.75	68.65	62.38	42.91
DE7	11.558	57.86	52.62	36.16
DE8	7.498	89.28	81.14	55.79
DE9	9.291	72.04	65.49	45.02
DEA	12.085	55.39	50.37	34.62
DEB	11.218	59.67	54.24	37.3
DEC	11.896	56.27	51.14	35.16
DED	9.347	71.61	65.11	44.74
DEE	8.535	78.43	71.29	49.03
DEF	7.162	93.46	84.94	58.44
DEG	8.908	75.14	68.3	46.96
DK01	7.128	127.88	116.27	79.96
DK02	7.128	127.88	116.27	79.96
DK03	7.128	127.88	116.27	79.96
DK04	7.128	127.88	116.27	79.96
DK05	7.128	127.88	116.27	79.96
EE00	6.991	31.98	29.07	19.99
ES11	9.442	62.43	56.73	39.02
ES12	9.18	64.5	58.62	40.3
ES13	9.365	63.38	57.63	39.61
ES21	9.571	61.67	56.05	38.53
FI19	4.269	91.67	83.26	57.33
FI1B	4.547	86.08	78.28	53.77
FI1C	3.55	110.25	100.1	68.91
FI20	0.893	438.1	399.2	274.22
FR10	12.365	51.57	46.89	32.23
FR21	10.921	58.32	53.03	36.44
FR22	11.338	57.26	52.06	35.78
FR23	12.828	50.61	46.01	31.64
FR24	10.836	57.44	52.22	35.91
FR25	14.341	45.27	41.14	28.29
FR26	11.615	54.27	49.32	33.91
FR30	12.278	52.88	48.06	33.06
FR41	11.668	55.64	50.6	34.78
FR42	11.397	56.96	51.77	35.59
FR43	12.88	50.41	45.82	31.5
FR51	12.281	50.97	46.33	31.85
FR52	12.984	50	45.46	31.25

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FR53	10.895	54.99	50.01	34.38
FR61	11.645	52.44	47.67	32.78
FR63	12.535	49.93	45.39	31.21
FR72	10.757	58.61	53.29	36.63
FR91	11.974	53.07	48.25	33.17
FR92	11.974	53.07	48.25	33.17
FR93	11.974	53.07	48.25	33.17
FR94	11.974	53.07	48.25	33.17
HR03	9.11	22.42	20.38	14.02
HR04	9.11	22.42	20.38	14.02
HU10	9.367	23.26	21.15	14.54
HU21	8.389	25.93	23.57	16.2
HU22	10.268	21.8	19.83	13.63
HU23	9.076	23.71	21.56	14.82
HU31	11.62	19.68	17.89	12.3
HU32	9.3	24.26	22.05	15.16
HU33	8.578	25.23	22.93	15.77
IE01	9.267	54.76	49.8	34.23
IE02	9.267	54.76	49.8	34.23
LT00	8.806	20.12	18.28	12.57
LU00	11.992	41.21	37.47	25.76
LV00	8.403	21.8	19.83	13.63
ME00	9.11		0	0
NL11	7.258	143.49	130.51	89.68
NL12	8.183	127.27	115.72	79.54
NL13	7.397	140.79	127.94	87.96
NL21	8.395	124.05	112.83	77.56
NL22	10.56	98.62	89.62	61.65
NL23	8.174	127.41	115.85	79.62
NL31	11.238	92.67	84.26	57.9
NL32	9.06	114.94	104.45	71.85
NL33	9.728	107.05	97.33	66.93
NL34	8.369	124.43	113.07	77.79
NL41	9.135	114	103.62	71.26
NL42	11.324	91.96	83.58	57.47
PL11	8.787	56.84	51.65	35.54
PL12	8.213	60.81	55.31	37.99
PL21	9.242	54.04	49.11	33.78
PL22	9.83	50.8	46.19	31.74
PL31	9.703	51.47	46.81	32.18
PL32	9.749	51.23	46.59	32.02
PL33	10.478	47.66	43.31	29.8
PL34	8.365	59.7	54.28	37.31
PL41	7.945	62.86	57.14	39.3
PL42	8.744	57.11	51.91	35.7
PL43	8.178	60.35	54.84	37.73

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PL51	8.883	56.22	51.12	35.14
PL52	9.293	53.74	48.87	33.59
PL61	8.241	60.6	55.06	37.87
PL62	8.475	58.93	53.59	36.83
PL63	7.972	62.64	56.94	39.14
PT11	8.351	44.62	40.55	27.89
PT16	7.403	48.28	43.91	30.19
PT17	7.403	48.28	43.91	30.19
PT20	7.403	48.28	43.91	30.19
PT30	7.403	48.28	43.91	30.19
RO11	10.907	19.19	17.44	11.99
RO12	9.02	21.78	19.8	13.62
RO21	10.276	19.71	17.92	12.32
RO22	11.059	18.64	16.95	11.65
RO31	10.8	19.19	17.45	11.99
RO32	12.098	17.57	15.97	10.98
RO41	11.661	18.23	16.57	11.4
RO42	11.303	18	16.37	11.25
SE11	8.547	84.8	77.11	52.98
SE12	7.888	91.88	83.5	57.4
SE21	8.841	81.98	74.49	51.23
SE22	4.785	151.46	137.78	94.7
SE23	0.602	1203.06	1097.33	754.42
SE32	8.277	87.57	79.65	54.74
SE33	8.089	89.61	81.44	55.99
SI01	12.889	15.19	13.81	9.49
SI02	12.889	15.19	13.81	9.49
SK01	9.117	20.44	18.58	12.78
SK02	9.768	19.5	17.74	12.19
SK03	10.747	18.19	16.54	11.37
SK04	11.332	37.74	34.3	23.58
UKC1	6.799	83.43	75.83	52.14
UKC2	6.799	83.43	75.83	52.14
UKD1	6.799	83.43	75.83	52.14
UKD3	6.799	83.43	75.83	52.14
UKD4	6.799	83.43	75.83	52.14
UKD6	6.799	83.43	75.83	52.14
UKD7	6.799	83.43	75.83	52.14
UKE1	7.228	78.48	71.35	49.07
UKE2	7.228	78.48	71.35	49.07
UKE3	7.228	78.48	71.35	49.07
UKE4	7.228	78.48	71.35	49.07
UKF1	8.157	69.54	63.24	43.46
UKF2	8.157	69.54	63.24	43.46
UKF3	8.157	69.54	63.24	43.46
UKG1	10.235	55.42	50.37	34.64

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UKG2	10.235	55.42	50.37	34.64
UKG3	10.235	55.42	50.37	34.64
UKH1	9.802	57.87	52.62	36.18
UKH2	9.802	57.87	52.62	36.18
UKH3	9.802	57.87	52.62	36.18
UKI1	8.194	69.23	62.96	43.28
UKI2	8.194	69.23	62.96	43.28
UKJ1	11.394	49.79	45.28	31.13
UKJ2	11.394	49.79	45.28	31.13
UKJ3	11.394	49.79	45.28	31.13
UKJ4	11.394	49.79	45.28	31.13
UKK1	11.282	50.28	45.71	31.42
UKK2	11.282	50.28	45.71	31.42
UKK3	11.282	50.28	45.71	31.42
UKK4	11.282	50.28	45.71	31.42
UKL1	9.241	61.38	55.77	38.36
UKL2	9.241	61.38	55.77	38.36
UKM2	8.993	63.08	57.36	39.43
UKM3	8.993	63.08	57.36	39.43
UKM5	8.993	63.08	57.36	39.43
UKM6	8.993	63.08	57.36	39.43
UKN0	8.993	63.08	57.36	39.43

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