

Lignocellulosic Crops in Agricultural Landscapes

Production systems for biomass and other environmental benefits – examples, incentives, and barriers



Cover image: Figure 14 in the report. View of a municipal wastewater plant in Enköping, Sweden, with water storage ponds and (behind the ponds) willow fields that are used as vegetation filters. The photo is taken from the roof of the heat and power plant that uses the locally produced biomass (Photo: Pär Aronsson, SLU)

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Lignocellulosic Crops in Agricultural Landscapes

Production systems for biomass and other environmental benefits – examples, incentives, and barriers

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In memorandum – Prof. Don Tyler

Introduction

Policies to support bioenergy have been promoted in part to address concerns about the negative impacts caused by fossil energy systems. Agriculture provides food, fibre and bioenergy products, but increased production can be sustainably achieved only if negative impacts on, e.g., soils, water, biodiversity and climate are avoided or minimized. Agriculture can also provide other social and economic benefits, ranging from rural income and employment, to the conservation of cultures, and pleasing visual landscapes. Many risks associated with conventional agricultural production systems and fossil fuels could be mitigated or avoided, through the development of sustainable production systems for lignocellulosic bioenergy crops.

Lignocellulosic crops can be cultivated on soils of varying qualities, providing high biomass output per unit area. Plants include perennial grasses, such as switchgrass and miscanthus, and tree species, such as willows, eucalyptus, and poplars, grown in relatively short rotations either in coppicing systems or with replanting after each harvest. They represent a promising option for producing biomass for energy and are referred to as one of the most efficient options for reducing greenhouse emissions through fossil fuel displacement. Studies that assess bioenergy potentials for the longer term consistently report that the production of biomass in dedicated plantations is a prerequisite for reaching higher end biomass supply potentials, i.e., levels necessary for meeting climate targets of 1.5 or 2 degrees.

During the last two decades, several predictions – primarily in Europe, but also elsewhere – have indicated the possibility of a dramatic increase in agricultural areas dedicated to lignocellulosic crops, in response to European energy and climate targets. Similarly, lignocellulosic crops have repeatedly been identified as an attractive option for bioenergy supply in N. America, Australia, and other parts of the world. Emerging options for converting lignocellulosic biomass into refined solid, liquid, and gaseous fuels build from access to new feedstock resources and more benign feedstock production systems. It is well-documented that such lignocellulosic cropping systems can be integrated into agricultural landscapes so as to make better use of available resources and provide multiple benefits in addition to the harvested biomass (Berndes et al., 2008; Dale et al., 2011). Not the least, such systems can – through well-chosen site location, design, management and system integration – offer additional ecosystem services that, in turn, create added value (Weih and Dimitriou, 2012). Understanding the positive and negative impacts of different agricultural land management options is critical for the development of management regimes that balance trade-offs between environmental, social and economic objectives that might be partly incompatible.

Yet, many of the lignocellulosic crop options identified as promising future biomass supply sources are either rarely used today, or used for other purposes such as animal feeding and pulpwood production. Thus, there is a need for a better understanding of the barriers to large-scale mobilization of these lignocellulosic crop options for bioenergy feedstock. Based on this, implementation strategies that facilitate sensible establishment and deployment of lignocellulosic production systems on agriculture land, that are considered attractive from both environmental, social and economic points of view, are necessary.

This case study concerns lignocellulosic crops that are commercially cultivated for bioenergy or other markets (e.g., pulp and paper production), as well as cropping systems that are presently little used but have much in common with already established options, concerning biomass properties and technologies in the production and supply chains. The scope for the main analysis is limited to feedstock production and supply to a conversion plant. Insights from the other case studies can be used to address the issue of matching feedstock quality with requirements

associated with specific conversion systems. A specific focus in this case study is placed on the integration of lignocellulosic crops in the agriculture landscape to provide biomass feedstock while at the same time providing additional benefits, such as enhancing biodiversity, reducing water and wind erosion, improving soil productivity and enhancing soil carbon storage, and reducing nutrient loading in aquatic ecosystems. Many of these negative environmental effects that can be mitigated are associated with the cultivation of conventional food and feed crops.

AIM

This report summarises a project that analysed options for integrating lignocellulosic crops in the agricultural landscape, to provide biomass feedstock while at the same time providing additional ecosystem services. This was done by analysing several concrete cases of relevant lignocellulosic cropping systems. Each case was evaluated on context, drivers for implementation, approach, and sustainability outcomes in terms of positive and negative environmental, social and economic impacts. General and case-specific incentives and constraints towards wider implementation were also analysed.

Here, six cases of different lignocellulosic cropping systems in Ireland, Australia, USA, Germany and Sweden are briefly described, focusing on biomass production systems and how dedicated ecosystem services can be co-delivered by these systems. Based on the analysis of incentives and constraints in each case, a synthesis is then provided summarising general incentives for lignocellulosic cropping systems as biomass feedstock for bioenergy, as well as main barriers for wider implementation.

Examples of lignocellulosic cropping systems in agricultural landscapes

For the purpose of this report, six indicative production systems were selected, based on lignocellulosic crops used, ecosystem services provided, and geographical location (from Task 43 countries), to be as representative as possible. Therefore, we include two examples focusing on "production" (case 1 and 2), two focusing on "selecting implementation areas" to achieve the highest positive impact on certain ecosystem services (case 3 and 4), and finally two examples where applied large-scale "multifunctional lignocellulosic crop plantings" are described (sections 5 and 6). A more detailed analysis of the background of these examples, as well as the research results behind of these systems are provided in the comprehensive full project report (Dimitriou et al., forthcoming 2019).

CASE 1: PRODUCTION OF SHORT ROTATION WILLOW FOR BIOENERGY IN IRELAND

In an effort to promote the use of bioenergy in Ireland and to contribute to meeting the EU targets, the government set out to implement co-firing of biomass at three peat-fired electricity generating plants owned by the state. The co-firing targets are limited to co-firing 30% of the maximum rated capacity in any plant until 2017, 40% between 2017 and 2019, and 50% thereafter (Ireland, 2009). Three hundred kilotonnes of biomass will be required to achieve 30% co-firing at Edenderry power plant alone. In order to meet this demand, additional quantities of biomass to those currently co-fired will need to be obtained. Short rotation coppice willow (*Salix* sp.) (SRCW) has been cultivated as an energy crop in Ireland to help meet the biomass demand of the three peat-fired power plants. In order to promote the cultivation of willow among farmers, a bioenergy scheme was introduced in 2007 that offers financial support for the establishment of willow crops. Similarly, the operator of Edenderry power plant offers support to farmers willing to establish a willow crop and supply it to the power plant. These incentives have led to an increase in willow planting since their inception, from around 100 ha in 2008 to more than 800 ha of willow crops planted in Ireland in 2015. In 2010, 5,208 tonnes of willow chip were co-fired with peat in Edenderry power plant, representing 5.4% of total biomass co-fired in Ireland on a mass basis. With the co-firing target increasing to 30% by 2017, a substantial increase in the area of energy crop plantations is required.

To further increase the SRCW land base needed to reach the expressed targets in Ireland, the importance of policy measures including incentives in promoting the uptake of energy crops have been clearly stated in many countries, not only in countries such as Sweden, which is now the European leader in SRCW for energy production on agricultural lands (Mola-Yudego et al., 2014). Despite the incentives needed that will come from political decisions, the features of the crops that will be potentially supported for broader implementation need to be adapted to the specific edaphoclimatic conditions in the area to ensure high production per unit area, and need also to offer other ecosystem services besides the biomass that will fulfil other governmental environmental, social and economic goals. In the case of willow, the crop is known to be suitable for cultivation on medium fertility sites, thus not competing for the most fertile land, which is currently used for food production. Moreover, the long life-span of willow crops (20 plus years) allows the accumulation of soil carbon in mineral soils, as well as promoting stable nutrient cycling and soil biological activity, resulting in increased soil fertility when compared to conventional agricultural crops. In addition, the cultivation of willow promotes higher biodiversity when compared to conventional agricultural crops. Willow crops are also known for their bioremediation potential. Willow has been proven to effectively take up nutrients and heavy metals and can, therefore, be used for treatment and utilisation of nutrient-rich municipal residues such as wastewater and/or sewage sludge, improving treatment efficiencies, but also the economic welfare of the farmers (Dimitriou and Aronsson, 2005). Under the Irish context, willow is an appropriate crop since it has relatively high water requirements, and the vast majority of Ireland receives upwards of 800 mm of rainfall per year. Surveys carried out with Irish farmers have shown high willingness of farmers to adopt energy crops in Ireland, with over 70% of respondents indicating interest in producing energy crops (Augustenborg et al., 2012).

All the above indicate that the potential of SRCW in Ireland is high, and therefore studies to evaluate the energy requirements and environmental impacts associated with the cultivation, harvest, and transport of SRCW for energy utilisation in Ireland have been conducted to quantify this potential. Detailed life cycle inventory (LCI) data for willow cultivation in Ireland considering a number of scenarios based on different management regimes for SRCW (synthetic fertilizer and biosolid application, chip and whole rod harvesting, and transport distances) have been conducted, and the energy and GHG balances of biomass to energy systems have been contrasted against

fossil fuel systems, to allow comparisons of the potential benefits/drawbacks of the bioenergy system in question (background in Table 1 and Figure 1).

Table 1: (Case 1) Willow production scenarios

Scenario	Fertiliser Type	Harvest Type	Transportation Method	Transportation Distance
1	Synthetic	Direct Chip	Truck	50 km
2	Biological	Direct Chip	Truck	50 km
3	Synthetic	Rod	Truck	50 km
4	Biological	Rod	Truck	50 km
5	Synthetic	Direct Chip	Tractor	50 km
6	Biological	Direct Chip	Tractor	50 km
7	Synthetic	Rod	Tractor	50 km
8	Biological	Rod	Tractor	50 km
9	Synthetic	Direct Chip	Truck	100 km
10	Biological	Direct Chip	Truck	100 km
11	Synthetic	Rod	Truck	100 km
12	Biological	Rod	Truck	100 km

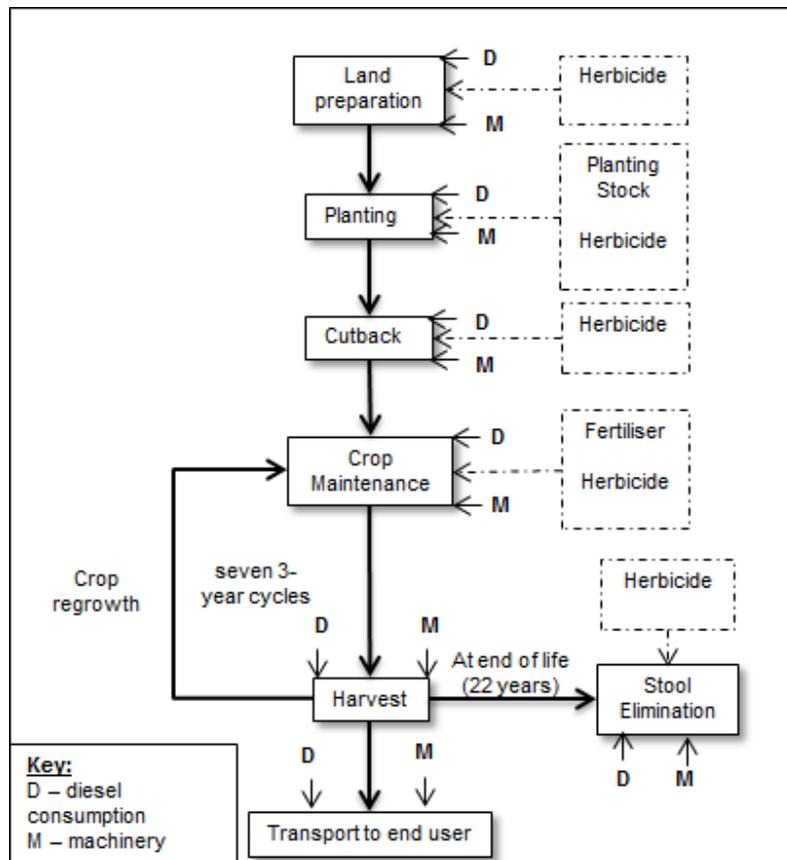


Figure 1: (Case 1) System boundary of willow cultivation. Dotted lines denote material inputs to the system

The results in brief highlight the positive environmental benefits of SRCW production. The results identify three key processes in the production chain that contribute most significantly to all impact categories considered, namely maintenance, harvest and transportation of the crop (Table 2). Sensitivity analysis on the type of fertilisers used, harvesting technologies, and transport distances highlights the effects of these management techniques on overall system performance. The use of biological fertiliser in place of synthetic fertiliser improves the energy performance of the system while negatively affecting each of the environmental impacts considered. Results highlight the importance of keeping biomass supply and use on a regional level, in order to keep transport distances low and thus maximise the environmental benefits attributable to biomass.

Finally, willow chip production compares favourably with coal provision in terms of energy ratio and global warming potential (for coal 12.28 kg CO₂ eq per GJ (Dones et al., 2007)), while achieving a higher energy ratio than peat provision but also a higher global warming potential (Fig. 2).

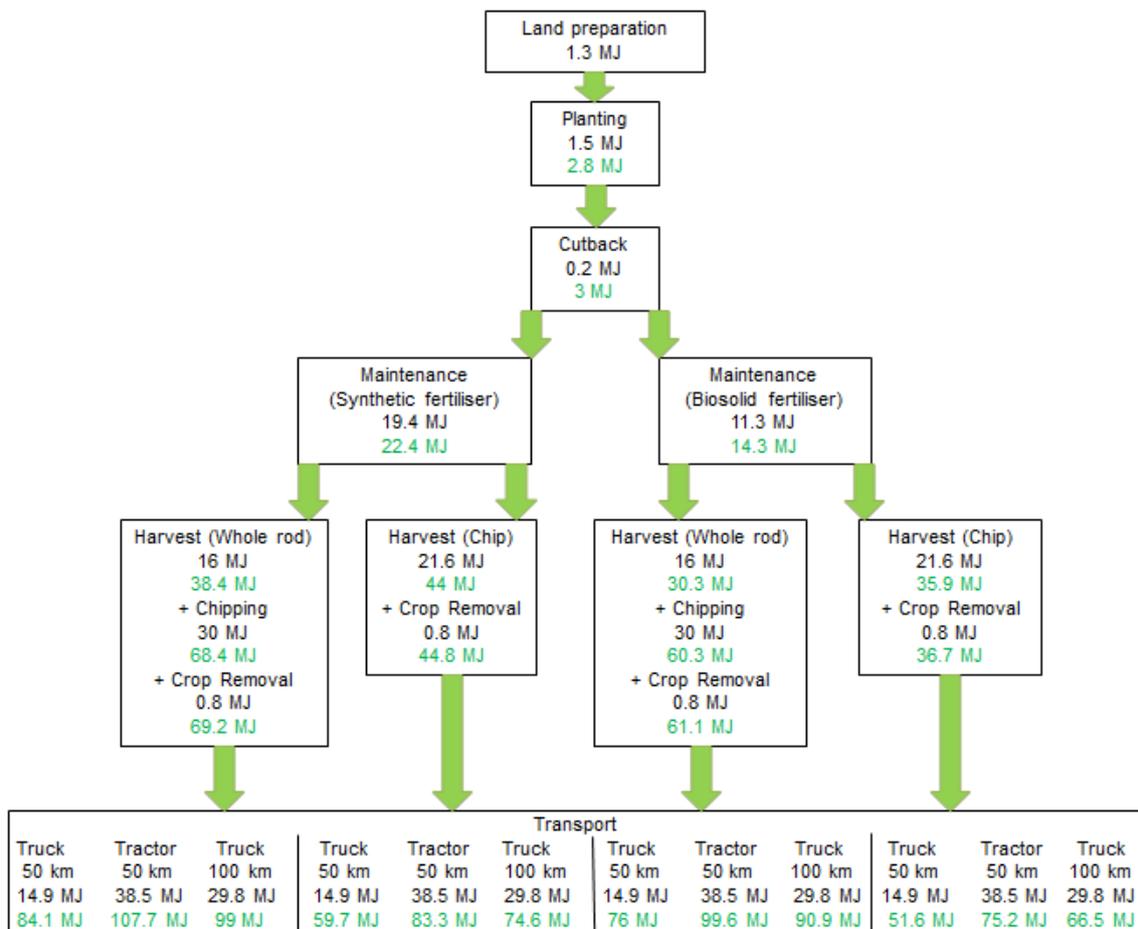


Figure 2: (Case 1) Energy flow diagram (per GJ of willow chip produced)

Table 2: (Case 1) LCA results per GJ of energy contained in willow chip biomass for the base-case scenario. AP = acidification potential, EP = eutrophication potential, GWP = global warming potential, CED = cumulative energy demand.

Impact category	Unit	Land Prep.	Planting	Cutback	Maintenance	Harvest	Crop Removal	Transport	Total
AP	kg SO ₂ eq	0.0005	0.0011	0.0001	0.0216	0.0058	0.0003	0.0043	0.0336
EP	kg PO ₄ -eq	0.0002	0.0009	0.0000	0.0052	0.0017	0.0001	0.0011	0.0092
GWP	kg CO ₂ eq	0.43	0.15	0.01	2.99	1.32	0.05	0.88	5.84
CED	MJ	1.3	1.5	0.2	19.4	21.6	0.8	14.9	59.7

CASE 2: WOODY BIOMASS PLANTATIONS FOR AVIATION FUEL IN AUSTRALIA

While Australia currently produces considerable biomass from its agricultural and forestry systems, the total production falls well short of being able to sustain Australia's energy consumption, indicating that Australia's biomass resources will need to be directed towards strategically important energy uses. Although there is significant scope to increase the use of biomass, very little of it is currently used for bioenergy production. There are several reasons for this. First, there is a policy limitation: the need to better understand and address the interrelationship between carbon, water and energy to promote integrated outcomes for the natural and built environments within Australia has been already identified in government reports, and the integration of food, energy and water resources is a major issue facing Australia (PMSEIC, 2010). Second there is a commercial limitation: while Australian broadacre farmers experienced declining terms of trade for most of the last 40 years with about a quarter not being profitable in recent years, this is not resulting in diversification away from grain cropping. For the coming five years the terms of trade and the area planted for cereal crops are projected to slightly increase. Farmers have adapted by increasing the scale of their operations and/or intensifying the production systems with increased innovation required to remain profitable. Studies have shown that the opportunity cost and perceived risk of displacing annual cropping with dedicated woody biomass plantings are significant impediments (Abadi et al., 2010). Third, delivery of environmental benefits have become unclear: the longstanding proposition that the problem of dryland salinity can be addressed by tree planting for biomass or other purposes, to increase water use in situ, has generally not shown discernible improvements at a catchment scale due to the limited extent of tree planting in salinized catchments. Revegetation as an integral part of other catchment actions is now recommended (Bennett et al., 2011).

Over the period 2007-14, the Future Farm Industries Cooperative Research Centre (FFI CRC)'s national R&D program addressed the challenge of how to improve the sustainability of Australian dryland agriculture through greater landscape scale water use with the introduction of new perennial pasture and forage species and cultivars. Woody tree cropping was researched for its potential to be a relatively small but strategically important part of land use change (provided it

was profitable in its own right and the economic trade-off with annual cropping could be sufficiently mitigated).

With that work coming to the attention of aviation companies looking to options to reduce greenhouse gas emissions, and to developers and users of biomass conversion technologies, the prospect of a more profitable value chain arose, namely integrating short-rotation biomass crops into existing mixed crop and livestock farming regimes for conversion to aviation and other biofuels, while providing broader environmental benefits including biodiversity protection. Australian airlines have shown strong interest in sustainable aviation fuels, since the global aviation industry has agreed to greenhouse gas reduction targets with the International Civil Aviation Organisation (ICAO) in 2010 declaring to achieve carbon neutral growth from 2020; and the International Air Transport Association (IATA) setting a target of 10% alternative fuels by 2017 and a vision to build an aircraft that produces no emissions within 50 years.

In the 2011 Sustainable Aviation Fuel Road Map report to the Sustainable Aviation Fuel Users Group, CSIRO concluded that sustainable aviation fuel derived from biomass was: "The only alternative fuel which can meet all of the environmental, economic and technical challenges..."; that "Australia and New Zealand are strongly positioned to incorporate sustainable aviation fuel into the aviation fuel mix. The scale of biomass production in the region is well matched to the aviation fuel industry's needs ..."; "there are currently no significant supplies of sustainable aviation fuel anywhere in the world at this time. Establishing a local commercially viable supply chain is the major challenge needing to be addressed" so that biomass derived aviation fuel could supply 5% of Australian needs by 2020 and 50% by 2050. CSIRO identified short rotation coppicing tree species (for example eucalypts), via pyrolysis and catalytic upgrading as one potential source of aviation fuel (Fig. 3). However, it estimated that jet fuel costs from coppicing eucalypts would be higher than other sources due to the low energy density of the feedstock and absence of cost effective harvesting equipment.

The lignocellulosic system under evaluation in the Australian case is based on mallee eucalypt species native to Australia and is targeted at farming lower rainfall areas (300 – 700 mm/yr) in southern Australia, generally known as the 'sheep-wheat' belt. To evaluate the sustainability of this system, a case study was undertaken in the Great Southern region of Western Australia (400-600 mm/yr rainfall). Compared to other locations in Australia, significantly more R&D has been conducted here, with a mallee biomass-to-jet fuel business case and farmer cooperation providing reliable data for assessing the viability and sustainability of commercial supply chain development.

In brief, the results when evaluating the coppicing eucalypts as a biomass feedstock system for energy in Western Australia show that it is technically feasible to integrate this new production system into the overall farming enterprise. With the development of regional processing and support infrastructure, modelling shows that the system could be profitable for farmers and contribute strongly to regional economic development (McGrath et al., 2016). The capacity of Australian agricultural systems to produce biomass is limited by the relatively dry climate, indicating the need to direct the available biomass resources to strategically important energy uses such as aviation fuel supplies. Progress in developing the biomass resources required to support the development of regionally based bioenergy industries has been limited by the political and economic uncertainties currently facing the renewable energy industry in Australia. However, the strong understanding of the technical, economic and environmental aspects of the biomass production system indicates that there are strong development prospects when these uncertainties are resolved.

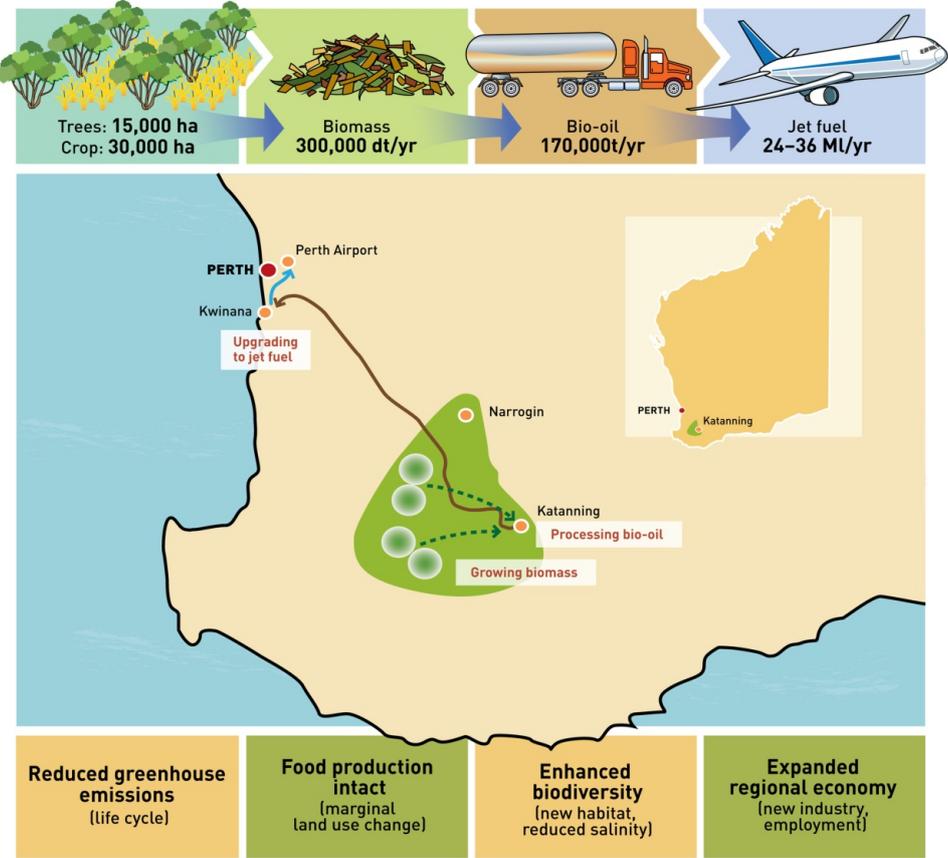


Figure 3: (Case 2) Integrated system for the supply of aviation fuel derived from mallee biomass based in the Great Southern region of WA



Figure 4: (Case 2) An aerial image of broad scale integrated mallee planting with a cereal cropping between the mallee rows

CASE 3: SWITCHGRASS-TO-ETHANOL PRODUCTION SYSTEM IN SOUTHEASTERN U.S.

Some perennial energy crops, such as switchgrass (*Panicum virgatum*) have considerable potential for being economically viable and environmentally beneficial in many crop producing regions of the U.S. (Dale et al. 2011). While most perennial crops (like annual crops) attain their greatest yield under optimum growing conditions, switchgrass has several varieties that produce reasonably high and consistent yields on marginal upland, and its perennial characteristics allow production with minimal erosion on highly erodible land. Conversion of land from traditional annual crops to perennial energy crops results in significant soil improvements (Post et al., 2004). The reduction in disturbance of the soil due to no-till reduces wind and water erosion and allows soil aggregation and fungal-dominated organic matter cycling processes to re-establish. An additional benefit resulting from perennial crops is that root penetration increases soil porosity and infiltration and reduces compaction. Great increases in soil carbon occur on poorer quality sites; for example, conversion from annual to perennial crops resulted in soil carbon increases primarily in the upper 10 cm (Tolbert et al., 2002).

A recent (2008-2013) demonstration-scale East Tennessee switchgrass-to-ethanol production experiment provided a unique opportunity to examine a variety of environmental and socioeconomic data needed to analyse the overall sustainability of a dedicated cellulosic bioenergy crop production system (Parish et al. 2016; Fig. 5). Switchgrass is native to Tennessee and has greater potential for consistent profit relative to corn production in the region than in some other areas of the U.S. This case study was a demonstration project supported by the State of Tennessee. Farmers were awarded contracts at an incentivized rate while the biorefinery was under construction, thereby ensuring an adequate supply of switchgrass by the time the biorefinery came on line three years later. Heavy involvement in the project by University of Tennessee (UT) faculty and students led to optimized yields and to the production of a variety of datasets and publications that might not be as readily available in other settings. All of these context-specific factors should be considered when comparing the sustainability assessment of this pilot-scale switchgrass-to-ethanol experiment with other bioenergy systems in other settings.

In order to make the best use of available data, this case study of sustainability was limited to the feedstock production and logistics portions of the supply chain (i.e., field to biorefinery gate). Context-specific sustainability information was synthesized into qualitative ratings for the recommended indicators based on a combination of experimental data, literature review and expert opinion. A hierarchical decision tree framework was used to generate an assessment of the overall sustainability of this no-till switchgrass production system relative to two alternative East Tennessee business-as-usual scenarios of unmanaged pasture and tilled corn production.

The results in brief show that both local and watershed-scale benefits can be achieved by growing switchgrass in place of traditional crops in east Tennessee. Improvements in both water quality and farm profit can be realized by selection of locations for planting perennial energy crops. With a small decrease in projected profit, water quality can be improved (Parish et al. 2012), but the acceptability of this trade-off to farmer-producers should be explored. Profit would be improved if there were a stable large-scale bioenergy production system and demand in the region. While focusing on individual targets can better achieve specific individual goals, this sustainability case study shows that a combination of goals can be addressed simultaneously (Parish et al. 2016).

Sustainability assessments will benefit from indicator measurements repeated over time and periodically incorporated into a sustainability evaluation framework (Fig. 6). By viewing of policies and system interventions as experiments that need to be continuously monitored, updated and adjusted, more complete understanding of bioenergy production systems will be gained over time,

and it will become possible to assign meaningful targets and weightings to the proposed suite of the Department of Energy sustainability indicators within different contexts. Conducting sustainability assessments of a variety of bioenergy feedstocks in diverse settings will enable the development of sustainable bioenergy crop management practices that meet multiple demands of stakeholders with understood tradeoffs (Fig. 6, Table 3).

Table 3. (Case 3) Summary of the overall sustainability and sustainability pillar ratings for the East Tennessee switchgrass-to-ethanol experiment compared to two alternative agricultural scenarios (Parish et al. 2016)

Type of sustainability	No-till switchgrass	Unmanaged pasture	Tilled corn
Overall	High	Intermediate	Intermediate
Environmental	High	High	Low
Economic	Intermediate	Low	High
Social	High	Intermediate	Intermediate

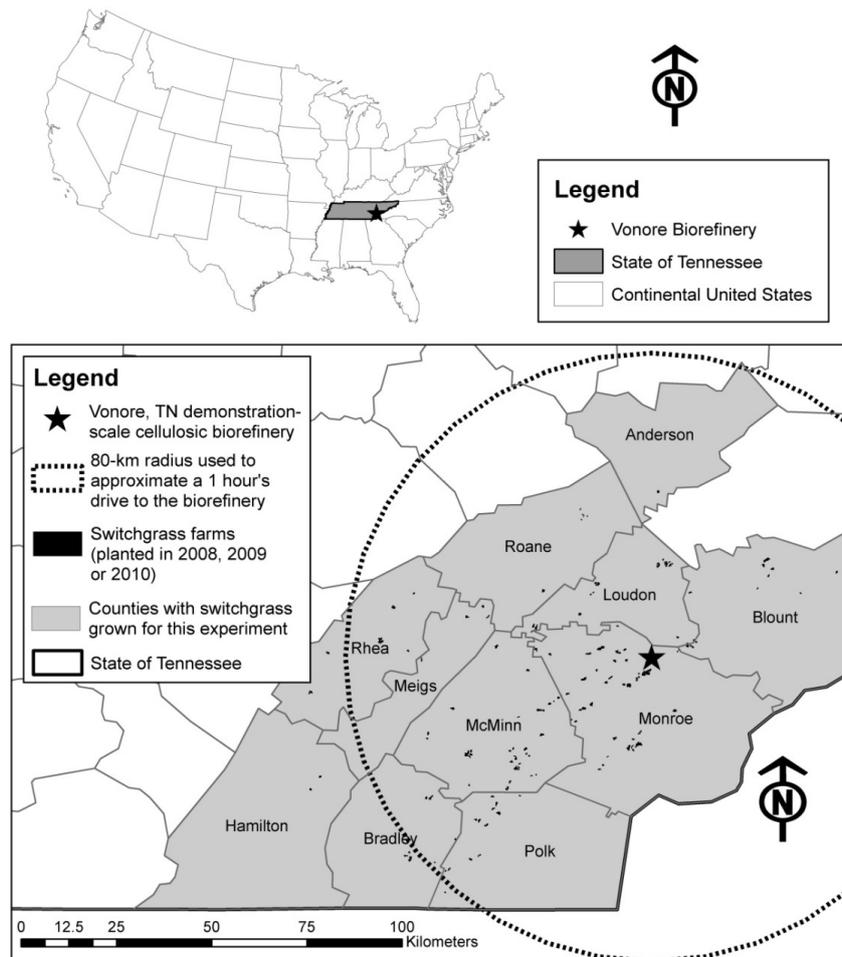


Figure 5: (Case 3) (a) Location the State of Tennessee and the Vonore biorefinery within the southeastern United States. (b) Location of the East Tennessee switchgrass-to-ethanol experiment, which included Tennessee farms within 80 km (50 miles)

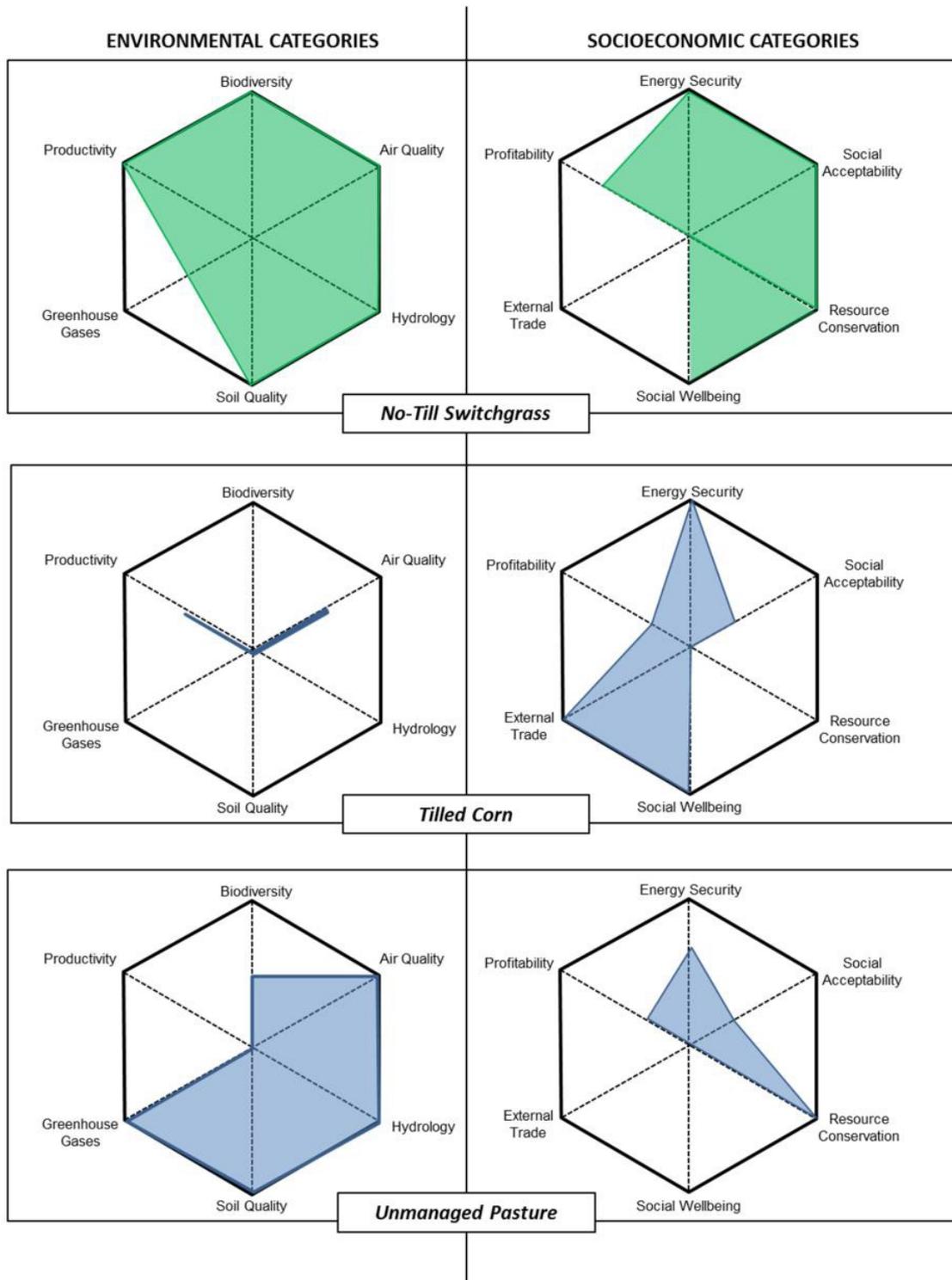


Figure 6: (Case 3) Ratings of six environmental and six socioeconomic sustainability categories for no-till switchgrass relative to alternative scenarios of tilled corn production and unmanaged pasture. The center points of the hexagons represent lowest possible sustainability ratings, and the outer edges of the hexagons represent highest possible ratings. Thus, larger shaded areas indicate higher sustainability. Each category value represents an aggregation of underlying individual sustainability indicator values. (Parish et al. 2016)

CASE 4: POPLAR SHORT ROTATION COPPICE FOR ENERGY PRODUCTION IN GERMANY

Climate protection is high on the regional political agenda in many German regions, and many regional governments have defined core actions via an "Integrated Climate Protection Plan." In the case of the region of Göttingen, a major goal of this innovative and participatory approach has been to establish a roadmap towards a 100% renewable energy supply by 2050. This ambitious goal is only achievable with a substantial decline of the energy demand. A considerable amount of renewable energy is expected to stem from biomass sources, and in most cases lignocellulosic crops such as short rotation coppice is not an option that is considered by local stakeholders. To link climate protection-related governance activities and a multidisciplinary view on ecosystem services and sustainable land use and to tackle stakeholder perceptions, a visualisation tool was constructed to address land-use aspects in an interactive way. This tool, called the 'Bio-Energy Allocation and Scenario Tool' (BEAST) and schematically described in Fig. 8, was developed to bridge parts of this perception gap by investigating the Short Rotation Coppice (SRC) allocation impact on (1) ecosystem functions and its associated ecosystem services, (2) the economic return compared to specific annual crops, and (3) to allow scenario generation with the aim to combine renewable energy supply from woody biomass sources with aspects of sustainable land use (Busch, 2012).

The results in brief showed that in terms of economy, the majority of arable sites in the case study area (Fig. 9) are not capable of providing a positive economic return for SRC under all circumstances.

The tool shows that SRC outcompetes the reference crop rotation with a 100% probability in only 19% of the scenario cases (Fig. 10). The minimum annuity difference a farmer could count on ranges between 0- 180 €. If farmers want to avoid the risk of a negative annuity difference under all circumstances, they have to stick to these 19% of arable land. The appropriate areas for SRC cultivation based on economic criteria compared to annual crops also have a positive effect to soil erosion, and since erosion protection is an environmental protection goal that is subsidized by government payments, minimum economic return would increase. This in turn, could be an additional incentive for a SRC implementation on these particular sites. On the other hand, SRC can have a negative impact on habitats that rely on high groundwater level or soil interflow from neighbouring areas, and a potentially negative effect of SRC on surrounding habitats has to be carefully considered in combination with the positive effects, such as soil erosion. See Busch (2017) for further results and information.

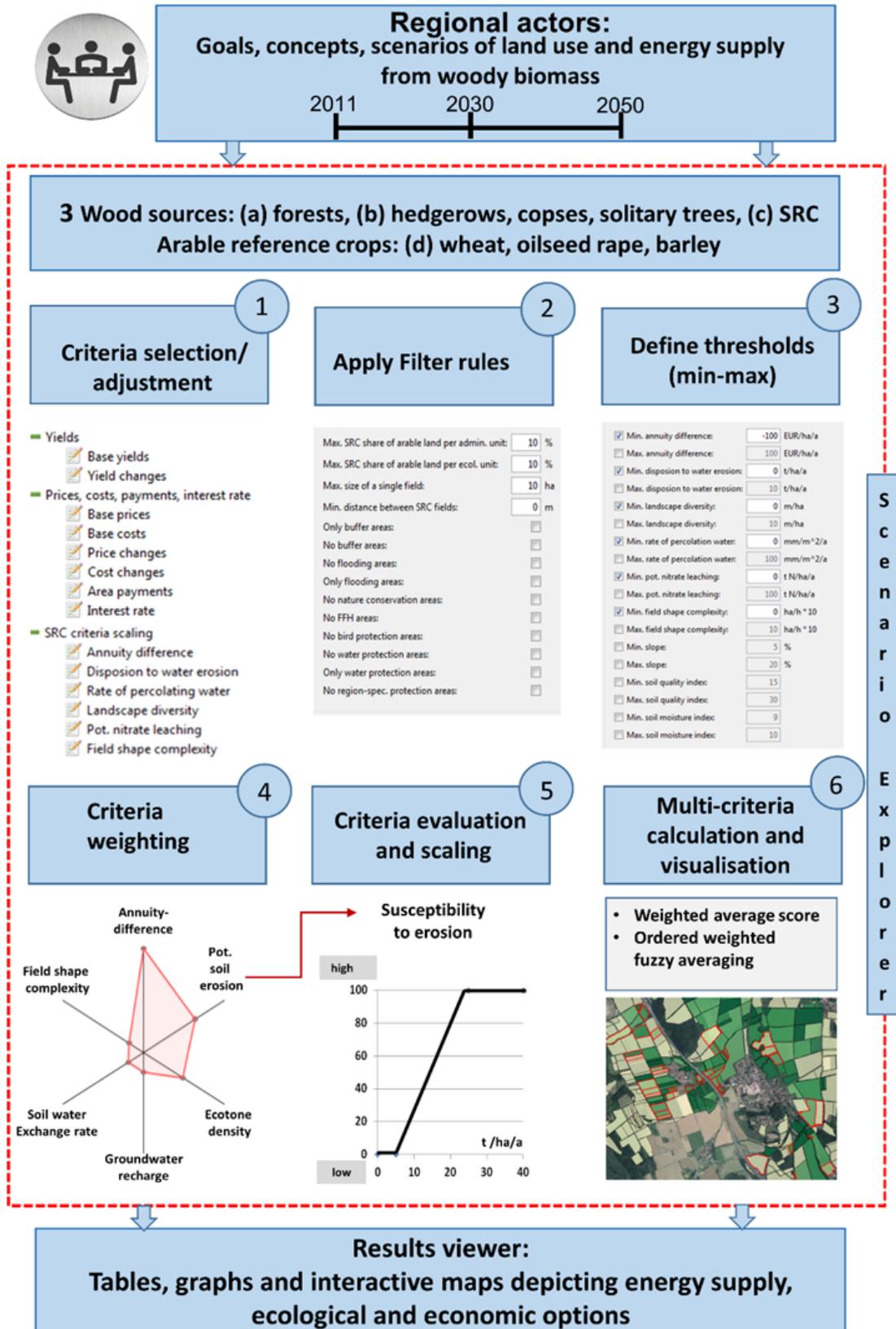


Figure 8: (Case 4) Schematic of the overall structure of BEAST (Busch, 2012)

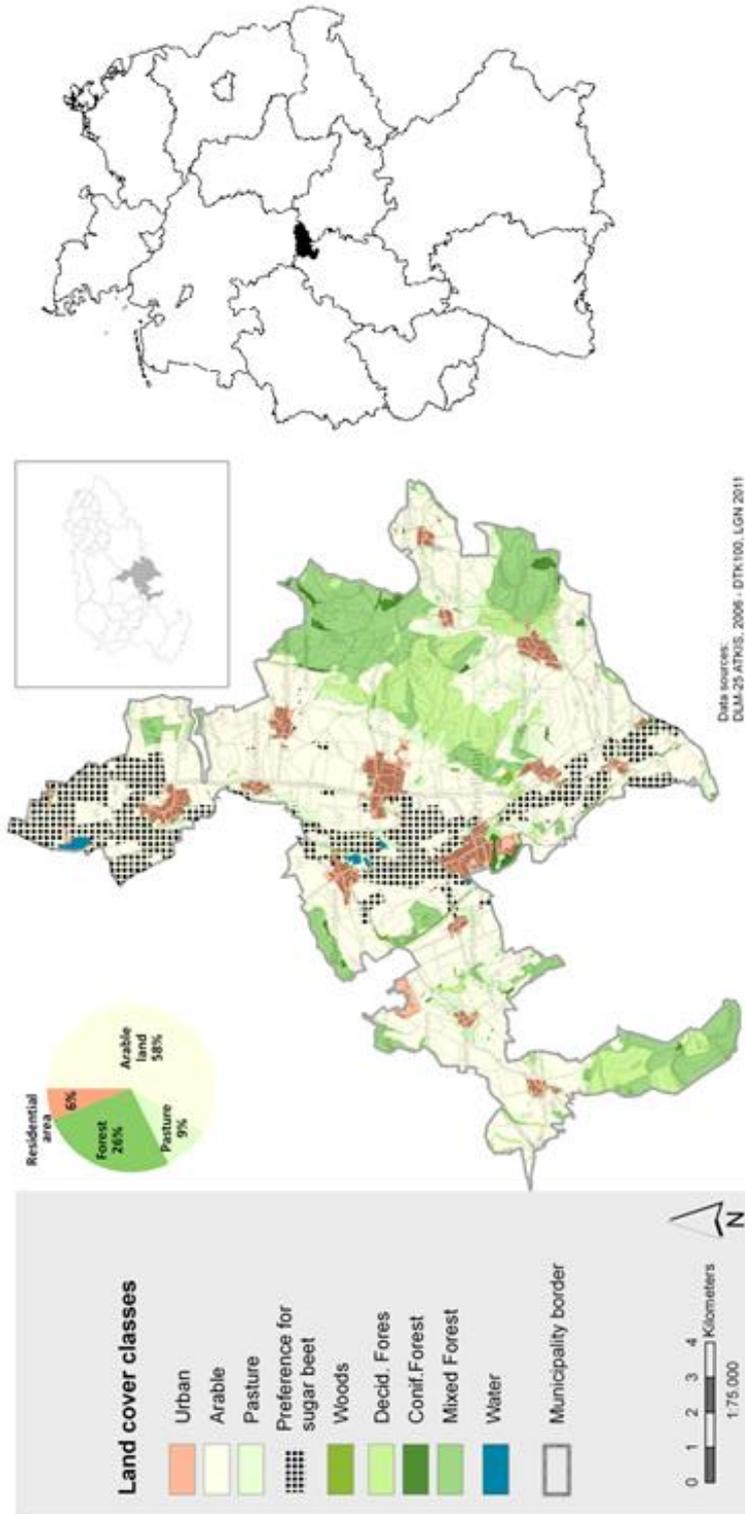


Figure 9: (Case 4) Study area: Landscape mosaic in the municipality of Friedland including preference sites for sugar beet-wheat rotations being excluded from SRC allocation assessment

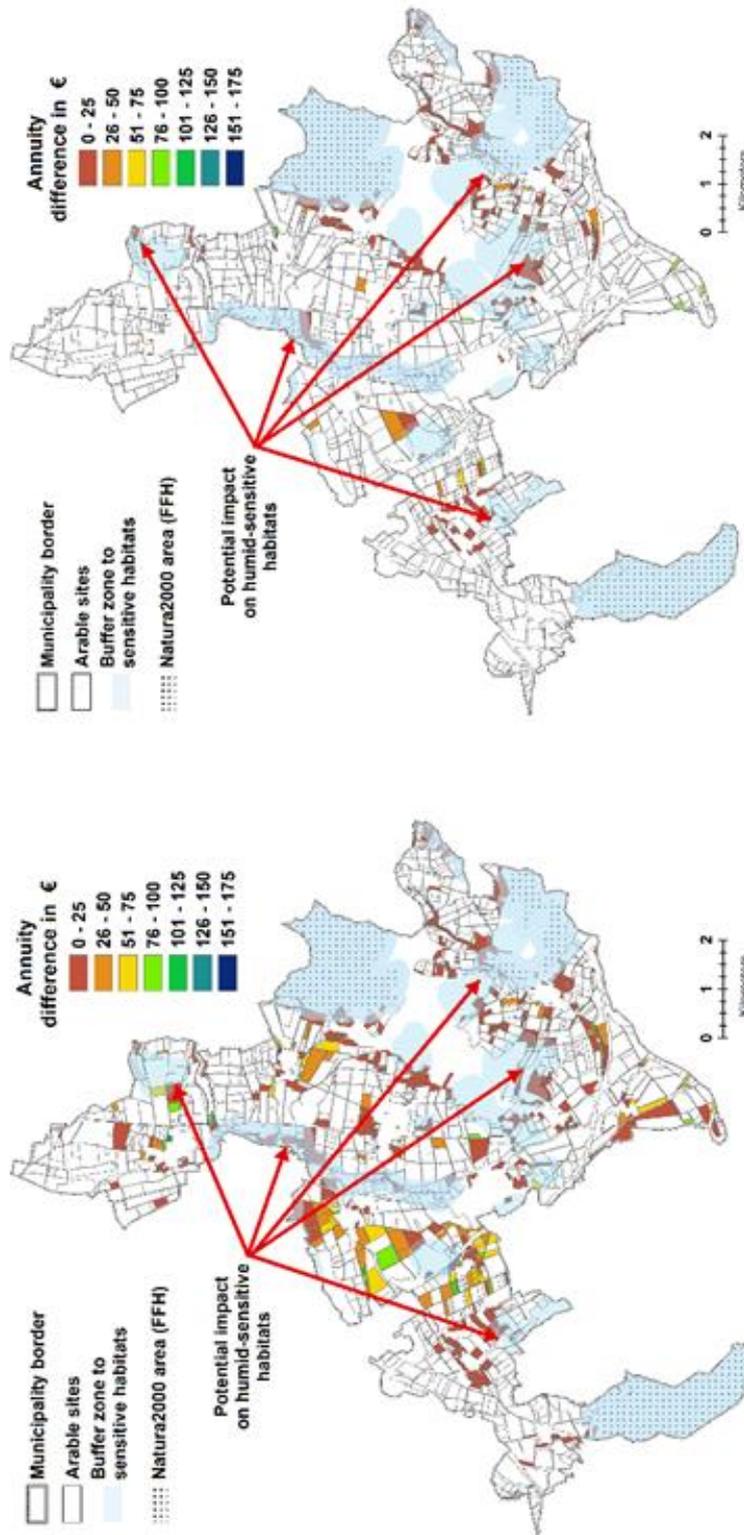


Figure 10: (Case 4) (a) economically competitive SRC sites, (b) economically competitive SRC sites that provide Cross Compliance-relevant erosion protection. Potential impacts on humid-sensitive habitats are separately illustrated

CASE 5: LIGNOCELLULOSIC PLANTS AS BUFFER ZONES IN THE US

The U. S. Energy Independence and Security Act of 2007 mandated aggressive biofuel production targets for the United States. Meeting those goals sustainably will require a new agricultural mindset that effectively balances concerns about economic viability with an ambitious focus on sustainability. Agricultural soil management practices—particularly fertilization— accounted for approximately 75% of U.S. nitrous oxide (N₂O) emissions in 2012 (USEPA, 2014). Furthermore, runoff from fertilization of corn crops (a large component of biofuel energy balance) is a significant source of non-point water pollution and economic loss. There is a concern that bioenergy crops grown in systems mimicking current large scale agricultural production systems may also increase the already significant impacts of commodity agriculture on water, air and wildlife. These concerns call for proactive thinking and development of a holistic vision for a future where a novel, integrated landscape design optimally produces goods and services to satisfy societal needs for food, feed, energy, and fibre, as well as environmental services, ecological health, human well-being and quality of life. One possible approach to develop this vision is to plan at the landscape level the use of land and water resources so that the most fitting crops and agricultural practices are used in the parts of the landscape that are most suited to them, and to use specific crop traits to gain beneficial environmental services. For instance, this approach would encourage the cultivation of main grain crops on the most fertile land while perennial crops are grown where the productivity of main food/feed crops would be lower. Alternatively, moisture tolerant bioenergy crops would be grown where the land is more vulnerable to flooding or ponding water, or deep rooted perennials would be grown where land is more susceptible to nutrient leaching or erosion. This approach relies heavily on landscape design concepts and is increasingly gaining momentum under the US Department of Energy (DOE) (ANL, 2014).

Landscape design, like conservation science, relies heavily on features such as buffers (Fig. 11). Conservation buffers are strips of vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services. Riparian buffers, buffer contour strips or filter strips and windbreaks are examples of conservation buffers. Buffer strips, together with wetlands, are a common tool used in conservation practices and are the subject of substantial programs by the U.S. government (Doering, 2015). In these programs, vulnerable or ecologically relevant land is not used for cropping purposes but instead is set aside for filtering water runoff and/or providing other ecosystem services. Overall, there is a broad recognition of the crucial role of riparian land and buffer strips in regulating nitrogen cycles and, more generally, water quality. Studies have also indicated that nitrous oxide emissions in buffer systems are a function of nitrate availability, soil conditions such as pH, temperature and moisture, microbial communities and plants growing in the system (Hefting et al., 2003; Kim et al., 2009).

In government-supported conservation buffers, removal of biomass via harvesting is usually not allowed. While this ban is considered beneficial to protect the environmental and ecological function of very fragile land, there are other cases where harvesting biomass for energy may provide an attractive income to farmers while at the same time delivering valuable environmental and ecological services. Harvesting biomass may also provide a way to remove nitrogen from the buffer area via the harvested vegetation, thus maintaining buffer function. Establishment of buffers can however remove some land from the current cropping system, thus creating an economic dilemma for farmers. It is clear that while many designs are possible and effective, the valuation of the water quality improvement may contribute to the adoption of buffers by providing support in case the bioenergy crop does not fully compensate the farmer.

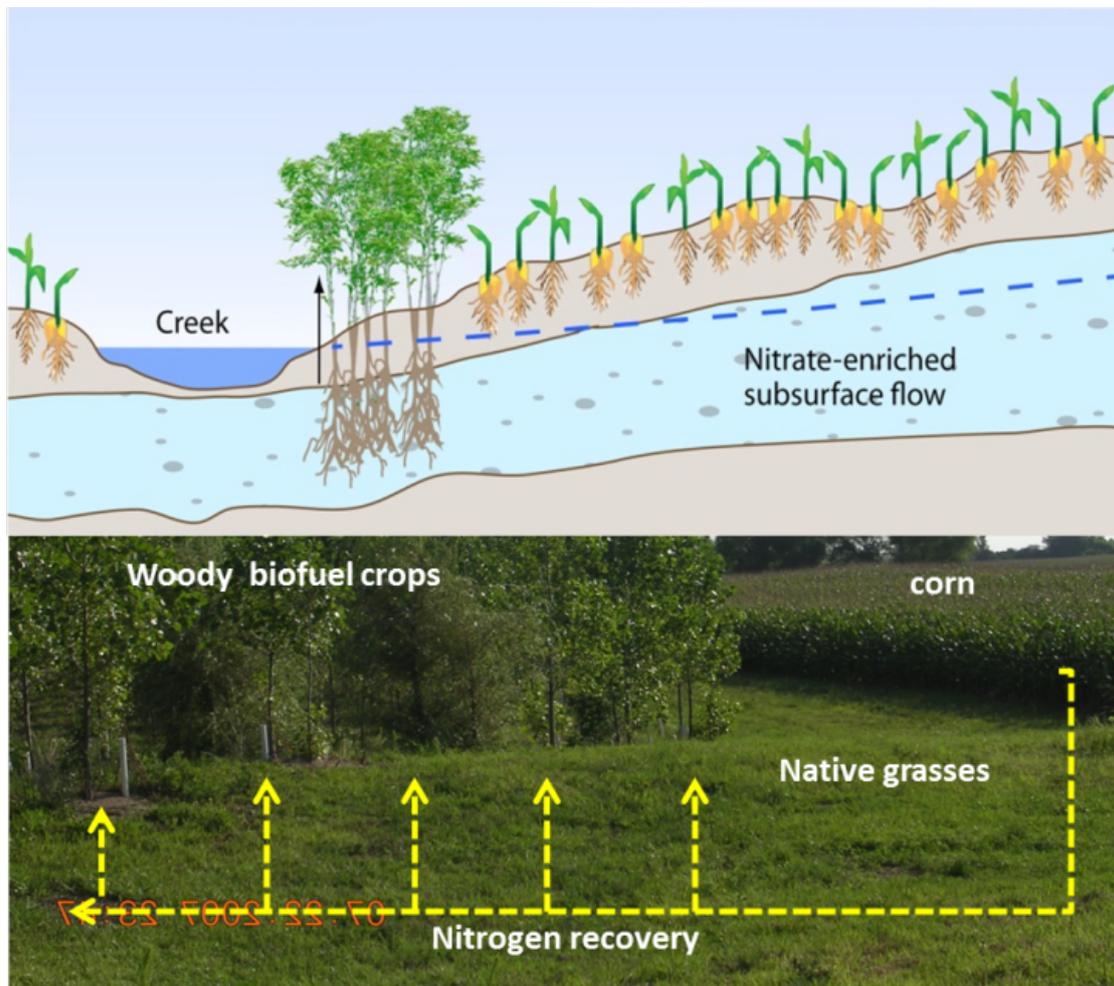


Figure 11: (Case 5) Conceptualization of bioenergy buffer function within a corn field

Experiments have been conducted to test the environmental performance of buffers and their social and economic sustainability (Ssegane et al., 2015), and while more study is needed to definitively assess the benefits and constraints of buffers as nutrient-scavenging bioenergy producers, a few conclusions have been derived (Fig. 12). First, not all buffers are created equal: while riparian buffers receive the lion's share in conservation applications, not all locations bordering a stream benefit from having a riparian buffer, and contour buffers may be more appropriate. Soil characteristics and easily available yield maps can be instrumental in positioning the bioenergy crops in locations that target the most vulnerable areas and those areas that can be converted to bioenergy in a cost-effective manner. Second, when deploying bioenergy crops in vulnerable areas, existing management practices developed for business-as-usual cropping may need to be reassessed to minimize impacts to water. Use of cover crops, double cropping and caution in the use of chemicals should be considered to address the long period of little ground cover during the bioenergy crop's establishment time and the management of weeds. Third, research needs to be conducted in establishing minimum patch size and field geometries that would allow farmers to easily subscribe to landscape-based bioenergy cropping, which would provide optimized logistics. Fourth, scaling up this approach to the watershed scale is necessary to integrate scientifically sound data with logistic choices and local interests. Finally, feedback from farmers and farm operators and consultants is essential in designing landscape solutions that are acceptable and likely to be adopted in farms (Fig. 13).

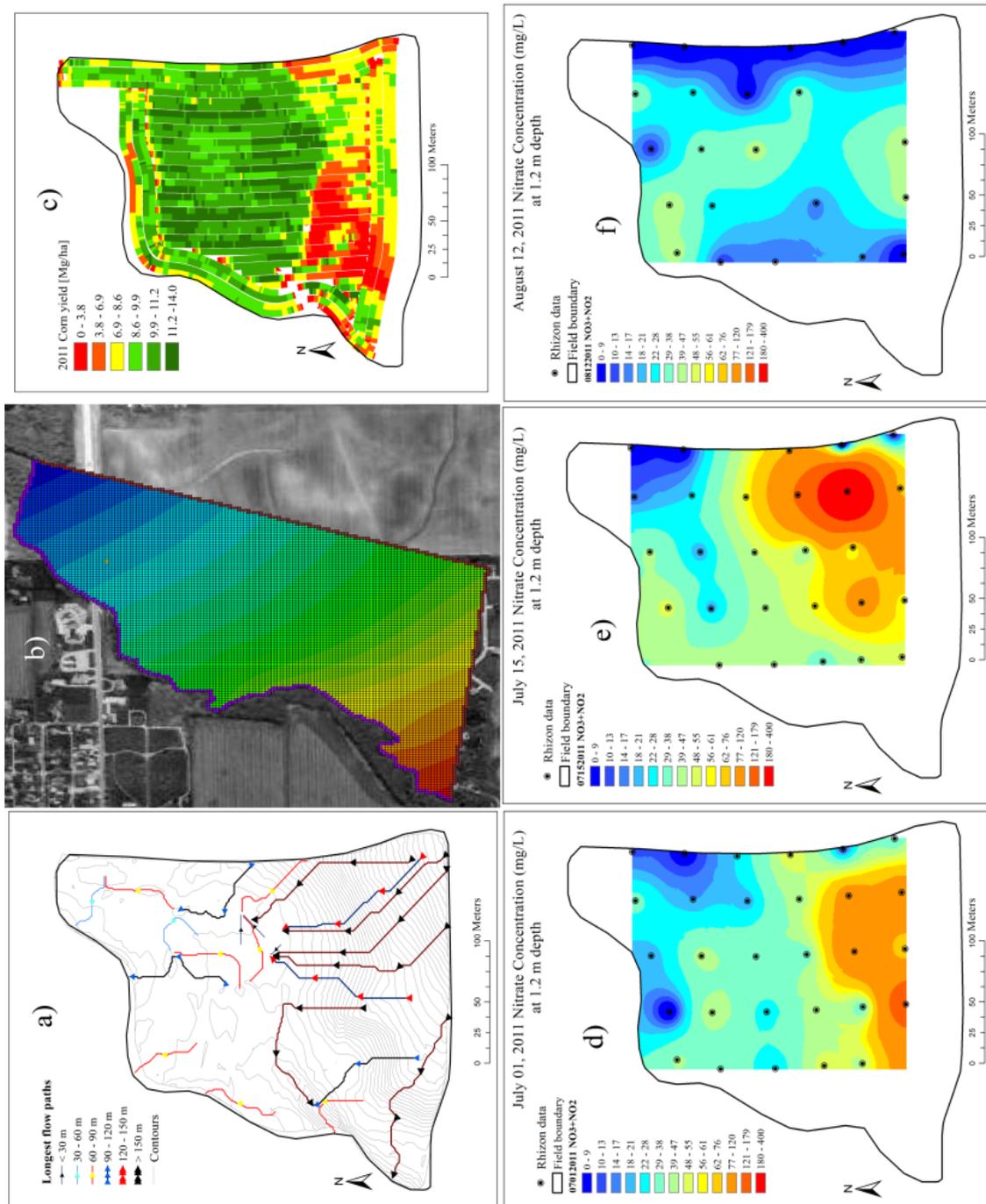


Figure 12: (Case 5) Baseline results: terrain analysis, groundwater flow direction, yield map, and nitrate plume at 1.2m below ground surface at different times over the spring/summer season of 2011

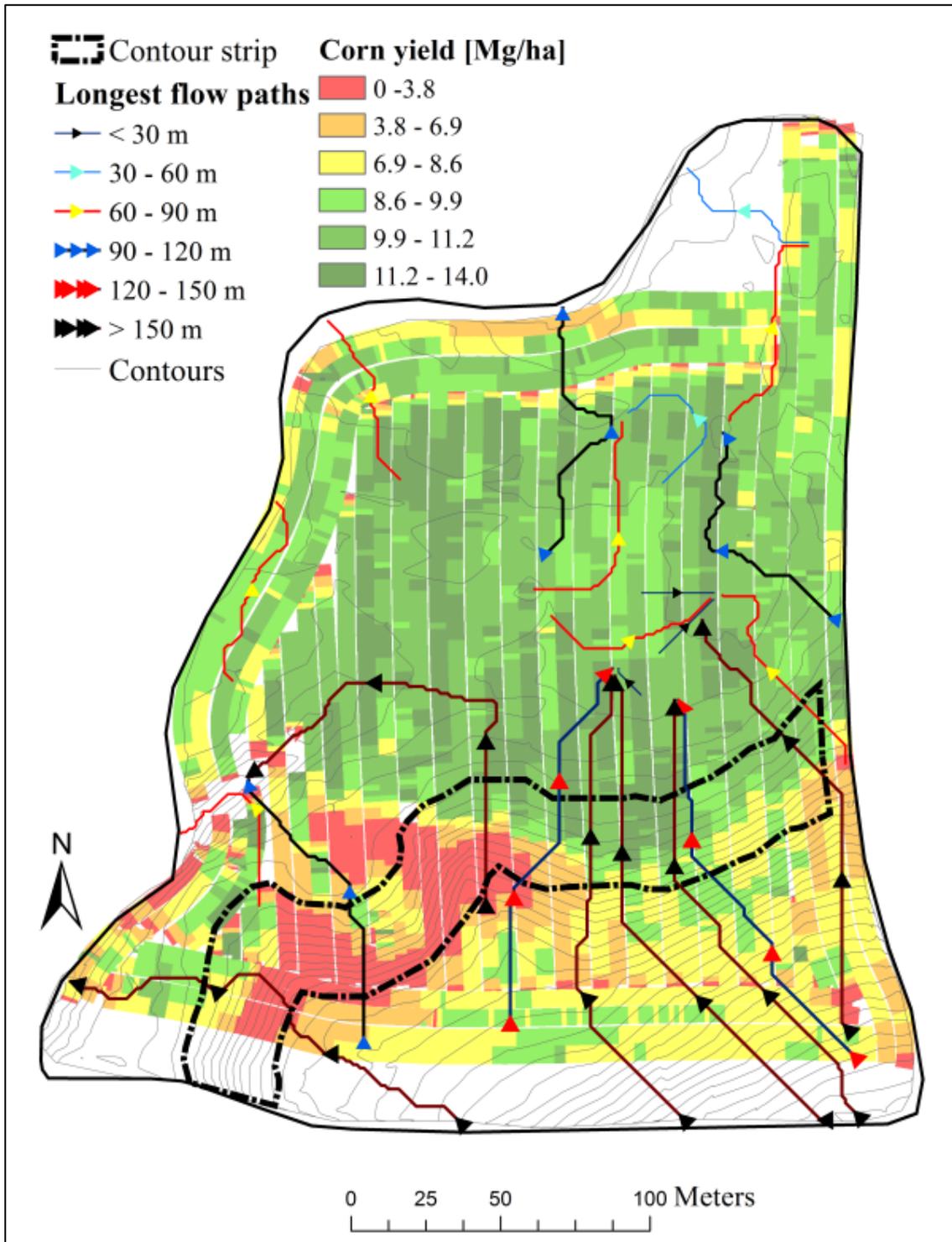


Figure 13: (Case 5) Final design of the contour buffer

CASE 6: RECYCLING OF SLUDGE AND WASTEWATER TO SHORT ROTATION COPPICE WITH WILLOW FOR BIOENERGY IN SWEDEN

Future lignocellulosic bioenergy systems in agriculture should be 'land-efficient', and the amount of energy produced per hectare should be the highest possible. Also, unless other incentives exist, cultivation practices for such systems should be more profitable for the farmer than those for food crops, to motivate farmers to grow bioenergy crops. With the current relatively low energy- and high food prices, few bioenergy systems can compete and be adopted by farmers on a large-scale. Therefore, multifunctional systems producing biomass for energy and additional dedicated ecosystem services should be developed, for promoting the establishment of lignocellulosic crops in agricultural landscapes. The application of society's nutrient-rich residues, e.g. municipal wastewater (Fig. 14) or sewage sludge (Fig. 15) to short rotation coppice plantations with willow (SRCW) has been identified as an attractive option for achieving environmental and energy goals, while simultaneously increasing farmers' income (Dimitriou and Rosenqvist, 2011).

SRCW is a non-food, non-fodder energy crop that offers advantages such as high evapotranspiration rate and tolerance to anoxic conditions and heavy metals, and therefore is considered appropriate for such applications. Using sewage sludge and wastewater to fertilise SRCW offers environmental advantages and economic profit to farmers cultivating SRCW due to reduced fertilisation costs and increased biomass produced.



Figure 14: (Case 6) View of a municipal wastewater plant in Enköping, Sweden, with water storage ponds and (behind the ponds) willow fields that are used as vegetation filters. The photo is taken from the roof of the heat and power plant that uses the locally produced biomass (Photo: Pär Aronsson, SLU).

The economic profit of the farmers can be substantially higher if using effluent from wastewater treatment plants instead of other alternatives. Even if a small amount of the phosphorous entering the wastewater treatment plant is applied to SRCW in the form of wastewater and/or sewage sludge, the agricultural land area planted with SRCW could be markedly increased, leading to a considerable increase of renewable energy from lignocellulosic crops (Table 4).

Table 4: (Case 6) Theoretical estimations of land required if all available sewage sludge (ss) and wastewater (ww) would be applied to SRC, and consequent increases of the renewable energy amounts in different European IEA Bioenergy Task 43 countries. Modified from Dimitriou and Rosenqvist (2011)

Country	Population (Millions)	SRC area to be fertilised with all available ss (kha)	SRC area to be fertilised with all available ww (kha)	Arable land surface with SRC fertilised with ss (%)	Arable land surface with SRC fertilised with ww (%)	Energy produced from SRC if all ss applied (PJ)	Energy produced from SRC if all ww applied (PJ)
EU-27	495.13	35673	1505	34	1.4	5636.3	309.2
Denmark	5.45	436	18	18	0.7	62	3.4
Finland	5.28	422	17	19	0.8	60.1	3.3
Germany	82.31	5931	250	50	2.1	937.0	51.4
Ireland	4.31	259	11	26	1.1	49.1	2.7
Italy	59.13	3550	146	50	2.1	673.1	36.9
Netherlands	16.36	1179	50	111	4.7	186.2	10.2
Sweden	9.11	505	23	19	0.9	103.7	5.7
UK	60.85	3654	150	60	2.5	692.7	38



Figure 15: (Case 6) Willow SRC field applied with sewage sludge (Photo: Pär Aronsson, SLU).

Incentives and barriers

The outcomes of this project, in terms of sustainability issues as well as incentives and barriers for wider implementation, are a result of the experience gained from several examples from different parts of the world, where different ecosystems services are provided through lignocellulosic cropping systems. Despite the different features of the systems, due to e.g. case-specificity and differences in context, the analysed examples can be considered as representative for implementation in other parts of the world.

Each example is context-specific, but common for all is that they could only have been achieved due to the existence of drivers for an increased biomass demand for energy, with a simultaneous implementation of good management practices, and a supportive social and political environment. There are also several similarities, e.g., in drivers, opportunities, and constraints, between the different systems, allowing for some general conclusions towards a wider implementation of lignocellulosic cropping systems, as summarised below.

INCENTIVES FOR IMPLEMENTATION OF LIGNOCELLULOSIC CROPPING SYSTEMS IN AGRICULTURAL LANDSCAPES

Replacement of non-renewable fossil energy

Fossil fuels include coal, petroleum, and natural gas, which can be used for energy production and other products such as plastics. The widespread use of fossil fuels has caused a wide range of environmental impacts – not the least climate change. Replacement of non-renewable fossil energy with renewable bioenergy from, e.g., lignocellulosic crops, can help mitigate these impacts while also allowing the conservation of fossil resources for future generations.

Enhanced energy security

Similar to food security, energy security can be considered from a perspective of household energy requirements in terms of the availability, affordability, accessibility, and awareness of clean, reliable energy sources to meet daily needs. Alternatively, it may refer to issues of economic security, national supplies and the lack of dependence on foreign sources to support national security goals. While access to inexpensive energy is essential to modern economies, uneven distribution of energy supplies leads to vulnerabilities. Fossil fuel reserves are located in many places around the globe, but their large-scale commercial extraction occurs in only a few regions making other regions/nations dependent on imports. Energy security is enhanced when sources are diversified and can be accessed locally within a region or country. For those countries that have appropriate climate and soils to support agriculture that can produce lignocellulosic crops, sustainably produced biomass from them can be transformed into bioenergy. Such locally available feedstock sources provide opportunities for enhanced energy security in regions able to produce their own bioenergy rather than relying on imports.

Reduced risk of catastrophic accidents

Fossil fuels have demonstrated significant risks for catastrophic accidents, including oil spills that pollute rivers, lakes and marine environments at the point of drilling; transport accidents involving tankers, trucks and pipelines; drilling and mining accidents involving explosions and loss of life, as well as fire and storage risks. Locally produced bioenergy, e.g. from lignocellulosic crops, has a lower risk of accidents compared with fossil energy. Risks associated with bioenergy is limited to accidents associated with transport, the possibility of fires where biomass is stored, and accidents associated with industrial processing.

Increased incentives for management of renewable resources in other sectors

Policies to develop bioenergy have gone hand-in-hand with efforts to define, measure and assess the sustainability of production systems. Aspirational sustainability goals for bioenergy systems could change the way that sustainability is understood and addressed. Sustainable production systems for bioenergy could therefore serve as a model for agriculture and other biomass dependent sectors, and help spur investment in deployment of more sustainable practices in general.

Rural employment and development

Biomass production from lignocellulosic crops and processing to produce biofuels can benefit rural communities by increasing employment opportunities and expanding the tax base that supports community services. Expansion of the bioeconomy could provide jobs in rural areas where unemployment is often high. Furthermore, while many jobs in fossil fuel extraction are difficult and risky (e.g., coal mining and work on oil rigs), replacing fossil fuels with bioenergy would substitute fossil-based jobs with bioenergy jobs.

Keeping land in agriculture

Bioenergy deployment would provide additional incentives for keeping land in agriculture and reduce pressure for urban development. The ecosystem services provided by agricultural land would thus be retained.

Improving environmental conditions

Biomass production of the type presented in this report can improve environmental conditions compared to conventional agriculture or forestry, or other energy options. A strategic integration of perennial plants into agricultural landscapes can enhance, e.g., landscape diversity, habitat quality, retention of nutrients and sediment, erosion control, climate regulation, pollination, pest and disease control, and flood regulation. It can thereby also mitigate environmental impacts from intensive agriculture.

Increased food security

Increased production and income associated with lignocellulosic biomass for biofuels have the potential to improve food security. Food security depends largely on household access to services and ability to pay. Providing additional markets for rural producers, incentives to invest in the infrastructure needed to grow and transport bioenergy feedstocks, and stabilizing prices at levels that create incentives for local production, are all expected to increase food security. Food price volatility contributes to food insecurity and is reduced by having multiple products and market options from a commodity.

Existing infrastructure, knowhow and technologies

Building bioenergy systems around existing agricultural and industrial infrastructures and technologies reduces costs and makes it easier for land managers to adopt new practices. Existing equipment can often be used or modified for use for bioenergy (feedstock) production. Lignocellulosic supply chains are more likely to survive the challenges of early market development if they can be supported by existing industries.

MAIN BARRIERS TO WIDER IMPLEMENTATION

Policy

Sustainable energy is often a general policy aspiration, but its definition is not always clear. While policy should be about managing risks and promoting opportunities, it often becomes more about promoting certain interests. The trade-offs inherent in specific policy recommendations are often not clear. Policy barriers related to bioenergy in general, and lignocellulosic crops in particular, are often specific to individual countries.

Cost of establishing new energy systems

The cost of developing and deploying any new energy system, including those based on lignocellulosic biomass, is high, and seldom compared to the large amount of existing and past financial support provided to fossil energy or conventional bioenergy production systems. Lignocellulosic bioenergy technologies need time to mature, and maturation should result in reduced costs via operational experience and scale.

Unlevel playing field

Knowledge infrastructure and investment for fossil energy are huge compared to renewables. The many opportunity costs associated with the use of fossil resources, e.g., pollution and potential costs to society of future climate change, are not reflected in fossil fuel prices. Fossil fuels have been created using areas many times as large as current production areas, and using energy from thousands of years of planetary effort is not accounted for in a life-cycle assessment. However, all costs associated with renewables, including lignocellulosic crops for bioenergy, are considered. Hence an across-the-board comparison of current one-time costs and benefits of different energy options is not entirely valid.

Public perceptions

In many arenas the common viewpoint is that bioenergy from agriculture is bad for the environment and competes with food production. More transparency of information about fossil fuels and bioenergy is needed. As also discussed above, comparisons between bioenergy and fossil fuels are not done in an even manner. Effective stakeholder participation requires engagement of all key stakeholders and sharing of information about the implications across all steps of the supply chain.

Easy access to relatively cheap fossil fuels

The attraction of inexpensive and readily available fossil fuels continues to influence political and economic activities to the detriment of biofuels and other clean, advanced renewable energy technologies.

Too optimistic about costs and timetables

Overly optimistic timetables about bioenergy production have resulted in the perception that lignocellulosic bioenergy is always "five years away." After hearing this claim too many times, the investment community, policy makers, and public do not believe that bioenergy is a realistic option. The use and dissemination of "good examples" that work in reality, as described in this report, is a necessity to further implement more bioenergy projects based on lignocellulosic crops.

Lack of Infrastructure

Bioenergy infrastructure is immature or wholly lacking in many areas. Most of the vast potential in natural resources remains stranded far from the ports and centres of demand. There are unique challenges in the collection, transportation, shipping, and logistics of lignocellulosic energy crops, but while production costs at field scale for many lignocellulosic crops, residues, and wastes are

relatively low and seem to be globally competitive, the delivered cost for bioenergy production pathways often increases dramatically due to added costs associated with poor infrastructure and limited logistics capacity. The lack of integration of bioenergy with other parts of the production system stymies optimal use of existing infrastructure.

Need for new investment

Investments in science and industry are required for the bioeconomy to grow. Investments have fallen since the financial crisis of 2008. More recently, the lignocellulosic industry faces difficulties competing with subsidized fossil energy and existing production of other biofuels such as demolition wood, household wastes, and others. Credit is more restricted and the many uncertainties about future policies and markets undermine additional investment needed to reach a critical economy of scale required for competitive lignocellulosic crop management and industry.

Uncertainty about future demand and price structure

Related to policy uncertainties and poor infrastructure is the lack of certainty about future demand and prices for bioenergy. Doubts about the viability of future bioenergy markets also affect interest in investment.

Sustainability concerns

“Sustainability” concerns remain an obstacle, particularly for European markets and on topics that social and environmental organizations continue to highlight as issues such as labour rights, food security, deforestation, biodiversity, and low yields. While there are examples of bioenergy projects compromising social and ecosystem services, there are also many counter-examples, such as the cases presented in this report, that provide insights on how to deploy biofuel production systems sustainably. This concern calls for reiteration of the need for full transparency of the costs and benefits related to other energy options.

Conclusions

The production of various lignocellulosic crops in agricultural landscapes can produce biomass for the bioeconomy as well as provide additional ecosystem services, and environmental, social and economic benefits. This report presents six concrete examples of such systems.

While each example is context-specific, common for all is that they could only have been achieved due to the existence of drivers for an increased biomass demand for energy, with a simultaneous implementation of good management practices, and a supportive social and political environment.

Benefits of such lignocellulosic cropping systems are well-established. For wider implementation of sustainable lignocellulosic cropping systems, additional research proving the sustainability of different systems in specific contexts is necessary.

It is also necessary to overcome several critical barriers, related to, e.g., lack of long-term policy support, and skewed public perceptions. Several barriers could be overcome by an increased transparency of the costs and benefits related to other energy options.

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