FOR BIO

FOSTERING SUSTAINABLE FEEDSTOCK PRODUCTION FOR ADVANCED BIOFUELS ON UNDERUTILISED LAND IN EUROPE

TECHNO-ECONOMIC FEASIBILITY OF THE CASE STUDY IN GERMANY

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1. Introduction

The techno-economic feasibility report was developed as part of the FORBIO project. The FORBIO project (Fostering Sustainable Feedstock Production for Advanced Biofuels on underutilized land in Europe, www.forbio.eu) is financed by the European Commission in the framework of the European Union Horizon 2020 Research and Innovation Program.

The main objectives of the techno-economic feasibility study are as follows:

- To identify promising options for biofuels and bioenergy production on former sewage irrigation fields near the city of Berlin and lignite reclamation sites in Lusatian coal mining area, based on the outcomes of the agronomic feasibility study in Germany (http://www.forbio-project.eu/documents);
- To assess the techno-economic feasibility of the selected most promising value chains of the former sewage irrigation fields near the city of Berlin and lignite reclamation sites in Lusatian coal mining area.

The techno-economic feasibility report will contribute to the dialogue with local stakeholders in the area of Berlin and Brandenburg in order to establish sustainable value chains for bioenergy production. In addition, it will assess the viability of using land for non-food bioenergy feedstock production without interfering with the production of food and feed, nature conservation and recreational purposes. The report can also be used to contact professional planners as a basis for further planning.

The most promising options for former sewage irrigation fields near the city of Berlin and lignite district in Lusatia (Lausitz) were identified by taking into account available land, soil quality, local context, stakeholders, available renewable energy production, good practice trial fields and running local projects as well as cost-benefit considerations within a longer time perspective.

Considering all aspects mentioned above, advanced biofuels production in the German case study area is not feasible due to limited biomass yields. However, realistic options for sustainable biofuels and bioenergy production as well as innovative biochemicals production via biorefineries were identified and are promoted to different stakeholders on the local level.

Using marginal sites for sustainable biofuels and bioenergy production from energy crops should be supported and promoted. This type of land use needs more encouragement on the national and local level as the potential is not yet exploited. It opens the opportunity of applying cultivation methods for an ecologically tolerant use instead of leaving this land fallow. In addition, **the use of marginal land for sustainable biofuels and bioenergy production is a feasible compromise between profitability and the preservation of ecosystem services**. Finally, the cultivation of energy crops for sustainable biofuels and bioenergy production helps to restore marginal land in a long term perspective.

In order to implement the analysed bioenergy value chains, exact data need to be collected. In addition, professional help (plant planners, engineers' office) should be involved in the implementation process. The authors and contributors of the feasibility report expressly do not guarantee the correctness of all contents as it relies on available literature and research results.

2. Baseline situation

This chapter provides a short overview on the identified case study area in Germany. It is based on the agronomic feasibility report elaborated by Research Institute for Post-Mining Landscapes (FIB, http://www.forbioproject.eu/documents).

The case study area is located in Brandenburg, Northeast part of Germany (Figure 1). Former sewage irrigation fields near the city of Berlin and lignite reclamation sites in Lusatia were selected for the case study.

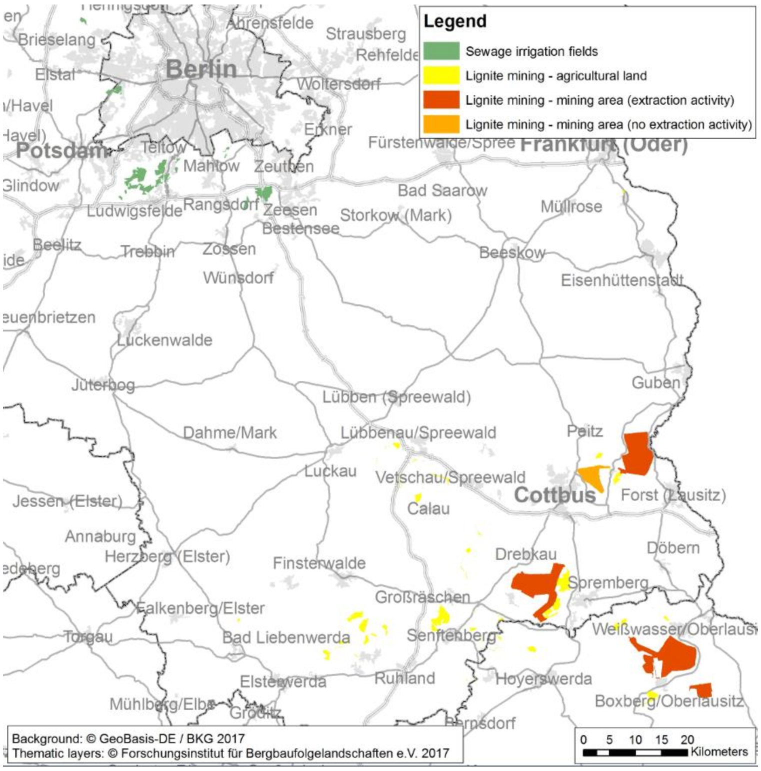

Figure 1: Case study area in the surroundings of Berlin and in Brandenburg

Agricultural soils in this area are dominated by sands. In addition, precipitation is moderate (500 mm - 700 mm). On 90% of the farmland there is an average water requirement of around 4 mm per day in the vegetation period while precipitation supplies only 2 mm. Although half of the rainfall is during the growing season, water deficit in the vegetation period is 125 mm - 225 mm. Therefore, water availability is a limiting factor for cropping activities in the region. With its dry and warm summers, the region is considered as one of the most climate sensitive areas in Germany. Agricultural land is mainly used for arable cropping, dry land farming, forage growing and pasture farming.

2.1 Sewage irrigation fields

Originally, 29,000 ha of low-yielding farmland were allocated for waste water irrigation and water impounding in Berlin and Brandenburg. Today, these irrigation fields are closed and substituted by modern sewage treatment plants. Considerable parts of the fields have been afforested, others have been transformed for purposes like housing, business parks and infrastructure or are used for compensatory measures in nature conservation. Therefore, currently the remaining former sewage irrigation fields offer an interesting recreation area with natural open spaces. In addition, significant areas are continuously changed into conventional agricultural sites.

The remaining areas that were not overbuilt amount for approximately 10,010 ha according to LUA 2003 and 9,981 ha according to the last comprehensive inventory by Ritschel & Kratz (2000). Around 6,707 ha thereof can be classified as agricultural land. As former irrigation fields fall under the category of “polluted areas” or “potentially contaminated sites”, site-specific restrictions shall be taken into account. Such “marginal land” requests higher operating costs and provides relatively low yield potential, therefore extensive pastureland is dominant at the moment. This clearly indicates that former sewage irrigation fields need an alternative use based on low-inputs and crops with relatively low demands well suited for cultivation on lighter soils and sites tending towards dryness. One of the attractive options for the region is sustainable bioenergy production.

The area that is available for sustainable bioenergy production in the surroundings of Berlin varies from 1,140 ha to 3,917 ha, depending on intended planning and use. Therefore, it is important to emphasize that it is a theoretical potential that does not take into account ecological, economic, social and political barriers.

This feasibility report considers 1,140 ha of former sewage irrigation fields as available realistic potential for sustainable bioenergy production in the western and southern surroundings of Berlin (Figure 2).

The most promising energy crops with acceptable yields were identified in the agronomic feasibility report. These are Miscanthus, Sorghum, Sudan grass and mixed Silphie. In addition, grass from current meadows could be an innovative option for biochemicals production via biorefineries. An overview on the potential biomass yields from the most promising energy crops is provided in Table 1.

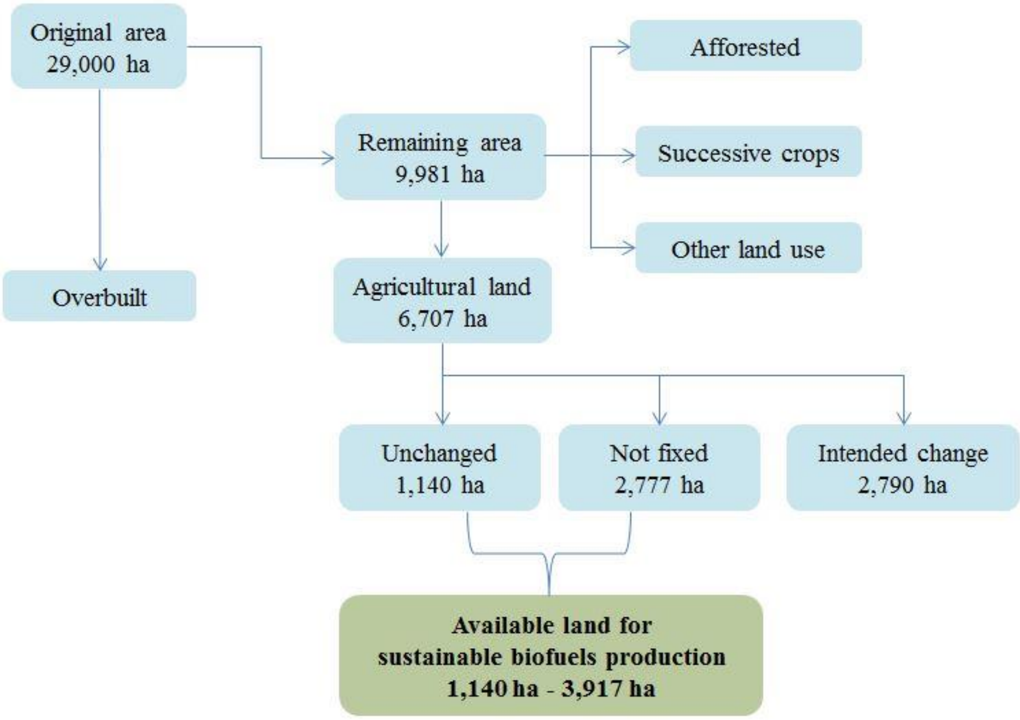

Figure 2: Technical potential of available land for sustainable biofuels production in the case study area around Berlin on the former sewage irrigation fields (FIB, 2017)

From the ecological point of view permanent, habitat-forming biomass feedstock cultivation is desirable. Therefore, low-input, perennial and self-regenerating biomass feedstocks are of high interest. Intended phytoremediation is a desirable cross-cutting effect making sense in terms of hazard prevention, especially on heavy metal polluted sites. The distribution of potential sites for sustainable bioenergy production on former irrigation fields is rather suitable for small, local processing facilities. It is important to mention that there is a lack of information on biomass feedstock production on former sewage irrigation fields, i.e. yield estimates, planting risks and economic feasibility. Therefore, estimations made in this report can serve as basis and guidance for further considerations on the local level.

Table 1: **Overview on the potential biomass yields from the most promising energy crops (Agronomic feasibility report, FIB, 2016, p.58-60)**

Annual and perennial crops	Biomass yield (Mg DM/ha/a)	Comments on experience in cultivation
Forage Sorghum (*Sorghum bicolor*)	3-16	First experiences from cultivation tests on former sewage irrigation fields in Berlin and Brandenburg are quite promising.
Sudan grass (*Sorghum sudanense*)	8-17	First experiences from cultivation tests on former sewage irrigation fields in Berlin and Brandenburg are quite promising.
Miscanthus (*Miscanthus x giganteus*)	5-25	Currently, there is no experience on former sewage irrigation fields. However, the crop is promising due to its properties and will be tested.
Mixed Silphie (*Silphium perfoliatum*)	13-18	Currently, there is no cultivation experience on former sewage irrigation fields. However, the crop is promising due to high yields on other soils.
Grassland	2-4	Grassland already exists in the area with extensive management for landscape conservation with 1-2 cuts per year, therefore, this biomass is already available.

2.2 Lignite reclamation sites

Eastern German lignite district is situated in the region called Lusatia (Lausitz), which is affected by one of the most extensive land use change in Germany in the last decades. Up to now, the total devastated area comprises approximately 900 km². In addition, further areas are approved for mining activities in the coming decades. At the moment the installed capacity of the coal plant in Lusatia (Lausitz) is 7.477 MW (Statistics of the Coal Industry e.V. 2016).

Out of 900 km² around 550 km² are already restored successfully (10,000 ha farmland and 30,000 ha mixed forests). Even though a landscape will remain affected by coal mining activities, it is being transformed into a lake district. The Lusatian lake district is now Europe's largest artificial lake area. Nevertheless, there are 32,000 ha under management of the mining and reclamation companies. This area needs to be reshaped and adapted for adequate use. 6,900 ha of the "working zone" are under reclamation and 1,858 ha thereof will be used as agricultural land. **In combination with the agricultural land in already reclaimed area (9,937 ha) and the use restrictions with respect to structural soil stability, there is a potential of at least 7,300 ha available for energy crops (Figure 3).** It is important to emphasize that it is a theoretical potential that does not take into account ecological, economic, social and political barriers.

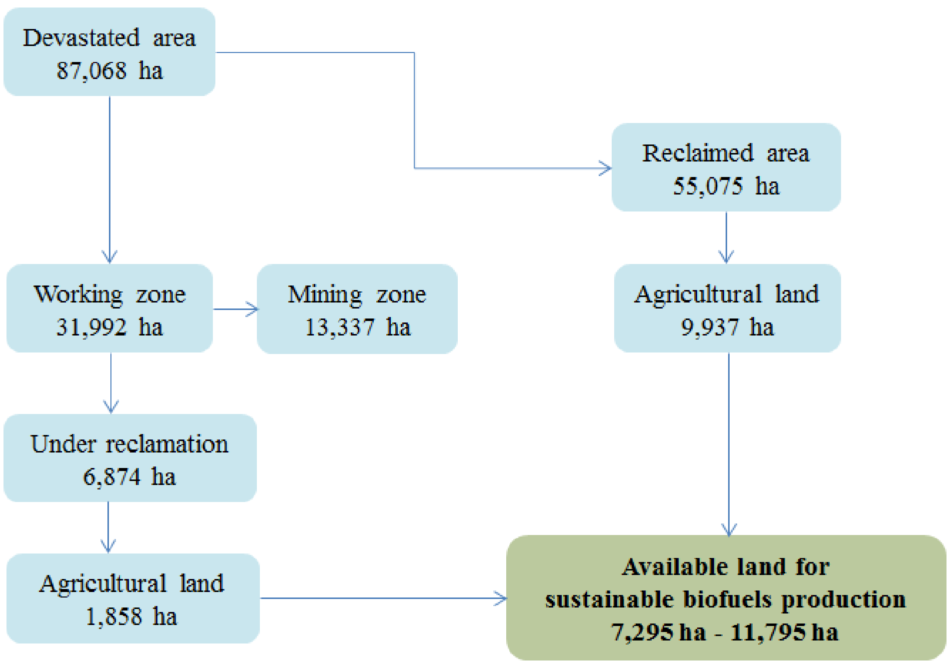

Figure 3: **Technical potential of available land for sustainable biofuels production in the case study area in the reclamation area of lignite mining (FIB, 2017)**

The most promising energy crops with acceptable yields were identified in the agronomic feasibility report. Results from field experiments showed that the most promising energy crops are forage Sorghum, Sudan grass, winter rye and winter wheat. In addition, Lucerne is

an attractive perennial crop which is already grown on reclamation sites because of current management practice (a special cropping system designed for the agricultural reclamation). An overview on the potential biomass yields from the most promising energy crops is provided in Table 2.

Table 2: Overview on the potential biomass yields from the most promising energy crops (Agronomic feasibility report, FIB, 2016, p.115-117)

Annual and perennial crops	Biomass yield (Mg DM/ha/a)	Comments on experience in cultivation
Forage Sorghum (*Sorghum bicolor*)	3-17	Profitable alternative to maize, experiences with cultivation on reclamation sites
Sudan grass (*Sorghum sudanense*)	8-17	Promising experiences on poor reclamation and marginal sites
Winter rye (*Secale cereale*)	6-8	Important element in the crop rotation, undemanding on low-yield sandy soils
Winter wheat (*Triticum aestivum*)	7-9	Important element in the crop rotation, resistant
Lucerne (*Medicago sativa*)	2-17	Self-regenerating, important for re-establishment of soil functions on reclamation sites, yields depend on the reclamation age
Black locust (*Robinia pseudoacacia*)	1-11	Good experiences with the cultivation on humus poor reclamation sites

In the lignite district around 90% of the abandoned mine land are sands and loamy sandy substrates. Therefore, it should be taken into account that energy crops grown on such land need nutrients at the right time and quantity. The lack of organic matter and a low nutrient availability requires a special cropping system for the agricultural reclamation during the first 16 years of cultivation. The major target of "biological reclamation" is the establishment of ecological soil functions with an increase of soil fertility and energy cropping capacities.

It is important to emphasize that compared to "undamaged" agricultural soils, mine reclamation soils remain quite unproductive. In many cases less than 30% of the maximum yields elsewhere in Germany can be expected in the best case scenario. Therefore, it is likely that the income for the local farmers might be unattractive.

In this case the establishment of stress tolerant energy crops with low water and nutrient demand is an attractive alternative which needs to be taken into account. Biogas production chain and upgrading biogas to biomethane could be an attractive option.

3. Selected promising options for sewage irrigation fields

In this chapter potential biomass supply chains for former sewage irrigation fields in the area near Berlin are analyzed in terms of techno-economic feasibility based on available data. Two main options were selected based on the agronomic feasibility study elaborated by the Research Institute for Post-Mining Landscapes. The first option is growing miscanthus as lignocellulosic feedstock for combustion. The second option is a grass biorefinery as grassland already exists in the case study area and the feedstock is already available. Eventually, grass could be used in operating biogas plants as additional feedstock and biogas could be upgraded to biomethane. Figure 4 shows the potential areas available for cultivation of energy crops in the southern and western part of Berlin.

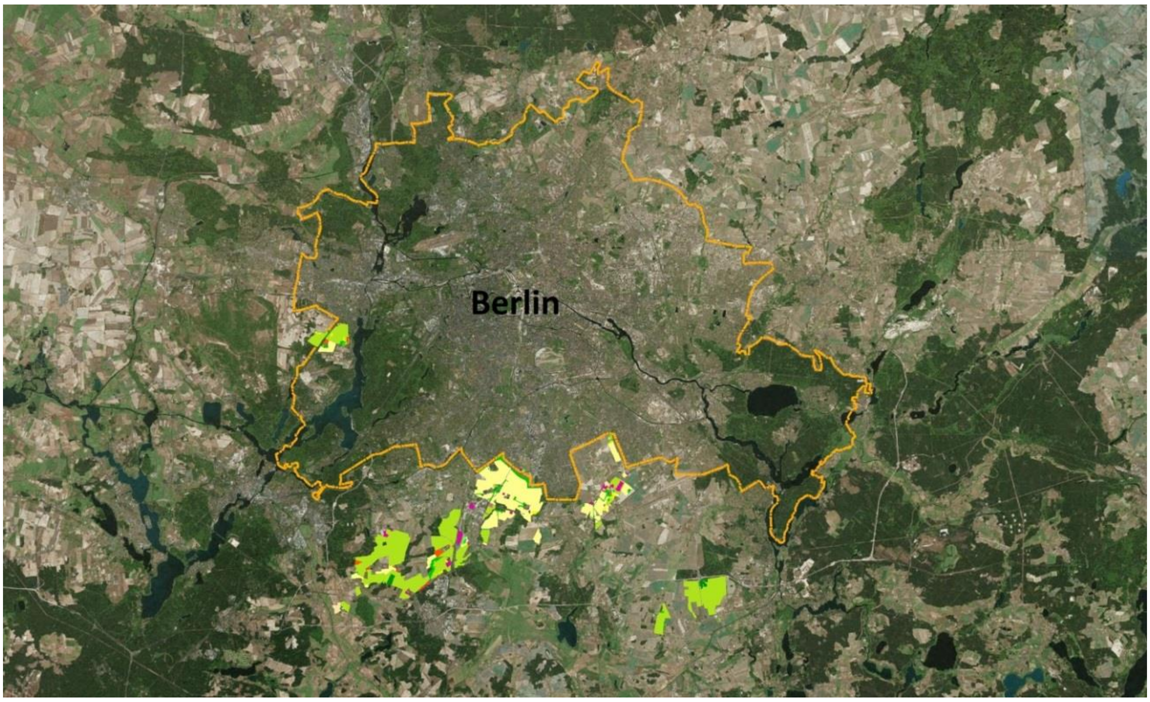

Figure 4: **Potential areas available for the cultivation of energy crops in the surroundings of Berlin (in total 5,000 ha, marked in green, FIB 2017)**

3.1 Option 1: Miscanthus for combustion

Unexploited potential of miscanthus

Miscanthus is a perennial crop with high biomass production potential and low input requirements. Cultivation of miscanthus as biomass feedstock for energy production is increasing due to its agronomical properties. At the moment, field experiments are mainly based on the genotype *Miscanthus x giganteus*. It is a clone-based hybrid which revealed its great photosynthetic efficiency, high biomass yield capacity, low input demands and good tolerance of temperate climates. Therefore, it is considered to be a leading candidate for lignocellulosic feedstock production. The main limitations for the cultivation of this energy crop are the rather high establishment costs and poor over-wintering, depending on the temperatures (Lewandowski et al., 2000).

The lignocellulosic biomass of miscanthus can be used for second-generation bioethanol production, however it is mostly utilized as raw material for the production of electricity or heat by direct combustion process (Bilandzijaa et al., 2016). In Germany, miscanthus is mainly used for heating as well as building material and bio-composites.

Only around 20,000 ha of miscanthus are commercially grown in the EU, mostly in the UK (10,000 ha), France (4,000 ha), Germany (4,000 ha), Switzerland (500 ha), and Poland (500 ha). It was reported, that miscanthus cultivation in Europe largely depends on public intervention. When state support is withdrawn, the cultivation of miscanthus declines (Lewandowski, 2016). Therefore, **growing miscanthus on underutilized lands is a good option to combine remediation of soils with sustainable bioenergy production.** Taking into account underutilized land for the production of miscanthus increases its chances for cultivation as these areas are not available for food production due to health reasons. In this case, miscanthus could contribute to the remediation of heavy metal contaminated soils and in the best case turn this land into areas suitable for food production. *Miscanthus x giganteus* grown on contaminated soils can accumulate in its biomass up to 5 mg Cd kg^{-1}, 150 mg Pb kg^{-1} as well as 700 mg Zn kg^{-1}. This shows that miscanthus is a promising crop for the phytoremediation (Pogrzeba et al., 2013). The case study area on the former sewage irrigation fields contains heavy metal pollution, which varies from low contamination to high contamination levels (Table 3). Miscanthus could reduce heavy metals in the soil if it is grown on the former sewage irrigation fields, especially Pb and Zn. Nevertheless, the remediation process can take decades, depending on the severity of heavy metal contamination.

Table 3: **Heavy metal pollution (HNO_3 extraction, total contents) of former irrigation sites nearby Berlin in percent of the total irrigation area (Agronomic feasibility report, FIB, 2016 p. 33; Grün et al., 1989)**

Element	No/low contamination		Medium contamination		High contamination	
	mg kg^{-1}	area %	mg kg^{-1}	area %	mg kg^{-1}	area %
Cadmium (Cd)	0.1-1.5	26	1.5-10	66	10-43	8
Copper (Cu)	8.1-90	81	90-180	17	180-730	2
Nickel (Ni)	1.4-15	79	15-25	15	25-95	6
Lead (Pb)	13-90	73	90-450	27	450-1,050	0.4
Zinc (Zn)	49-240	67	240-400	23	400-1,830	10

Finally, cultivation under marginal conditions is much more challenging than on agricultural land. This leads to lower yields which directly impacts the profitability of such projects. The ash after biomass combustion can contain high levels of metals and cannot be used as a fertilizer (Pogrzeba et al., 2013).

Potential areas for Miscanthus x giganteus near Berlin

Based on the agronomic feasibility report, the identified potential for the cultivation of miscanthus on the former sewage irrigation fields in the surroundings of Berlin is approximately 1,140 ha. This is the **minimum potential** available on the former sewage irrigation fields. It can be expected that the actual potential area is much higher (see Figure 2).

Figure 4 shows the potential areas available for miscanthus cultivation in the area of Berlin. The former sewage irrigation fields in the north are not considered as large parts are forests, agricultural land and urban or recreation areas (parks, golf areas etc.). In addition, the potential areas in the north available for cultivation of energy crops are small-sized and distributed.

The areas marked in color account for more than 5,000 ha, however the highest potential is in the areas marked in green. The calculation of potentially available areas is based on statistical data published in 2000 which indicates around 1,140 ha available for the cultivation of energy crops. It is not possible to say which areas exactly will be available for the cultivation of miscanthus as there is no new statistics with detailed spatial reference available at the moment.

Planting and establishment

Miscanthus is a relatively low-demanding perennial energy crop which can grow up to 4 meters in height, therefore its cultivation is possible on a variety of soils (Figure 5). Temperature and rainfall requirements are comparable to those of maize. In autumn, light soils are loosened 25 cm deep and leveled with a cultivator-harrow combination in spring. Heavy soils might require a deeper loosening with a cultivator or strip processing. In order to minimize the weed burden, it is recommended to apply a preceding crop, for example maize or grain. Pre-planting requirements are essential for good establishment of the plantation as miscanthus has the potential to be in the soil for around 20 years.

It is important to use high quality cuttings in order to obtain good establishment. In practice planting rhizomes has been successful since the establishment of the plant is easier and the rhizomes are less expensive than young plants. Rhizomes can usually be purchased from nurseries. The rhizomes should be kept moist before planting.

Figure 5: Miscanthus plantation in Germany (© Mergner)

Usually rhizomes are planted at a soil depth of 5-10 cm in a way that allows some expansion of the plant during its life. The plant density should be limited to one rhizome per m^2 (10,000 rhizomes/ha). The optimal planting time is until the middle of May. At this time, there are no late frosts that could threaten the rhizomes. After 20th May it is no longer recommended to plant miscanthus as the vegetation period becomes too short.

In the first year, optimal planting date, healthy and well developed rhizomes, sufficient water supply and no use of nitrogen fertilizer are crucial measures that significantly reduce the risk of wintering in the first year. Plants usually remain winter-hardy if stocks are harvested at the right time and approximately 10 cm of stubble is left.

In the first year weed control is important due to low population density of around 10,000 rhizomes per hectare. Mechanical or chemical weed control measures can be applied. Miscanthus requires comparatively small amounts of nutrients to produce high yields. The amount of nutrients that are extracted as a result of harvesting at average yield of 15 t DM/ha are as follows: 70-100 kg N/ha, 12-15 kg P/ha, 105-150 kg K/ha and 16-24 kg S/ha (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2014). In general, N fertilization is reasonable under good water supply conditions. In most cases it causes unwanted production of leaves and lowers strength of the stems, which increases the risk of breaking, especially at wet snow conditions. K, Mg, P fertilization is recommended every 2-3 years. **Regular sampling of the area is the basis for the calculation of the fertilizer quantities.** Organic fertilization, e.g. with manure or digestate, is also possible, but it should be applied in the third year at the earliest.

The identified potential for the cultivation of miscanthus on the former sewage irrigation fields in the surroundings of Berlin is 1,140 ha. Initial costs for the set-up of miscanthus plantation were calculated based on available literature. Table 4 shows approximate investment costs for miscanthus plantation per hectare. **Initial costs for 1,140 ha will be approximately 3,684,480 EUR without VAT.** As different VATs are applied for various steps in cultivation, the calculation does not include VAT.

Considering 20 years of cultivation for miscanthus plantation, annual investment costs for the establishment and maintenance of a mischanthus plantation will be around 161,6 EUR/ha. **For 1,140 ha area this leads to 184,225 EUR costs per year.** Land rental issue is not relevant in the German case study, as the land is mainly owned by Berliner Stadtgüter GmbH which is the potential stakeholder for the implementation of proposed promising options in this report.

Table 4: Initial costs for miscanthus plantation (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2014)

Steps	EUR/ha
Mechanical weeding	44
Ploughing	77
Sowing preparations	23
Planting	456
Rhizomes	2,000
Replanting	246
Rhizomes for replanting	300
Weeding	62
Maintenance	24
Total	**3,232**

Harvesting

The yields of miscanthus depend on the local conditions such as soil quality, water supply and temperatures. Depending on the local conditions stable yields can be expected from the third year when miscanthus reaches its highest potential yields. Yields can reach 4 – 7 t DM/ha/a in the second year and 12 – 20 t DM/ha/a from the third year. Based on the agronomic feasibility study, the potential yields of miscanthus on former sewage irrigation fields are considered to be around 5 t DM/ha/a in the second year and 15 t DM/ha/a from the third year. These are the average values, therefore, the yields could be lower or higher, depending on soil quality, water supply and temperatures.

Considering 1,140 ha area for miscanthus the yields could reach 5,700 t DM in the second year (5 t*1,140 ha) and 17,100 t DM (15 t*1,140 ha) as of the third year.

The optimal harvesting time is at the end of February – beginning of March, shortly before sprouting starts. The stems are dead (yellow) and largely defoliated. The following harvesting operations can be applied:

- **Chopping**: self-propelled forage harvesters with row-independent cutter are suitable for this harvesting method. Two machines are needed: a harvester and a collecting tractor with trailer. Chopping provides homogenous miscanthus chips (0.5-6 cm) with little dust. The density of the chopped feedstock is around 60-80 kg/m^3, therefore only short transporting distances are economically feasible.

- **Baling**: There are different types of balers, each producing different bales (rectangular, round, rolls etc.). Baling can be done in one or two stages. **One-stage baling** is done with a harvester that cuts and bales miscanthus. In this case bales need to be picked up by a tractor with a trailer. **Two-stage baling** is done with two different machines: swather and baler. In addition, a collecting tractor with a trailer is needed for the transportation, therefore one-stage harvesting is more favourable due to economics.

Harvesting and transportation costs depend on the harvesting method, the size of miscanthus plantation, storage needs and transportation routes (Table 5).

Transportation of miscanthus chips to existing biomass power plants

In the case study, miscanthus could be transported to existing biomass plants next to the miscanthus plantations. Three locations have been identified as potential options for the combustion of miscanthus in the region. The advantages of selling miscanthus chips for combustion in existing biomass power plants are as follows:

- Miscanthus chips can be transported to the biomass power plants directly after harvesting, therefore, there is no need for storage;
- Short distances to the biomass power plants have a positive impact on the transportation costs;
- No additional investments would be needed for a new biomass power plant.

Figures below show approximate distances from potential miscanthus plantations to existing biomass power plants and potential locations for miscanthus plantations. Transportation distance from miscanthus plantation to the CHP power plant of Henningsdorf is around 14 km from the South and 9 km from the West (Figure 6, Figure 7). Transportation distance from miscanthus plantation to the CHP power plant of Ludwigsfelde is around 3 km. Some smaller areas could be located around 15 km from the CHP plant (Figure 8, Figure 9). Transportation distance from miscanthus plantation to the biomass power plant of Königs Wusterhausen is around 9 km (Figure 10, Figure 11).

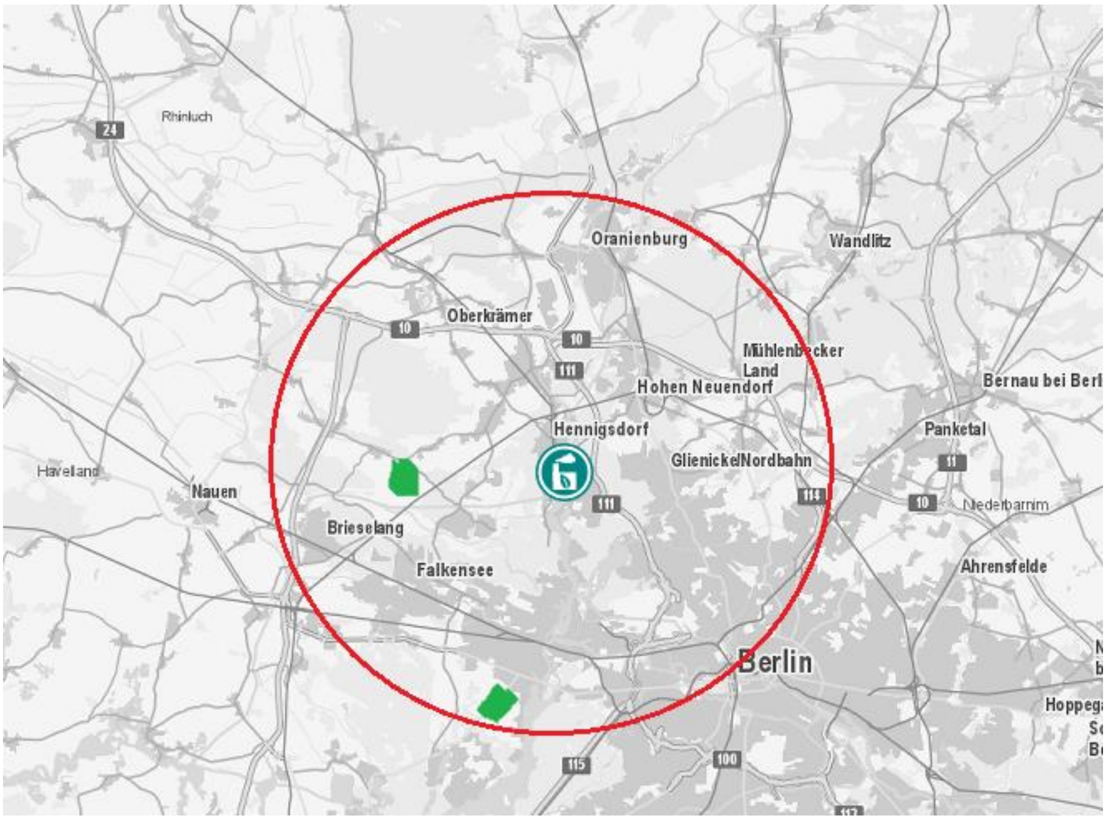

Figure 6: Radius (max. 14 km) of the potential miscanthus plantations in the West of Berlin (potential areas are marked in green; Energie - und Klimaschutzatlas Brandenburg)

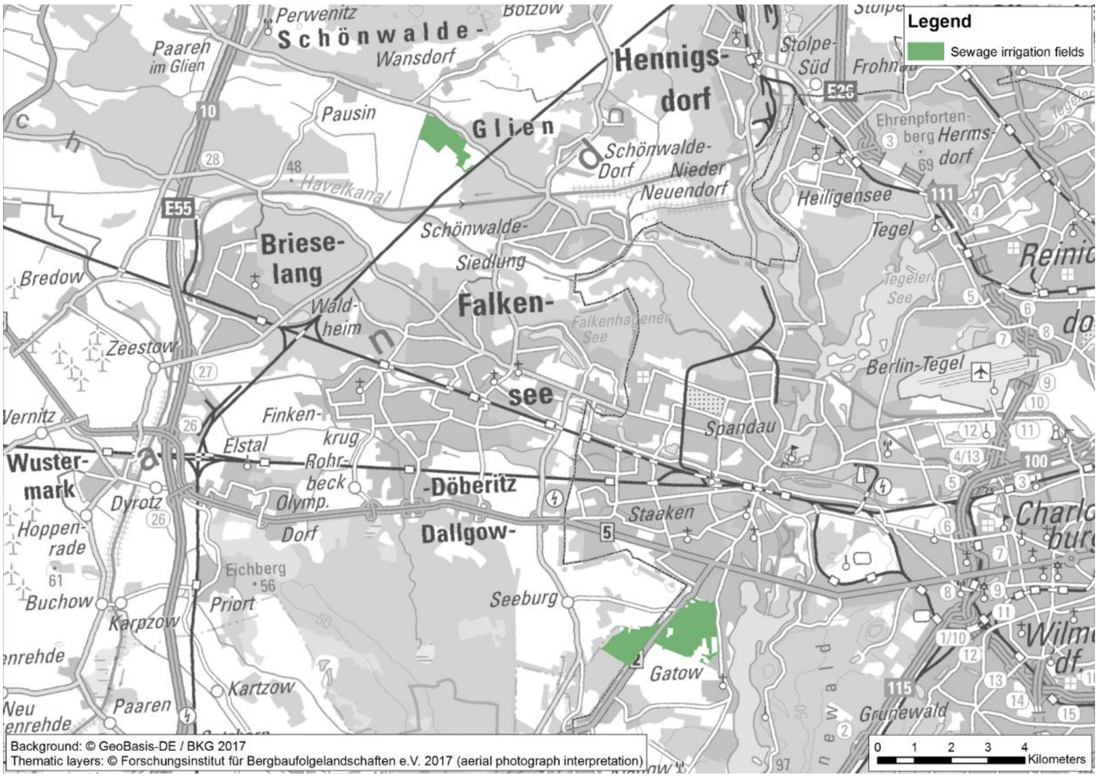

Figure 7: Potential areas for miscanthus plantations in the West of Berlin (FIB, 2017)

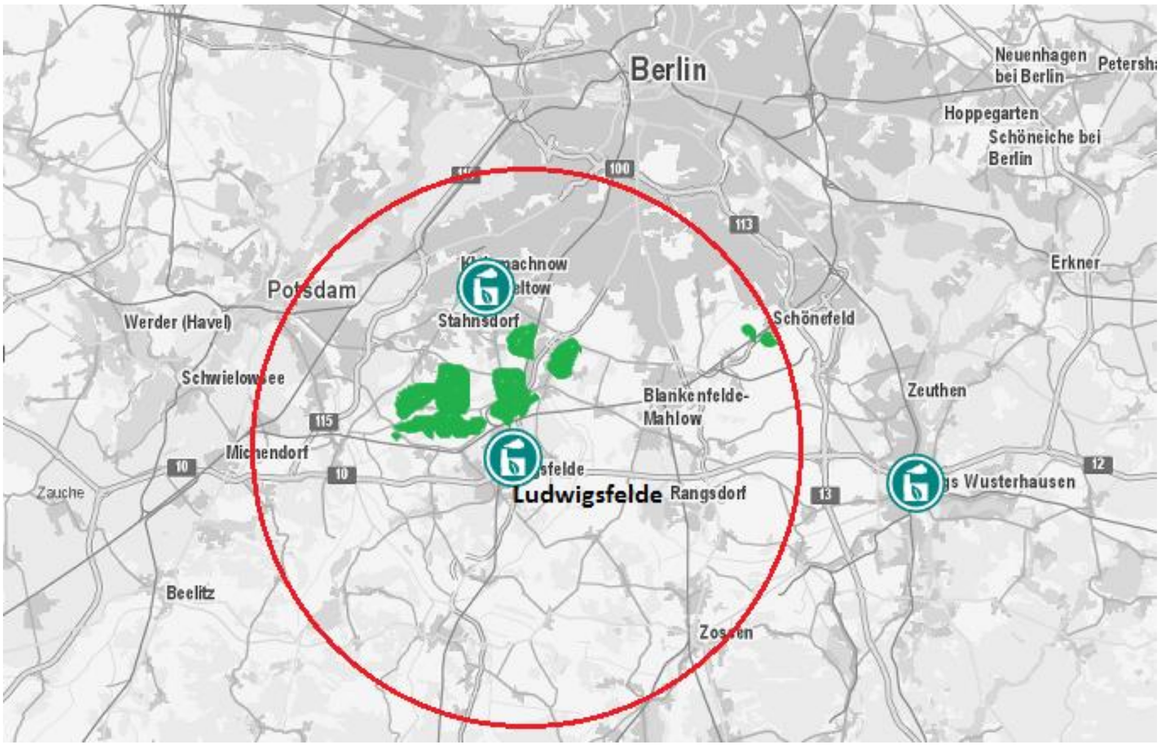

Figure 8: **Radius (mainly 3 km) of the potential miscanthus plantations in the South of Berlin (potential areas are marked in green; Energie - und Klimaschutzatlas Brandenburg)**

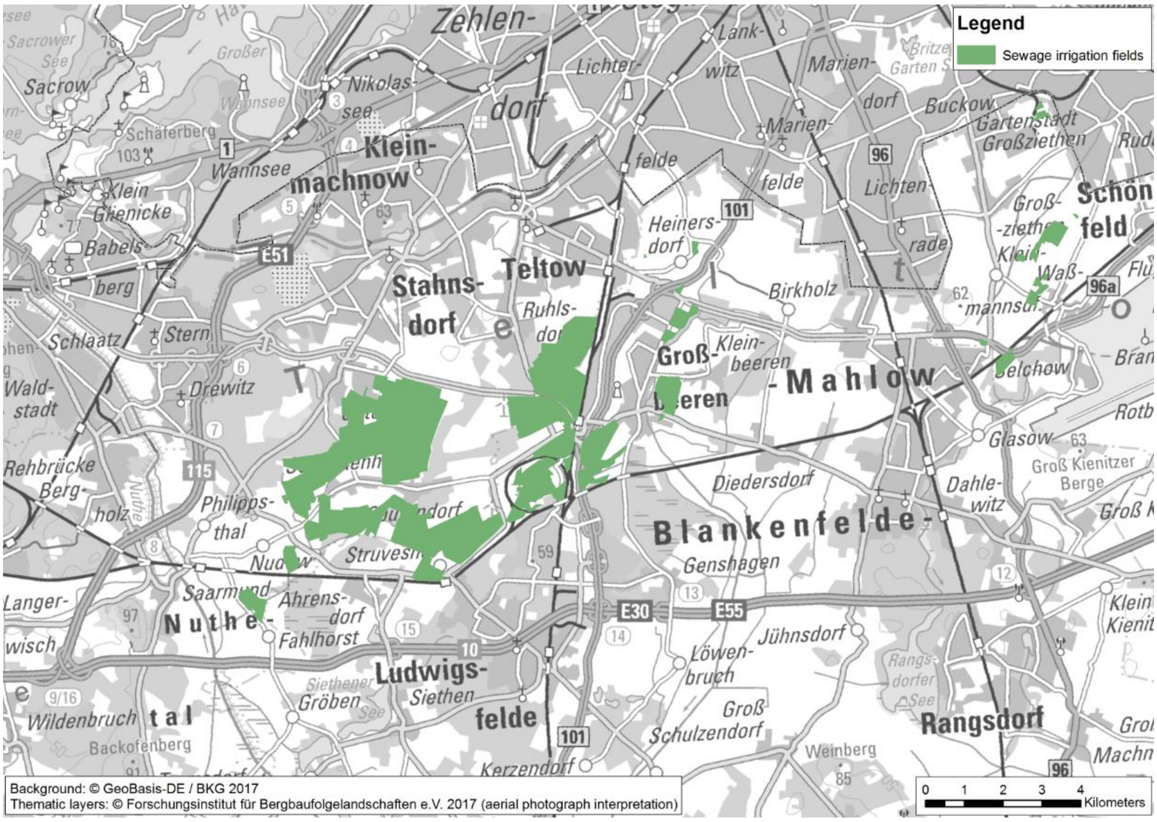

Figure 9: **Potential areas for miscanthus plantations in the South of Berlin (FIB, 2017)**

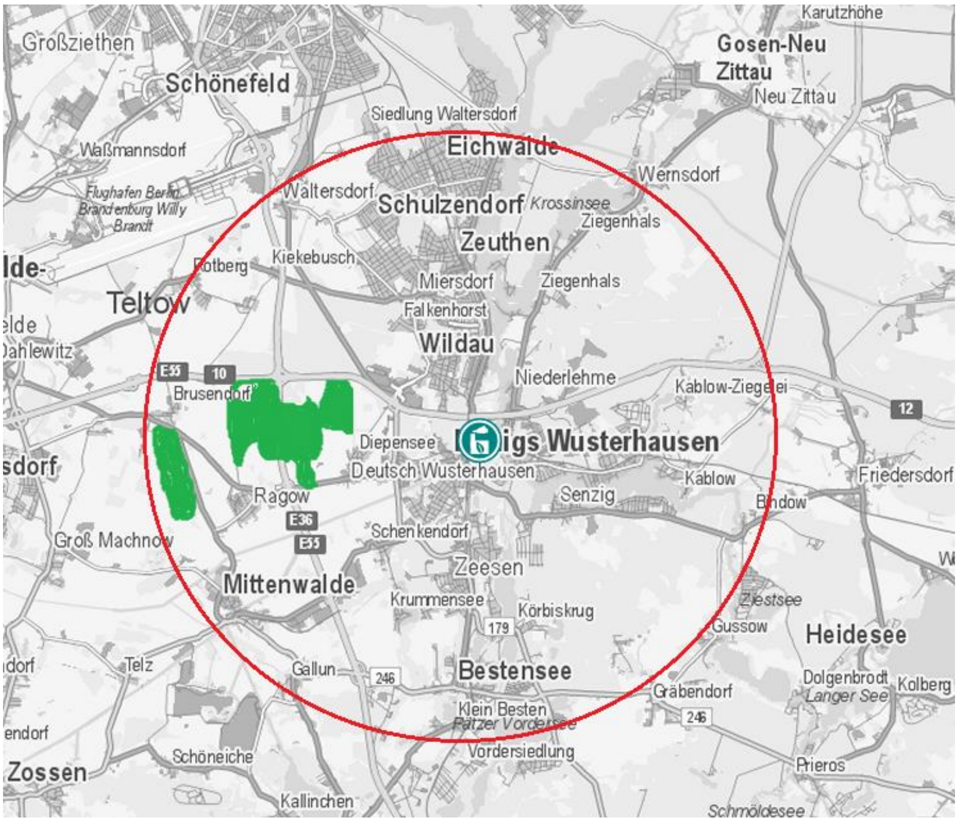

Figure 10: **Radius (9 km) from potential miscanthus plantation in the South of Berlin (Energie - und Klimaschutzatlas Brandenburg)**

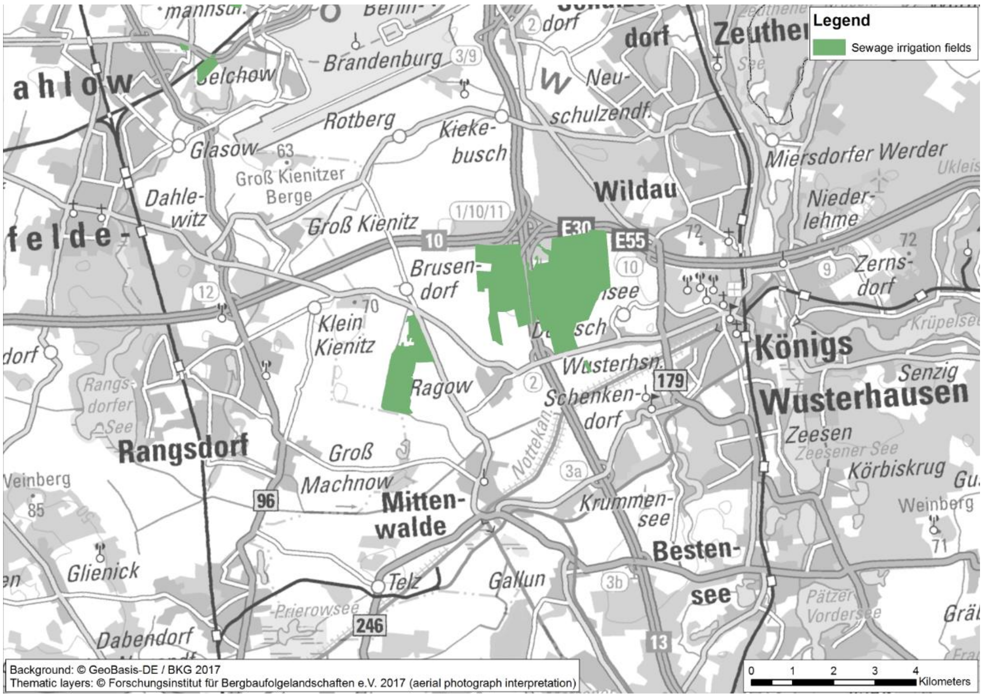

Figure 11: **Potential areas for miscanthus plantations in the South of Berlin (FIB, 2017)**

An example of harvesting and transportations costs is shown in Table 5. This can be used as basis for the calculations in this case study. The harvesting method which is taken into account is chopping and parallel loading for 5 ha fields. Calculating 20 years for miscanthus plantation and yields of 15 t DM/ha with a revenue of 80 EUR/t/DM leads to an economically feasible result (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2014).

Table 5: Estimation of harvesting and transportation costs (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2014)

Fresh mass t/ha	Transport route (e.g. from field to final customer) km	EUR/ha	Costs for chipping EUR/ha	Total costs EUR/ha
20	4	150	278	**428**
	6	184	278	**462**
	20	448	278	**726**

Consideration of building a new biomass CHP power plant

Depending on the biomass CHP plant, chips or bales of miscanthus can be combusted for electricity and heat production. 2.5 t DM of miscanthus can replace 1 t of heating oil. Calculating 15 t DM/ha it will lead to 6 t of heating oil that can be substituted by the combustion of biomass. In total, 6,840 t of heating oil can be substituted by biomass if miscanthus is grown on 1,140 ha area around Berlin. Only the southern area can be considered, as the distance between possible miscanthus plantation in the West and possible miscanthus plantations in the South is too long (around 40 km) (Figure 12).

Dry miscanthus stalks have a caloric value of around 17 to 18.5 MJ/kg (4.3-4.8 kWh/kg). **17,100,000 kg DM (15 t DM*1,140 ha) *4.8 kWh/kg lead to the energetic value of 82,080,000 kWh.**

The efficiency of a CHP power plant is around 90%, therefore, 82,080,000*0.9 leads to 73,872,000 kWh. 40% thereof goes to electricity production (29,548,800 kWh_{el}) and 60% to heat production (44,323,200 kWh_{th}).

In general, a full-load operating time for a CHP plant is about 8,000 full-load hours per year. 29,548,800 kWh_{el}/8,000 hours=3,694 kW=3.6 MW installed capacity. This shows the theoretical energy potential, as in practice there is no miscanthus CHP plant of similar installed capacity. Usually miscanthus is mixed with woodchips, straw and other woody biomass in CHP plants.

There are three biomass plants in the South of Berlin: CHP power plant of Ludwigsfelde, biomass power plant of Königs Wusterhausen and biomass power plant of Teltow. Therefore, it should be further assessed if a new biomass plant could create added value in the region.

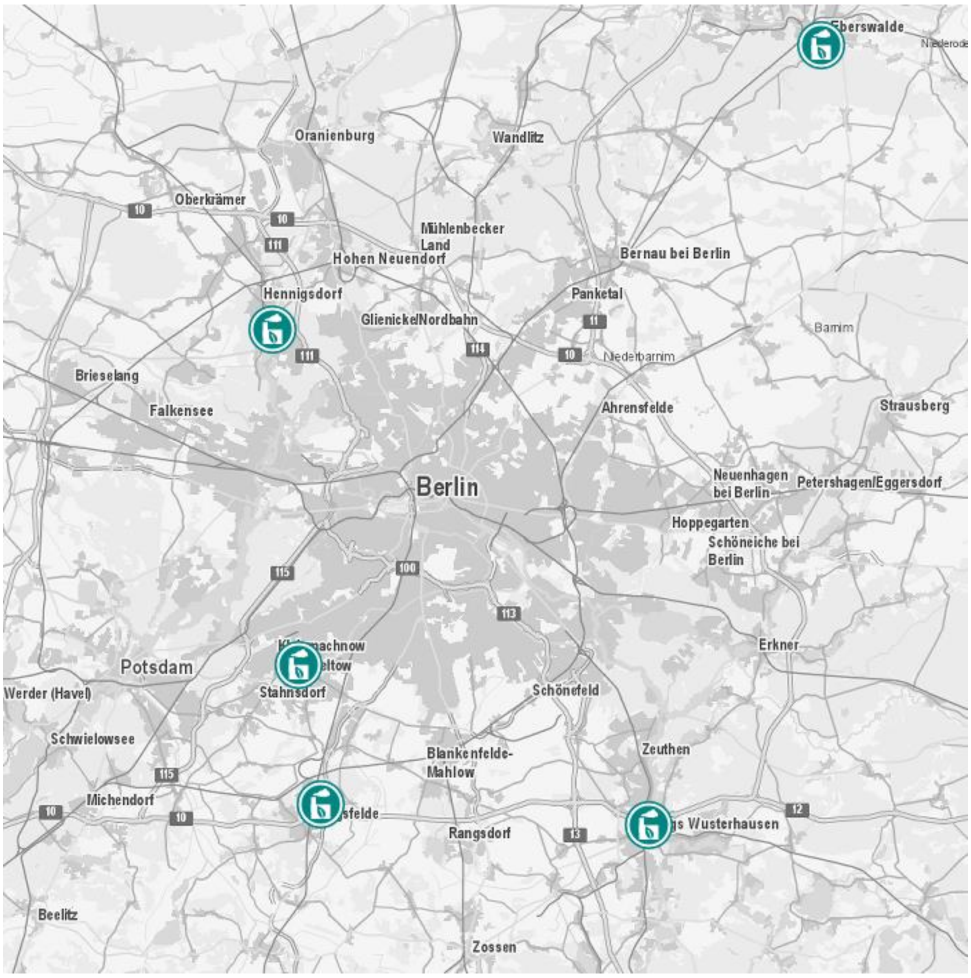

Figure 12: **Existing biomass plants around Berlin (Energie - und Klimaschutzatlas Brandenburg)**

Supply chain

There are different possibilities for the supply chain of micanthus. Figure 13 shows different possible supply chains in the area around Berlin. This report analyses the most common option - chopping of miscanthus directly during the harvesting, storage and transportation for combustion in the existing biomass power plants or in a new biomass CHP plant for miscanthus. For such local chains, it is important to mobilize the stakeholders (investors, providers and end users), to have enough storage capacities and to meet energy demands in the local area.

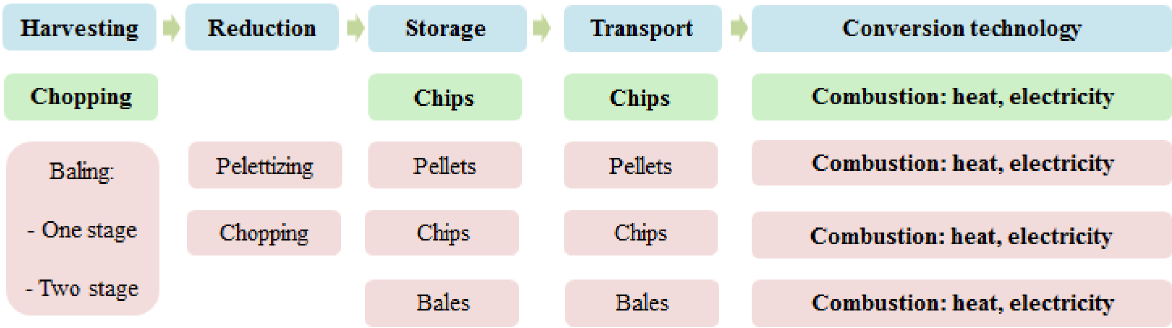

Figure 13: Possible supply chain for miscanthus on former sewage irrigation fields

Funding opportunities

The Federal Office for Economic Affairs and Export Control (BAFA) is involved in the promotion of further expansion of renewable energies in Germany. New highly efficient CHP plants can receive a fixed compensation for generated electricity (a CHP bonus) according to CHP Law (KWKG 2016). The bonus is applicable only if electricity is fed into the electricity network. For the plants between 1-50 MW the contract is determined via a tender procedure. Tenders are issued by the Federal Network Agency and are implemented by BAFA.

According to the CHP Law (KWKG 2016), the CHP bonus for plants over 2 MW is 3.1 cents per kWh. However, due to the new tendering procedure it is not possible to say if the bonus will remain the same in the future.

KfW Banking Group offers different funding programs for new renewable energy projects. The Renewable Energy Premium funding program supports large-scale plants for the use of renewable energy sources in the heat market. It offers low interest rates and long-term financing of new renewable energy facilities. CHP biomass plants and biomass combustion plants are relevant for this program. The funding is provided in a form of a low interest loan. The loan can be provided up to 100% of the eligible investment costs, max. 10 mln. EUR for one project. Additional grants from federal funds can be provided in this program. The Renewable Energy Standard funding program aims at electricity production and CHP plants. This program offers low interest loans which can be up to 100% of the eligible investment costs, max. 50 mln. EUR for one project.

With RENplus 2014-2020 funding program ILB (Investitionsbank des Landes Brandenburg) supports measures to increase energy efficiency and the use of renewable energy sources in the region. Highly efficient CHP plants can receive grants under this program. Depending on different criteria, max. 3 mln. EUR can be granted under this program.

Contribution to biodiversity

Miscanthus can contribute to biodiversity as it provides habitats which encourage the diversity of different species. In addition, it can act as a nesting habitat and protection area for birds.

Different bird species find a variety of bugs and wild herbs which are a good source for food. High miscanthus plants offer protection also for bigger animals such as deers and rabbits. Field voles, wood mice, brown rats, harvest mice, pygmy shrews, skylarks, yellowhammers, greenfinches, linnets, buzzards, partridges, sparrowhawks, quails and over hundred species of bugs and spiders were detected in miscanthus fields (Fritz et al. 2009).

The effect on the nature by large cultivation areas of miscanthus was analysed in 1995 by comparing a miscanthus field with maize and reed. Small animals seemed to prefer miscanthus fields. Contrary to maize cultivation, no tillage is necessary for miscanthus plantation which is also an important factor for biodiversity (Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe, 2009).

Summary and conclusions

Different options are possible for growing miscanthus on the former sewage irrigation fields in the area near Berlin. The following pathways for the cultivation and combustion of miscanthus around Berlin were identified:

- Option 1: Supplying miscanthus chips to three existing biomass power plants around Berlin
- Option 2: Building a new CHP biomass power plant and combusting miscanthus chips for heat and electricity production

Supplying miscanthus chips to three existing biomass power plants around Berlin is a realistic option. Firstly, the calculation of costs and revenues is more precise as rather detailed data is available for this option. Secondly, this option requires less effort as no new plant needs to be built. This also minimizes the risk in case the option would not be feasible in the long term. Table 6 summarizes the potential costs for this option. It is important to emphasize that the possible distribution of 1,140 ha around Berlin is not clear. Therefore, this report presumes that most of the areas will be located in the southern areas around Berlin. For supplying miscanthus chips to three existing biomass power plants around Berlin, 1,140 ha were allocated as follows: 140 ha around Henningsdorf, 500 ha around Ludwigsfelde and 500 ha around Königs Wusterhausen. This allows calculating possible transportation costs from miscanthus fields to three selected operating biomass power plants around Berlin. Establishment costs, annual maintenance costs and harvesting costs are indicated for the entire 1,140 ha area.

It should be taken into account that additional transportation costs influence the economic feasibility of this option. Therefore, this factor needs to be assessed in more detail in the planning phase. A sufficient option would be to allocate 1,140 ha around Ludwigsfelde as the radius is only 3 km. This would allow minimizing the costs for transportation (calculated in Table 6 for comparison). The calculations were made for 20 productive years as miscanthus plantation is usually established for 20 years.

For building a new CHP biomass power plant and combusting miscanthus chips for heat and electricity production, 1,140 ha area should be located ideally next to Ludwigsfelde due to short distance from potential miscanthus fields to the potential CHP plant.

Table 6: Costs for the cultivation of miscanthus for 20 productive years, Option 1

Establishment of a miscanthus plantation (once in 20 years)	
1,140 ha area (3,208 EUR/ha)	3,208*1,140=3,657,120 EUR
Land rental	0 EUR
Annual maintenance	
Maintenance services (24 EUR/ha)	1,140*24=27,360 EUR/a
Logistics	
Harvesting (chipping) (278 EUR/ha)	278*1,140=316,920 EUR/a
Transportation (from the field to the final customer)	
3 km (Ludwigsfelde, 140 ha, 113 EUR/ha)	15,820 EUR
9 km (Königs Wusterhausen, 500 ha, 276 EUR/ha)	138,000 EUR
14 km (Henningsdorf, 500 ha, 314 EUR/ha)	157,000 EUR
Best option: 3 km (Ludwigsfelde, 1,140 ha, 113 EUR/ha)	**128,820 EUR/a**
Total costs for 20 productive years	**13,119,120 EUR**

Table 7 summarizes the potential revenues for this option. Calculating 20 years for miscanthus plantation and yields of 15 t DM/ha with a revenue of 80 EUR/t/DM can lead to an economically feasible result (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2014). In the German case this would lead to 26,448,000 EUR revenues. It should be taken into account that the yields and selling price might be different. Calculating 15 t DM/ha and 50 EUR/t/DM would still lead to an economically feasible result, however the price should not be lower as not all factors can be considered in this report. Therefore, calculating 15 t DM/ha and 50-80 EUR/t/DM could lead to a good economic result.

Table 7: Potential revenues from selling miscanthus chips for 20 productive years, Option 1

Selling miscanthus chips (80 EUR/t/DM)	
Second year (5,700 t)	456,000 EUR
As of third year (17,100 t)	1,368,000 EUR/a
Total income in 20 years	**26,448,000 EUR**
Selling miscanthus chips (50 EUR/t/DM)	
Second year	285,000 EUR
As of third year	855,000 EUR/a
Total income in 20 years	**16,530,000 EUR**

The feasibility of building a new CHP biomass power plant and combusting miscanthus chips for heat and electricity production (Option 2) needs to be further assessed in more detail. Around 29,548,800 kWh_{el} electricity and 44,323,200 kWh_{th} heat could be produced in the CHP biomass plant. Investment for building a local district heating system depends on the exact location of the CHP plant and distance to the potential customers. The potential customers could be private houses as well as industrial buildings. Table 8 provides a summary on the costs for the cultivation and combustion of miscanthus in a new biomass CHP power plant for 20 years.

Table 8: Costs for the cultivation and combustion of miscanthus for 20 productive years, Option 2

New biomass CHP power plant	
Total investment costs for a new CHP plant (3.6 MW; 4,200 EUR/MWel.)	>15 mln. EUR
Operating costs	
- Disposal of ashes, electricity, service etc.	100,000 EUR/a
- Personnel (6 staff members, full time)	500,000 EUR/a
- Feedstock supply, annual maintenance and logistics for 20 years	13,119,120 EUR
Total costs for 20 years	**App. 40 mln. EUR**

Table 9: Potential revenues from selling heat and electricity

Sales	
Electricity sales (0.1488 EUR/kWh)	4.4 mln. EUR/a
Heat sales (0.05-0.09 EUR/kWh) per year	2.2 – 3.9 mln. EUR/a
Total income in 20 years from electricity sales	88 mln. EUR

It should be taken into account that in this report the calculations are based on available literature. The main goal is to show the potential for the implementation of this option. For the calculation of revenues electricity sales were considered as the main revenue (revenues from heat sales is rather low compared to electricity and does not influence the total financial feasibility of this option). In addition, for the calculation of the potential investment costs for building a district heating system more data is needed (potential customers, distance to the potential customers, number of customers etc.). Business from heat sales would cover the cost for the district heating system and its operation, however the main part of revenues will come from electricity sales.

Option1: supplying miscanthus chips to three existing biomass power plants around Berlin

The calculations indicate that selling miscanthus chips to existing biomas plants could be financially feasible if the price is between 50-80 EUR/t/DM. Additional payments and subsidies need to be calculated in addition. The payback period is 10 years if the feedstock is sold for 80 EUR/t/DM.

Option 2: building a new CHP biomass power plant and combusting miscanthus chips for heat and electricity production

The calculations indicate that building a new biomass CHP power plant could be financially feasible and the repayment time would be around 10 years, considering only electricity sales. Finally, additional payments and subsidies need to be calculated in addition.

3.2 Option 2: Grass for biorefinery

Unexploited potential of permanent grasslands

Currently, grassland is mainly used for cattle farming, however during the last decades notable changes in grassland use can be noted. Nowadays there are new options to use grassland biomass for energy purposes as well as for biobased products. Therefore, the use of grassland is becoming partly independent from livestock production (Thumm et al. 2014).

Estimates indicate a surplus grassland area of 9.2-14.9 mln ha in the EU for the year 2020. In the EU surplus grassland represents around 13-22% of permanent grassland. Therefore, grassland could cover 16-19% of the energy crop potential and 6-7% of the total bioenergy potential without interfering with land needed for animal feed (Prochbow et al. 2009). Surplus grassland has a remarkable bioenergy potential and biomass supply for energy or biobased products is regarded as one suitable way to make use of it.

Permanent grassland can be defined as land used permanently to grow herbaceous forage crops, through cultivation or naturally. In addition, it is not included in the crop rotation scheme under the EU Regulation 1307/2013. Permanent grassland can be classified into the following types with regard to management intensity and productivity (Thumm et al. 2014):

- High-yielding, intensively-managed, agriculturally-improved grasslands
- Grassland biomass from semi-natural grasslands
- Grassland biomass from landscape conservation areas

The characteristics and yields of grassland depend on site conditions and management intensity. During the last 50 years, most grassland areas with extensive grazing and mowing were converted into productive, agriculturally- improved grasslands with high mowing frequencies (three to six cuttings per year) (Rose 2012).

Grass is often a waste product of necessary landscape management measures and its use is sustainable. Usually, grass is cut, mulched and left on the field. Therefore, the use of such biomass neither displaces food production nor causes loss of biodiversity. In the context of a rapidly developing bioeconomy, there is an increasing demand for sustainably produced biomass, not only for the renewable energy sector, but also for the production of biobased products. Therefore, it has the potential to become an important resource for sustainable biomass supply (Thumm et al. 2014).

Grasslands could provide biomass feedstock suitable for anaerobic digestion and for green biorefineries. Furthermore, combustion, pyrolysis and gasification or enzymatic hydrolysis and subsequent fermentation to ethanol are additional options to process grass to bioenergy. Its use in biogas plants is a well-established practice, whereas a grass biorefinery is an innovative concept offering different options for biobased products. The green biorefinery concept is currently in an advanced stage of development in several European countries, especially in

Germany and Denmark. This novel pathway opens new opportunities to use grass as a feedstock for biobased products (Thumm et al. 2014).

Potential grassland areas around Berlin

Based on the agronomic feasibility report, the identified potential for the cultivation of grasslands on the former sewage irrigation fields in the surroundings of Berlin is approximately 1,140 ha. This is the **minimum potential** available on the former sewage irrigation fields. It can be expected that the actual potential area is much higher (see Figure 2, Chapter 2.1). However, it is difficult to predict how much land in addition could be available for the cultivation of grasslands, as it will be decided in the coming years. Figure 4 shows the potential areas available for the cultivation of grasslands in the southern and western part of Berlin.

The former sewage irrigation fields in the north of Berlin are not considered as they are mostly located in the urban area of Berlin and are used for other purposes such as buildings or recreation areas (forests, parks, golf course etc.). The areas marked in color account for more than 5,000 ha. However, areas marked in green have the highest potential. The calculation of potentially available areas is based on statistical data published in 2000 which indicates around 1,140 ha available for the cultivation of energy crops. It is not possible to say which areas exactly will be available for the cultivation of grasslands as there is no new statistics available at the moment.

Current situation

Currently, grasslands on the former sewage irrigation fields around Berlin are not managed intensively. These areas show a considerable ecological biodiversity and some of them fall into declared protected landscapes and nature conservation areas. This leads to several limitations in management, i.e. only grassland use, no applications of herbicides, prohibition of grassland conversion into arable land. This “marginal land” is managed extensively, with a special focus on landscape maintenance, in particular by mowing of meadows (FIB 2016).

These grasslands can be classified as heavy metal tolerant, semi-natural grasslands. The dominant vegetation is sub-cosmopolitan (undemanding, quite stress-tolerant, perennial) and rhizomatous grasses. The dominant grasses are wood small-reed (*Calamgrostis epigeios*), smooth brome (*Bromus inermis*), couch grass (Elymus) and meadow grass (*Poa pratensis*) which is typical for semi-dry grasslands. They are flood, cold and heat resistant, but prefer warm and dry conditions as well as nutrient rich soils (FIB 2016). An attractive option is to mobilize the unused biomass from the former sewage irrigation fields as a by-product of necessary landscape conservation measures to generate profits.

In July 2016, an on-site biomass analysis was carried out on the sewage irrigation fields at Cottbus-Saspow and Finsterwalde in South-Eastern Brandenburg. Table 6 shows that biomass yields range from 1.5 to 3.7 Mg DM ha/a for one cutting just before ripening of the grasses. The differentiating yields are illustrating the small-scale soil heterogeneity of irrigation fields. The data are comparable to other semi-natural, not NPK-fertilised and water limited grassland formations in Germany. In general, with a sufficient water supply, yields of 5.5 to 9 Mg DM ha/a for sedge reed or even 9.5 to 12 Mg DM ha/a for reed grassland are possible. These biomass yields are similar to intensively managed forage grass on sewage farms nearby Berlin-Malchow. There the yield potential was ranging from 9.5 Mg DM ha/a (non-irrigated) to 13 Mg DM ha/a (irrigated) (FIB 2016).

Table 10: Biomass yields at former sewage irrigation fields Cottbus-Saspow and Finsterwalde (one cutting before ripening in July 2016, test plots of 10-50 m², harvest of herbs and forage sorghum in late September 2016)

Dominant vegetation	Yield/one cutting (t DM ha/a)
Sewage irrigation fields "Cottbus-Spaspow" (19 ha)	
Smooth brome (*Bromus inermis*)	1.9-3.3
Herb mixture	2.7-3.1
Sewage irrigation fields "Finsterwalde" (20 ha)	
Wood small-reed (*Calamagrostis epigejos*)	2.8
Smooth brome (*Bromus intermis*)	2.9
Reed canary grass (*Phalaris arundinacea*)	1.5-3.7

Harvesting

The yields of grass on former sewage irrigation fields depend on the local conditions such as soil quality and water supply. Temperatures are not a limiting factor, as such grasslands are flood, cold and heat resistant. Depending on the local conditions, soils on the former irrigation fields are nutrient rich, therefore, the yields of grass are rather stable every year. **Based on the agronomic feasibility study, the potential yields of grass on former sewage irrigation fields are considered to be around 3 t DM/ha/a**. Calculations in this report will be based on this value as it is the realistic average yield. However, the yields could be lower or higher, depending on soil quality and water supply.

Considering 1,140 ha area of grasslands, the yields could reach 3,420 t DM per year (3 t*1,140 ha). Taking into account around 50% moisture content, the yields of grass fresh matter would be 6,840 t per year. The optimal harvesting time is before the beginning of seed formation. The advantage is a high protein yield and the better availability of substances such as free sugars. The dominant grasses are wood small-reed (*Calamgrostis epigeios*), smooth brome (*Bromus* *inermis*), couch grass (*Elymus*) and meadow grass (*Poa pratensis*). Further assessment should be done in order to define the optimal harvesting time for grasses on the selected sites. Harvesting operation applied in several pilot-stage biorefineries is baling (e.g. BIOFABRIK Green Refinery). It is done with three different machines: mower, baling press and baler (Figure 15). In addition, a collecting machine is needed for the transportation.

Harvesting and transportation costs depend on the size of areas and transportation routes. The calculation of costs for the machinery, fuel and personnel is based on the prices indicated by Maschinen- und Betriebshilfsring Laufen e.V. Mowing costs are around 27 EUR/ha, baling costs are around 14,5 EUR per bale including machinery, fuel and personnel. Taking into account that at least 1,140 ha need to be mowed and a mower works 8 hours per day with the capacity of max. 10 ha/day, 114 days would be needed to cut the grass on 1,140 ha. 1 bale weights around 1 t, therefore 1,140 ha*3 t/ha leads to 3,420 t of grass silage which sums up into 3,420 bales. Calculating 1 bale per m^3 and 40 m^3 loading capacity of the transporting truck, 40 bales could be transported in one way. In total the truck trailer would need to be loaded 86 times in order to transport 3,420 bales from the field to the grass biorefinery in the radius of 12 km. Calculating 12 km from the field to a biorefinery and 12 km back to the field, in total 24 km route is necessary to transport 40 bales. 24 km*86 times sums up to 2,064 km for the entire transportation of bales. The cost of the machinery, fuel and personnel for 200 km and 40 m^3 loading capacity is around 68 EUR per hour. Calculating 1 hour and 24 km for loading, transportation to the biorefinery, reloading and driving back to the field, 8 working hours and around 200 km can be calculated for transporting 320 bales in one day (8 hours * 40 bales). As 86 working hours (2,064 km/24 km) are needed to transport all bales to the biorefinery (around 10.5 working days), the cost for the transportation could reach 5,848 EUR (68 EUR/hour*86 hours). VAT is not included in the calculations. In addition, these calculations are valid for one harvesting per year. Land rental issue is not relevant in the German case study, as the land is mainly owned by Berliner Stadtgüter GmbH which is the potential stakeholder for the implementation of proposed promising options in this report.

Table 11: Estimation of costs for harvesting and transportation (without VAT)

Harvesting steps	Costs	Total costs
Mowing	27 EUR/ha	1,140*27=30,780 EUR
Baling	14,5 EUR/bale	14,5*3,420=49,590 EUR
Transportation	68 EUR/hour	68*86=5,848 EUR
Total		**86,218 EUR/a**

Figure 14: Harvesting and grass silage preparation (Mandl et al. 2006)

Potential location for a grass biorefinery

In the case study, grass silage bales would need to be transported to a grass biorefinery. Taking into account the distribution of available areas around Berlin, the southern part of Berlin can be considered as a suitable place for a biorefinery (Figure 14). Grass silage would need to be collected in the southern part as the distance between grasslands in the West and possible biorefinery in the South it too long (around 40 km). In general, two options can be considered for the location of a grass biorefinery:

- A stand-alone grass biorefinery
- A grass biorefinery next to an existing biogas plant in the southern part of Berlin

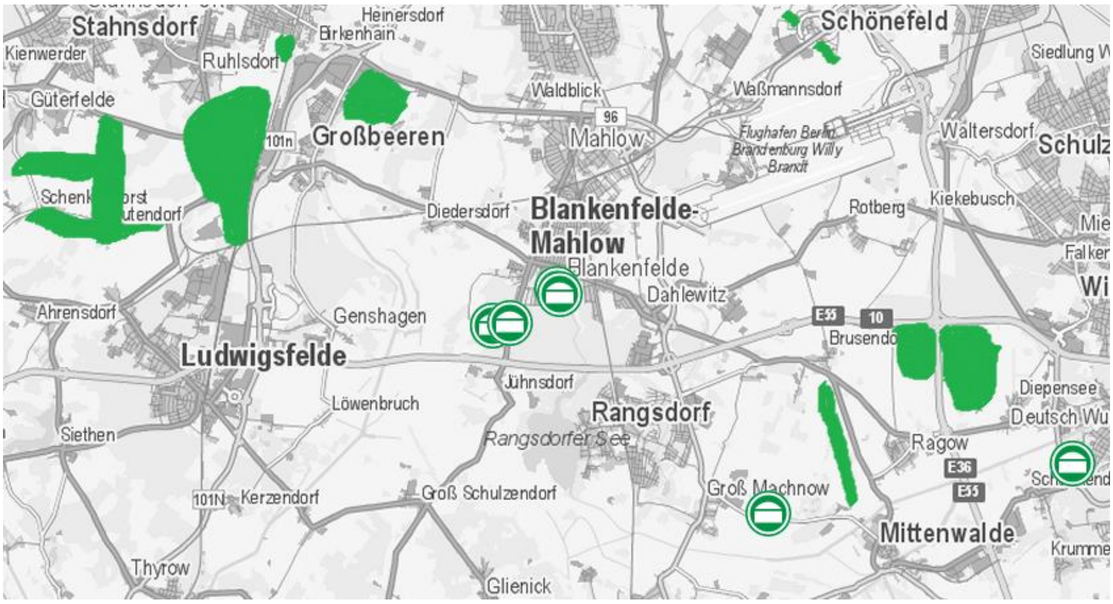

Figure 15: Operating biogas plants and potential grasslands on the former sewage irrigation fields in the South of Berlin (Energie - und Klimaschutzatlas Brandenburg)

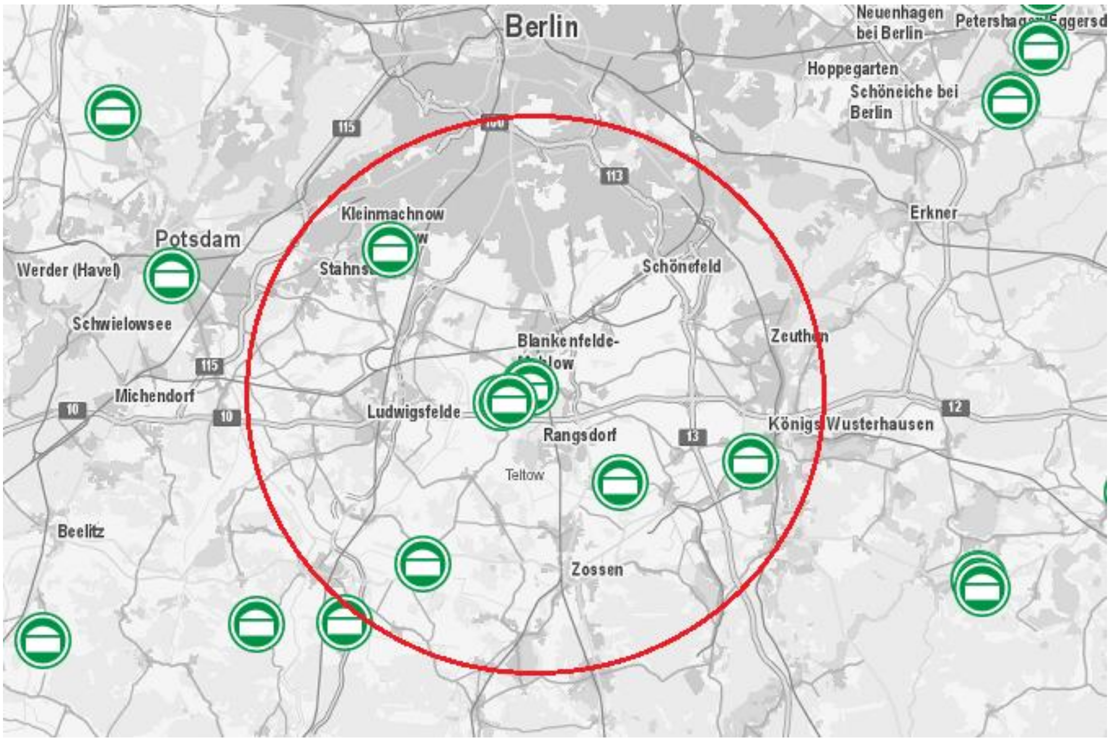

Figure 16: Radius (12km) around a potential grass biorefinery (Energie - und Klimaschutzatlas Brandenburg)

A stand-alone grass biorefinery would lead to higher investment costs, therefore, an integrated approach is preferred. In the South of Berlin area, seven operating biogas plants were identified (Figure 16, Figure 17). Four biogas plants are around Blankenfelde-Mahlow, one in Teltow, one around Mittenwalde and one around Königs Wusterhausen. The biogas plants around

Blankenfelde-Mahlow would be quite suitable as they are located in the middle of available grasslands, and the distance (radius) to the fields would be only around 12 km (Figure 17).

Grass biorefinery concept

A grass biorefinery transforms biomass into a spectrum of marketable products (chemicals and materials, food and feed ingredients) and energy (fuels, power, heat) where fresh grass or grass-silage is used as input material. In general, biorefineries can be energy-driven and product-driven. Energy-driven biorefineries produce low-value energy or fuels out of biomass. Even though the full value chain infrastructure exists, the profitability of energy-driven biorefineries is a challenge as significant financial support is still required. This is due to the lack of potential markets to guarantee large-scale market deployment (IEA Bioenergy, 2009). Product-driven biorefineries produce smaller amounts of high value-added biobased products. Currently, a limited number of product-driven biorefineries are in operation, as some key technologies are in the R&D, pilot and demo-phase. The potential for such biorefineries is high and it is predicted that the focus will shift from optimal sustainable biomass use for energy applications to chemical and material applications (IEA Bioenergy, 2009).

In a grass biorefinery, the primary step is the mechanical fractionation of the biomass by pressing. The extracted green (from fresh material) or brown juice (from silage), as well as the press cake recovered are used for the further processing of various products and energy. Decomposition methods (enzymatic, fermentative, hydrolytic, thermal or chemical) are sometimes applied before fractionation. The freshly-pressed green juice contains several components including proteins, lipids, glycoproteins, lectins, sugars, amino acids, dyes, minerals and enzymes. In addition, silage juice contains relatively high concentrations of lactic acid, which can be used for the production of plastics and salts (Kamm et al., 2010). The press cake is a fibrous fraction, which can be used as raw material for products such as insulation material, bio-composites, pulp and paper, as well as thermoplastics (Thumm et al. 2014). Figure 17 shows possible biorefinery products from different feedstock fractions. A grass biorefinery is typically coupled with a biogas plant.

In the case study, production of biochemicals (amino acids and lactic acids) was selected as a promising option (Figure 18). Currently, only one biorefinery produces these biochemicals in a grass biorefinery (BIOFABRIK Green Refinery in Dresden, Germany). Therefore, this approach is highly innovative. The concept is based on the Austrian research project “Fabrik der Zukunft”. It is important to mention that only limited data is available on this innovative option, therefore, precise calculations for the German case study cannot be made.

As different grasses can be used in a grass biorefinery, the amounts of produced biochemicals depend on the feedstock properties. In the research project “Fabrik der Zukunft” two different types of grasses were used: clover grass silage and Lucerne (alfalfa) silage. The results show, that per ton of silage (dry matter) about 150-210 kg of lactic acid and about 80-120 kg of amino acids can be recovered from the juice. By-products and residues can be used for onsite generation of power (biogas) and heat (Mandl et al. 2006). However, this data is based on other grass feedstock which is not comparable to the former irrigation fields. In addition, the above mentioned data was extracted from a lab-based pilot plant. Therefore, in reality the amount of extracted biochemicals might be much lower. An overview on the biorefinery concept of the “Fabrik der Zukunft” project is shown in Figure 18. The mechanical separation was carried out by chopping and mixing of silage, the first pressing, adding water to the first press cake, remixing and the second pressing.

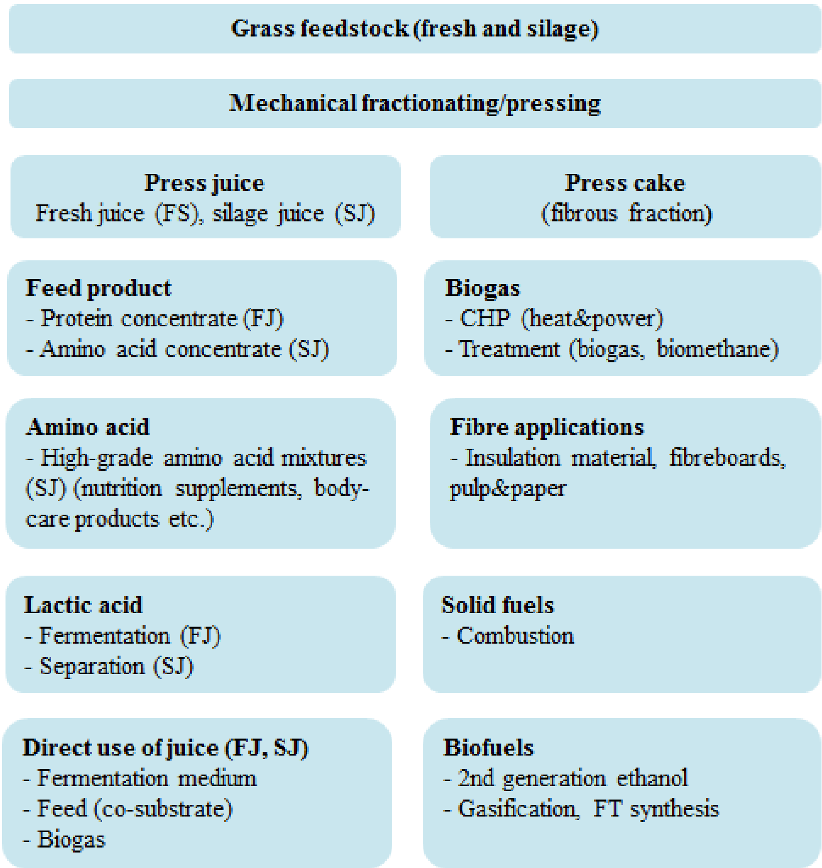

Figure 17: Possible biorefinery products from different feedstock fractions (Mandl 2010)

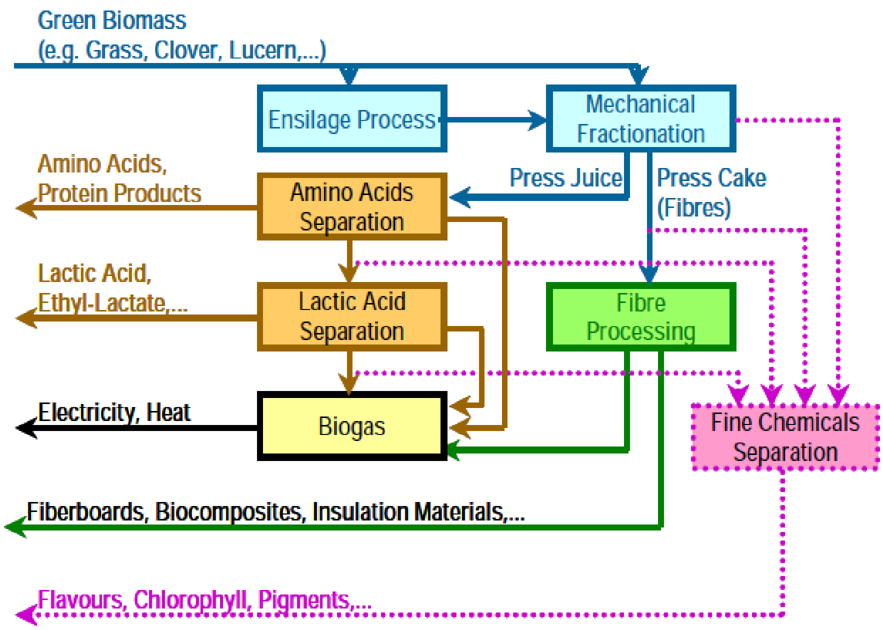

Figure 18: The concept of a grass biorefinery (Mandl 2006)

Considering 1,140 ha area of grasslands the yields could reach 3,420 t DM/a. 84-120 t of lactic acids and 36 t of amino acids could be recovered from fresh juice. It should be taken into account that more data needs to be collected and analysed as the output depends on the feedstock.

As grass biorefinery concepts are rather new, no exact data on full investment costs is available. 700,000 EUR is a realistic indication, however more information needs to be collected in the further step.

Approximate revenues from selling biochemicals (lactic acid and amino acids) were indicated in the study Novalin et al. 2005 (Table 12). Depending on produced amino acids, the income ranges from 1,000 EUR/t to 30,000 EUR/t (reference). It is difficult to calculate accurate profits as the price is variable, depending on different produced amino acids. However, the prices can be used as a starting point for further research.

According to the research project "Fabrik der Zukunft", economic feasibility of processing is possible at moderate scales (app. 10,000 t DM/a feedstock) if 2-3 products are produced. As different amino acids can be produced and the price per ton differs a lot, required revenue for amino acid mixture shall be at least 4 EUR/kg (4,000 EUR/t). Considering 1,140 ha of available grasslands on the former sewage irrigation fields and the average yield of 3 t DM/a, the total predicted yield would be 3,420 t DM/a. This result might not be feasible for a grass biorefinery. Therefore, more data needs to be collected and analysed.

Over 10,000 DM/a of grass would be possible if the annual yields on 1,140 ha area are at least 9 t DM/a. This is rather unrealistic, therefore an alternative is to collect additional grass from other available areas located not far away from the potential location of the grass biorefinery.

Table 12: Approximate income from selling biochemicals (reference)

Biochemicals	Price per ton in EUR
Amino acids 30 EUR/kg, Tyr	30,000 EUR/t
Amino acids 10 EUR/kg, Phe	10,000 EUR/t
Amino acids 10 EUR/kg, 40 % BCAA	10,000 EUR/t
Amino acids 10 EUR/kg, Cys²	10,000 EUR/t
Amino acids 5 EUR/kg, Asp	5,000 EUR/t
Amino acids 1 EUR/kg below 25 %	1,000 EUR/t
Amino acids 2 EUR/kg above 40 %	2,000 EUR/t
Lactic acid, 0.6 EUR/kg	600 EUR/t

Grass as additional feedstock for operating biogas plants and biogas upgrading to biomethane

An alternative to grass biorefineries is to use grass silage bales as additional feedstock for operating biogas plants in the area (Figure 15). This means that grass silage bales could be sold to a biogas plant operator.

Harvesting and transportation are described on 31-32 p. as this step would be the same as in the case of a grass biorefinery. Therefore, the costs for harvesting and transportation will be as described in Table 11 (86,218 EUR). Considering 1,140 ha area of grasslands, the yields could reach 3,420 t DM per year (3 t*1,140 ha). The price of grass silage per ton is around 60 EUR, therefore, 3,420 t*60 EUR will lead to 205,200 EUR revenues from selling grass silage bales.

Several operating biogas plants were identified for the German case study. Four biogas plants are well located next to the potential grasslands near Ludwigsfelde and Rangsdorf (Figure 16, Table 13,). Upgrading biogas to biomethane could be an option to consider for these biogas plants in the future. Three biogas plants are located next to each other in Blankenfelde-Mahlow (164-200 kW_{el}) and one biogas plant is in Groß Machnow (1.123 MW_{el}). Additional data on these biogas plants is not available at the moment. More data needs to be collected to explore this alternative, as the installed capacity of a biogas plant and the mix of used feedstocks play an important role for the feasibility of this option.

Table 13: Operating biogas plants

Overview on operating biogas plants	
Biogas plant Groß Machnow	In operation since 2007 Feedstock: maize, grass silage, grain, pig manure etc. Electricity injected: 10 mln.. kWh/year Installed capacity: 1,123 kW DH system for the heat use (more data is not available)
Blankenfelde-Mahlow 1	In operation since 2010 Electricity produced: 1,227,064 kWh/year Installed capacity: 164 kW
Blankenfelde-Mahlow 2	In operation since 2010 Electricity produced: 1,594,047 kWh/year Installed capacity: 200 kW
Blankenfelde-Mahlow 3	In operation since 2011 Electricity produced: 1,447,364 kWh/year Installed capacity: 200 kW

Technically it is feasible to upgrade biogas to biomethane at nearly every size. However, on a commercial level it is rather feasible for larger plants. Thereby, the costs for the production of the raw biogas are a crucial factor. Currently, upgrading facilities with a capacity of about 250 m^3 to 500 m^3 upgraded biomethane per hour are economically feasible in Germany.

Supply chain

There are different possibilities for the supply chain of grass. Figure 19 and Figure 20 show different potential supply chains in the area of Berlin. This report analyses grass biorefinery and anaerobic digestion options, in particular biomethane production. In the grass biorefinery option, grass silage is collected during the harvesting, baled, transported to a grass biorefinery, stored and processed in a grass biorefinery for the production of biochemicals such as amino acids and lactic acid. Logistic costs for this option may reach around 86,218 EUR (harvesting and transportation, Table 11). In the anaerobic digestion option, grass silage is collected during the harvesting, baled, transported to an operating biogas plant, stored and processed in a biogas plant for the production of electricity, heat and digestate. Upgrading biogas to biomethane production is also an option.

For such local chains, it is important to mobilize the stakeholders (investors, providers and end users) and cooperate with local biogas plant operators. As a green biorefinery is an innovative approach, a long-time perspective and research potential should be taken into account.

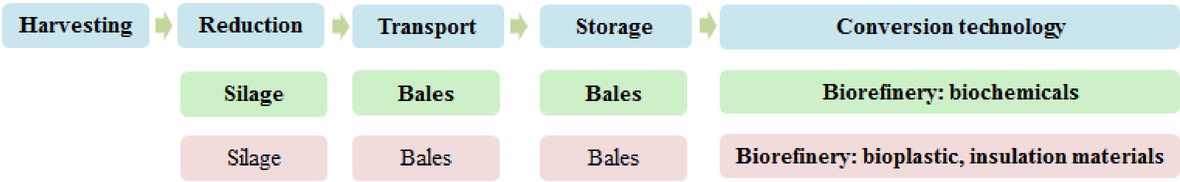

Figure 19: **Possible supply chain for grass on former sewage irrigation fields (grass biorefinery)**

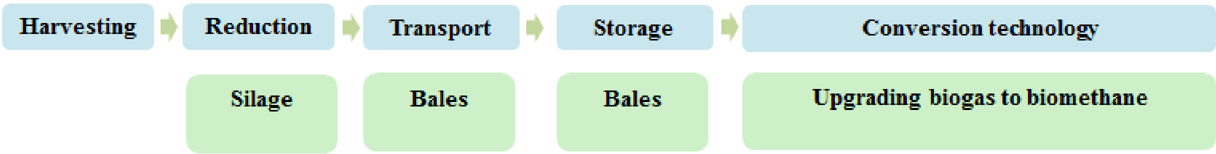

Figure 20: **Possible supply chain for grass on former sewage irrigation fields (biomethane)**

Funding opportunities

In 2010, the German federal government approved 2.4 billion EUR funding over a period of six years (project funding and institutional support) as part of the 'National Research Strategy BioEconomy 2030'. This also applied for biorefinery implementation concepts. Around half of the supported projects for the conversion and material- and energetic utilization of biomass in the Federal Ministry of Agriculture and Consumer Protection (BMELV) 'Renewable Resources' funding programme were regarded as projects for the support and technology development of biorefineries. As six years passed by the end of 2016, currently there is no new funding announced.

Biodiversity

Permanent grasslands fulfil a multifunctional purpose by regulating water flows, storing carbon and nitrogen, preventing soil erosion, and providing habitats for different species (Thumm et al. 2014). Therefore, the advantage of the grass biorefinery option is that existing grasslands remain untouched and grass is collected via landscape management which is implemented anyway.

In order to increase the annual yields, an option would be to introduce additional grasses such as clove or lucerne. In the case study, the potential areas do not include nature conservation areas, fauna-flora-habitat (FFH) areas, or special protection areas for birds, therefore introducing additional grasses could be considered.

Summary and conclusions

Different options are possible for using grass silage on the former sewage irrigation fields in the area around Berlin. The following pathways for the cultivation of grass silage around Berlin were identified:

- Option 1: Building a grass biorefinery and supplying grass silage as feedstock for the production of biochemicals – main option

- Option 2: Supplying grass silage to one of the operating biogas plants in the area and upgrading biogas to biomethane

Tables 13 and 14 summarize the potential costs and revenues for Option 1. Calculating 20 operating years for a grass biorefinery and yields of 3 t DM/ha might lead to an economically feasible result. It should be taken into account that the grass biorefinery option needs more in-depth research as the feedstock has to be analysed in terms of realistic production of biochemicals.

As different amino acids can be produced and the price per t differs a lot, required revenue for amino acid mixture shall be at least 4 EUR/kg (4,000 EUR/t). Considering 1,140 ha of available grasslands on the former sewage irrigation fields and the average yield of 3 t DM/a, the total predicted yield would be 3,420 t DM/a. This amount of biomass is rather too low, therefore, grass from surrounding areas needs to be collected.

Table 14: Costs for the cultivation of grass for 20 productive years, Option 1

New grass biorefinery integrated into operating biogas plant	
Total investment costs for a new biorefinery	>700,000 EUR
Operating costs	
- Service etc.	50,000 EUR/a
- Personnel (1 staff member, full time)	30,000 EUR/a
- Feedstock supply and logistics for 20 years	1,724,360 EUR
Total costs for 20 years	**4,024,360 EUR**

Table 15: Potential revenues from selling biochemicals, Option 1

Sales	
Mixture of amino acids (84-120 t, 4,000 EUR/t)	336,000 – 480,000 EUR/a
Lactic acid (36 t, 600 EUR/t)	21,600 EUR/a
Total income in 20 years from biochemicals sales	**6,720,432– 9,600,432 EUR**

Supplying grass silage to existing biogas plants around Berlin is a realistic option. Firstly, the calculation of costs and revenues is more precise as rather detailed data is available for this option. Secondly, this option requires less effort as no new plant needs to be built. This also minimizes the risk in case the option would not be feasible in the long term. Tables 15 and 16 summarize the potential costs and revenues for this option. It should be taken into account that additional transportation costs influence the economic feasibility of this option. It is important to emphasize that the possible distribution of 1,140 ha around Berlin is not clear. Therefore, this report presumes that most of the areas will be located in the southern areas of Berlin next to Ludwigsfelde. This allows calculating possible transportation costs from grasslands to operating biogas plants in the area (12 km radius, Figure 16).

Table 16: Costs for the cultivation of grass for 20 productive years, Option 2

Harvesting and transportation of grass silage to an operating biogas plant		
Mowing	27 EUR/ha	1,140*27=30,780 EUR
Baling	14,5 EUR/bale	14,5*3,420=49,590 EUR
Transportation	68 EUR/hour	68*86=5,848 EUR
Total costs per year		**86,218 EUR/a**
Total cost for 20 years		**1,724,360 EUR**

Table 17: Potential revenues from selling grass silage to an operating biogas plant in the area, Option 2

Sales	
1 t of grass silage (60 EUR/t)	3,420*60=205,200 EUR/a
Total income in 20 years from grass silage sales	**4,104,000 EUR**

Option 1: Building a grass biorefinery and supplying grass silage as feedstock for the production of biochemicals

The calculations indicate that building a new grass biorefinery could be financially feasible, however more research is needed for this option as the concept is innovative and the calculation of costs and revenues is rather general. Finally, additional payments and subsidies need to be calculated in addition.

Option 2: Supplying grass silage to one of the operating biogas plants in the area and upgrading biogas to biomethane

The calculations indicate that selling grass silage to operating biogas plants in the area could be financially feasible if the price is around 60 EUR/t/DM. Additional data on these biogas plants is not available at the moment, therefore upgrading biogas to biomethane option is considered in general as an alternative to grass biorefinery, which is the main option.

4. Selected promising option for lignite reclamation sites

In this chapter potential biomass supply chains for lignite reclamation sites in the Eastern German coal mining area (Lausitz) are analysed in terms of techno-economic feasibility based on available data. One option was identified based on the agronomic feasibility study elaborated by the Research Institute for Post-Mining Landscapes (FIB). The option includes growing Lucerne and Sorghum as feedstocks for biogas production and upgrading to biomethane. As crop rotation system is necessary, Lucerne, Sorghum, winter rye and winter wheat are considered. However, only the biomass from Lucerne and Sorghum is considered for bioenergy production. Experiences for growing Lucerne and Sorghum in the case study area already exist, therefore the identified option has a lower risk compared to other potential energy crops. Figure 21 shows the potential areas available for cultivation of energy crops in Lusatia (Lausitz). The organge colours represent the lignite mines that have recently been closed. It is important to mention, that for these areas an accurate localization of the agricultural areas for bioenergy production is not yet possible. These areas are in reclamation process and some of the areas could be available for bioenergy production.

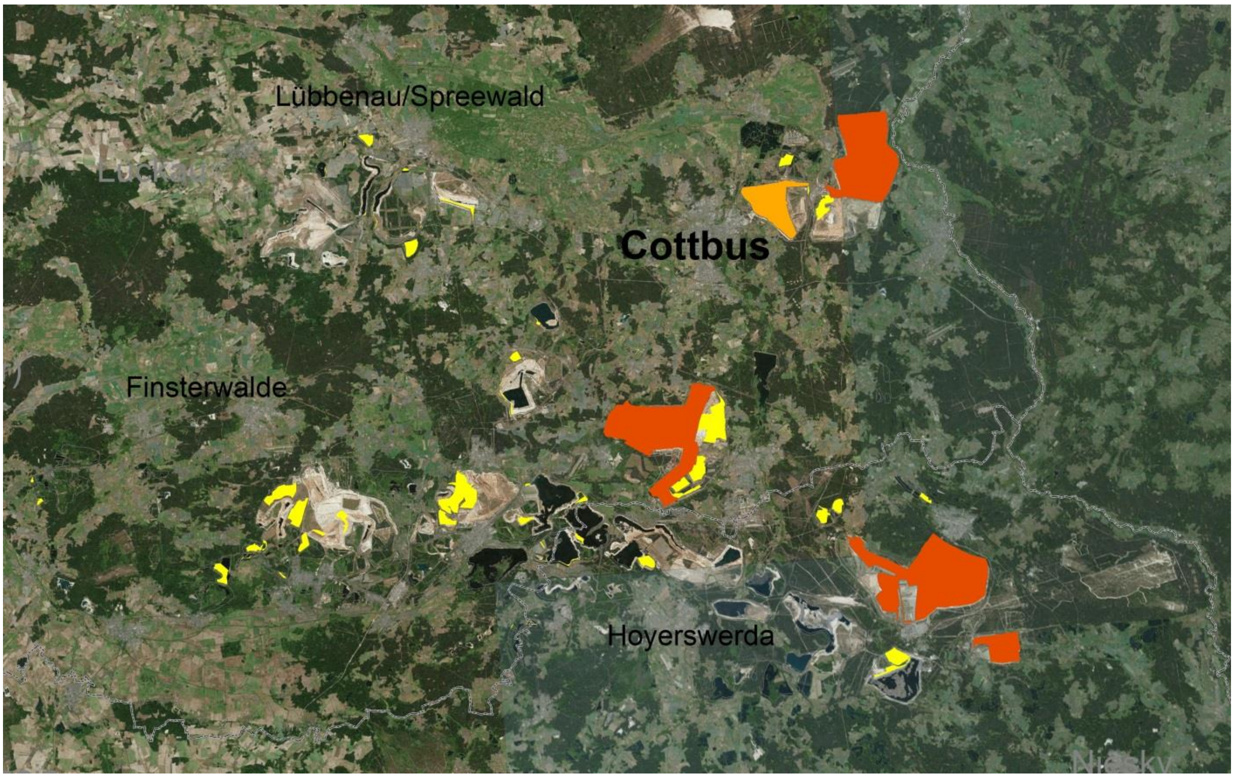

Figure 21: Potential areas available for biomass production in Lusatia (Lausitz) (in yellow – available areas; in dark and light orange – areas under reclamation) (FIB 2017)

The yellow areas are the agricultural lands available for bioenergy production (in total around 5,437 ha). The restricted areas amount for around 4,500 ha are not included in the figure as these areas cannot be used due geotechnical instability. Figure 21 shows that the areas are very scattered. This factor has an impact on the economic feasibility of the selected option for bioenergy production. **However, the key target of mine restoration is the reduction of negative environmental impacts by designing multifunctional post-mining landscapes in accordance with the presetting of regional planning. The re-vitalisation is an ongoing process which has to fulfill a variety of requirements ranging from the re-establishment of functioning ecosystems through reclamation, nature preservation areas and water bodies to public infrastructure. Nevertheless, the multi-stage planning procedure is under public participation, and the landscape of the future is still discussed controversially (FIB 2016).**

It is important to highlight that areas marked in yellow are reclaimed agricultural lands which theoretically could be used for food and feed production. However, the yields offered by such post-mining areas are limited for the next 60 years. Therefore, it is not economically feasible to grow food and feed on these areas for a long time. This offers an opportunity to go for bioenergy production and benefit in terms of positive environmental impacts at the same time.

4.1 Lucerne and Sorghum for biomethane production

Unexploited potential of Lucerne and Sorghum

Lucerne or alfalfa (*Medicago sativa*) is a deep-rooted, perennial pasture legume. It is important for phytoremediation, re-establishment of soil functions, and achievement of defined topsoil target values (e.g. humus content, plant available nutrients) on reclamation sites.

Lucerne tolerates a wide range of edaphic conditions, but prefers well drained, deep loamy soils with a growth-optimum pH between 5.8 and 7.2. It is quite undemanding and drought tolerant due to the deep rooting. In addition, it is pre-adapted to high uptake rates of toxic hydrocarbons and heavy metals which are very important for humus accumulation, soil life and the establishment of nutrient cycling (nitrogen, phosphorous) (Agronomic feasibility report, FIB, 2016).

Yields of Lucerne strongly depend on the reclamation age, substrate quality, soil fertility, rooting layer, cutting frequency (3 to 4 cuttings per year) and harvest date (2 - 17 Mg DM/ha/a). Table 18 summarizes biomass yields from Lucerne on typical agricultural mine soils (substrate group 4-5) in the case study area (Agronomic feasibility report, FIB, 2016). **In this report 5 t DM/ha/a is considered as a realistic value for the case study areas which are over 17 years in reclamation.**

Table 18: Biomass yields from Lucerne depending on reclamation age

Reclamation age	Yield (Mg DM/ha/a)	Silage (Mg DM/ha/a)
3 - 5	2.2 – 2.8	2.0 – 2.6
13 - 15	4.5 – 4.8	4.1 – 4.4
23 - 25	5.2 -5.3	4.7 – 4.9

Sorghum is a genus of flowering plants in the grass family Poaceae. It is important for phytoremediation and soil improvement. Sorghum has rather low soil requirements and offers highest yields on loamy soils where an optimum pH range is between 6.5 and 7.5. Due to its origin from the north-eastern savannah areas of Africa, Sorghum tolerates climates. Under changing climatic conditions with more frequent summer drought periods, it is also a supplement to maize in Europe. However, sorghum has much higher heat requirements than maize and is also more sensitive to cold weather conditions. The focus of Sorghum cultivation in Germany is on its use as a substrate for biogas plants. For this purpose Sorghum Bicolor and Sorghum Sudanese as well as different hybrids of these two species are suitable for biogas production. Sorghum species are not invasive which is an important factor for the selection of this crop for bioenergy production. Table 19 summarizes biomass yields from Sorghum on typical agricultural mine soils in the case study area (Agronomic feasibility report, FIB, 2016). **In this report 10 t DM/ha/a is considered as a realistic value for the case study areas which are over 17 years in reclamation.**

Table 19: Biomass yields from Sorghum depending on reclamation age

Reclamation age	Yield (Mg/DM/ha/a)	Silage (Mg/DM/ha/a)
10	12.7-14.1	11.7-13.0
60	14.0-16.0	12.9-14.7

Potential areas for Lucerne and Sorghum and crop rotation system

Based on the agronomic feasibility report, the identified potential for the cultivation of Lucerne and Sorghum on the post-mining reclamation sites is approximately 7,295 ha. This is the **minimum potential** available on the former sewage irrigation fields. It can be expected that the actual potential area is much higher (see Figure 2).

As shown in Figure 21, the potential areas for cultivation of energy crops are small-sized and scattered. **Therefore, biomass would need to be collected in a radius of around 48 km from**

the potential biomethane installation. This value will be used for further calculations in this report.

Figure 22 shows potential areas for biomass production divided into 6 main areas: area 1 in green, area 2 in red, area 3 in dark orange, area 4 in light orange, area 5 in yellow and area 6 in white. It is presumed that each block of areas is around 1,216 ha (1/6 of the total potential identified area of 7,295 ha). As for the areas marked in red, dark orange and light orange colours the precise identification of available agricultural land is not possible at the moment, these areas look much larger in the figure, however the presumption is to have around 1,216 ha for each block of areas. In this case the purpose is to show the approximate location of potential areas in the accuracy that is possible at the moment.

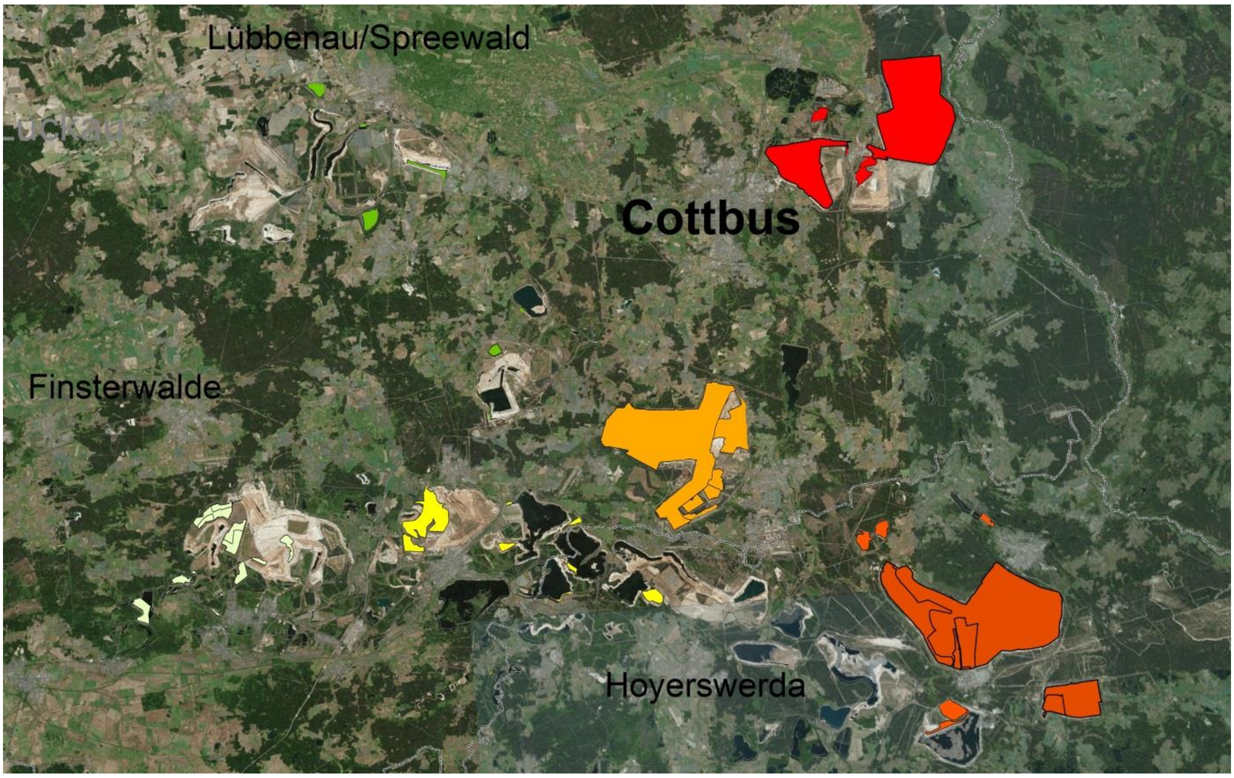

Figure 22 Potential areas for biomass production divided into 6 blocks for the crop rotation (green, red, dark orange, light orange, yellow and white) (FIB 2017)

In order to ensure sustainable production systems, crop rotation system needs to be considered for the selected case study. Crop rotation system corresponding to good agricultural practice was identified and is shown in Table 20.

Table 20: **Crop rotation system for the post-mining areas in Lausitz (Lusatia)**

Year	Crop rotation for one block area for 6 years
1	Lucerne, sowing in spring, 2 cuts
2	Lucerne, 4 cuts
3	Lucerne, 4 cuts
4	Sorghum, sowing after 1 cutting of Lucerne in May, harvesting between September and October (1 cut of Lucerne and 1 cut of Sorghum)
5	Winter wheat – crop for grain (not used for bioenergy production)
6	Winter rye – cut in Mai (green cutting, not used for bioenergy production), followed by sowing of Sorghum

In each block of areas the crop rotation system ensures that the same amount of hectares and the same amount of biomass feedstock is available every year. Table 21 shows the crop rotation system for 24 years (4 times of 6 year crop rotation) as the feasibility of the options needs to be calculated for at least 20 years. The table demonstrates that after the preparation phase the yields are stable every year and the crops are rotating in all six blocks of areas. This assumption allows calculating stable yields of Lucerne and Sorghum for a period of over 20 years. 50% of the total area of 7,295 ha shall be planted with Lucerne (3,648 ha) and 33% of the total area with Sorghum (2,431 ha), which is distributed in different block areas to ensure the sustainable crop rotation system. Winter wheat and winter rye are not included in the calculations as they will not be used for bioenergy production. Table 21 shows the crop rotation system for 20 years. After the preparations the crop rotation system can begin. **In total 18,240 t DM of Lucerne (3,648 ha * 5 t/a) and 24,310 t DM of Sorghum (2,431 ha * 10 t/ha) would be available for bioenergy production every year.** Figure 23 shows the trial fields of Lucerne and Sorghum.

Figure 23: **Trial fields of Lucerne and Sorghum on the post-mining reclamation sites in Lusatia (Lausitz) (FIB 2017)**

Table 21: **Crop rotation system for the post mining areas identified in the German case study (WR – winter rye, WW – winter wheat, L – Lucerne, S – sorghum; Y1- first year, Y2 – second year, Y3 – third year)**

Year	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
Preparation	WR	WW	WW	L Y1	WW	S
Preparation	WW	WR	L Y1	L Y2	WR	WR
Preparation	WR	L Y1	L Y2	L Y3	S	WW
Year 1	L Y1	L Y2	L Y3	S	WW	WR & S
Year 2	L Y2	L Y3	S	WW	WR & S	L Y1
Year 3	L Y3	S	WW	WR & S	L Y1	L Y2
Year 4	S	WW	WR & S	L Y1	L Y2	L Y3
Year 5	WW	WR & S	L Y1	L Y2	L Y3	S
Year 6	WR & S	L Y1	L Y2	L Y3	S	WW
Year 7	L Y1	L Y2	L Y3	S	WW	WR & S
Year 8	L Y2	L Y3	S	WW	WR & S	L Y1
Year 9	L Y3	S	WW	WR & S	L Y1	L Y2
Year 10	S	WW	WR & S	L Y1	L Y2	L Y3
Year 11	WW	WR & S	L Y1	L Y2	L Y3	S
Year 12	WR & S	L Y1	L Y2	L Y3	S	WW
Year 13	L Y1	L Y2	L Y3	S	WW	WR & S
Year 14	L Y2	L Y3	S	WW	WR & S	L Y1
Year 15	L Y3	S	WW	WR & S	L Y1	L Y2
Year 16	S	WW	WR & S	L Y1	L Y2	L Y3
Year 17	WW	WR & S	L Y1	L Y2	L Y3	S
Year 18	WR & S	L Y1	L Y2	L Y3	S	WW
Year 19	L Y1	L Y2	L Y3	S	WW	WR & S
Year 20	L Y2	L Y3	S	WW	WR & S	L Y1

Planting, harvesting and transportation of Lucerne and Sorghum

Lucerne requires deep soils having nearly neutral pH value and easily-warmed sites with an annual average temperature above 8.5°C. If the establishment of Lucerne is successful, high yields can be expected. As a result of the deep root penetration, Lucerne can overcome dry periods. In general, sowing takes place in April-July in the even-surfaced sowing bed with fine crumbly soil as Lucerne seeds are small. Lucerne needs to have good establishment in the first year in order to achieve winter resistance. Therefore, sowing should take place in early spring.

The first cutting should be carried out at least 75 days after sowing or at the beginning of the blossoming as this is important for the good establishment of Lucerne. In general, after the first cutting it is recommended to have not less than 50 days between cuts in order to avoid negative effects. In the German case study the following cutting are considered: two cuts in the first year of establishment and four cuts in the second and third year.

During the harvesting phase it is important to keep the cutting height of around 10 cm in order to avoid negative effects on the subsequent growth. In general, swather is used for harvesting Lucerne.

Sorghum is a suitable energy crop in dry climates and can serve as an extension to maize under varying climatic conditions with more frequent dry summer periods. The focus of sorghum cultivation in Germany is on its use as a substrate for biogas plants, especially S. bicolor and S. sudanense as well as S. bicolor x S. sudanense. The mentioned sorghum species are not invasive plant species. Sorghum does not have any special soil requirements, however cold and waterlogged sites should be avoided. Sorghum thrives in the pH range of 5.0 to 8.5 and is salt-alkali tolerant.

The cultivation of sorghum is similar to maize or sugar beet. However, the demands of sorghum on a well-developed, settled soil with a fine-grained seedbed are significantly higher than for maize. For a rapid bursting of Sorghum the soil temperature should be at least 12° C. Due to the high sensitivity to cold weather conditions, sowing is advisable from mid-May. In general, the sowing date should not be after 20th June. The seed quantity depends on the type of sorghum and the intended use. For biomass production, S. bicolor with a seed thickness of 20 to 25 germable grains/m^2 should be applied. For S. bicolor x S. sudanense and S. sudanense, a seed thickness of 30 to 40 germable grains/m^2 is recommended. The sowing machine which uses the seed drill concept is recommended (the sowing depth should be 2 to 5 cm).

Sorghum is harvested from the middle of September to the end of October, preferably before the first night frosts with the usual chipping technique for maize. The chopped material can be easily silted. To ensure a safe fermentation process, a dry substance content of 28 to 32% should be ensured. It should be noted that sorghum reaches dry substance contents above 20% only at the beginning of the panicle emergence. In the lignite mining sites weed control as well as N-P-K fertilization are necessary operations once a year. These operations are taken into account in the sustainability assessment of the proposed value chain for the lignite reclamation sites.

Table 22 provides an overview on the cultivation costs of Lucerne and Sorghum for 20 productive years. It is important to mention, that the identified potential areas fall under the property of Lusatian and Central German Mining Management Company. At the moment it is not possible to say under which conditions the potential areas will be sold or leased. It is presumed that the mining company will get interested in exploiting the potential of biomass on the marginal lands, therefore, land rental is not calculated in the costs for the cultivation of Sorghum and Luzerne.

Table 22: Costs for the cultivation of Sorghum (annual crop)

Steps	**EUR/ha** **Sorghum silage**
Direct costs	
Seeds	144
Herbicides	70
Fertilizer	308
Operating costs	
Machinery (sowing, maintenance, harvesting, transportation, unloading)	164
Staff costs	65
Other costs	
Land rental	-
Total EUR/ha	**751**
Total EUR per year (2,432 ha*751)	**1,826,432 EUR**
Total costs for 20 productive years within crop rotation system	**36,528,640 EUR**

Table 23: Costs for the cultivation of Lucerne (perennial crop)

Steps	EUR/ha Lucerne silage
Direct costs	
Seeds	20 (every 3 years)
Herbicides	70
Fertilizer	244
Operating costs	
Machinery (sowing, maintenance, harvesting, transportation, unloading)	135
Staff costs	65
Other costs	
Land rental	-
Total EUR/ha (with seeds)	**534**
Total EUR/ha (without seeds)	**514**
Total costs for 20 productive years within crop rotation **(6 years with seeds, 3,648 ha)**	**37,939,200 EUR**

Sowing, maintenance, harvesting, transportation and unloading operations of Sorghum and Lucerne for 20 years will cost app. 74,467,840 EUR.

In the case study, Sorgum and Lucerne silage shall be transported to a biogas upgrading plant for biomethane production. Drebkau and the industrial park Schwarze Pumpe next to Spremberg were identified as two potential locations for the biogas upgrading plant.

- Locating an upgrading biogas plant in Drebkau. There is one industrial park area which potentially would have 1.2 ha available space for a new industrial activity.
- Locating an upgrading biogas plant in the industrial park Schwarze Pumpe as it has around 720 ha area and a comprehensive infrastructure (Figure 24). Over 120 companies are already located in the industrial park. This option was selected as a better option compared to Drebkau, especially regarding the good connection to the natural gas grid. This location would be surrounded by all potential areas for the feedstock production and ensure acceptable average transport distances between all potential areas for the feedstock production and the processing plant. The average distance from fields to the upgrading plant would range from min.8 km and to max. 48 km. As the

areas are very scattered, more detailed estimation of the transportation costs is necessary in the planning step.

Figure 24: **Potential location for the biogas upgrading plant in Drebkau (red triangle) surrounded by lignite reclamation sites (Source: Google Maps)**

Table 24 below shows approximate distances from potential crop rotation areas to Schwarze Pumpe (linear distance).

Table 24: Distances from six crop rotation areas to the potential biogas upgrading plant in the industrial park Schwarze Pumpe

Field	Distance in km (max.)	Distance in km (mean)
1	48	38
2	48	40
3	27	16
4	14	8
5	31	18
6	39	32

Estimation of costs and income

In total 18,240 t DM of Lucerne (3,648 ha * 5 t DM/ha) and 24,310 t DM of Sorghum (2,431 ha * 10 t DM/ha) would be available for bioenergy production every year. This would lead to 8,098,516 Nm^3 biogas from Lucerne and 7,074,210 Nm^3 biogas from Sorghum. **In total 15,172,726 Nm^3 of biogas could be produced annually in the biogas plant. 1 m^3 of biogas has 5 kWh of energy leading to 75,863,630 kWh (75.8 MWh).** In general, a full-load operating time for an upgrading biogas plant is about 8,000 full-load hours per year. This would lead to **3.1 MW_{el} installed capacity of the biogas plant.** Approximate investment costs for a 1,000 kW_{el} biogas plant are app. 2.500 EUR/kW_{el}. **Therefore 3.1 MW_{el} biogas plant would require app 7.7 mln. EUR investment.**

In addition, the investment costs for the biogas upgrading installation would require app. ca. 2,200 EUR/Nm^3 at the production volumes of 948 Nm^3/h. **This would lead to the investment of app. 2 mln EUR.**

In total the investment costs for the biogas plant and upgrading facility would reach 9.7 mln EUR. Operational costs of the biogas plant and the upgrading facility usually account for 10-15% of the investment per year. Calculating 10% the total operational costs would be app. **1 mln EUR for 20 years**.

The total costs for the installations for 20 operational years would reach app. 10.7 mln. EUR (7.7 mln EUR +2 mln EUR +1 mln EUR). Total costs for the cultivation of Lucerne and Sorghum for 20 years would reach app. 74.4 mln EUR. **In total the overall costs for 20 years would be app. 85.1 mln EUR.**

15,172,726 Nm^3 of biogas has 50-75% of methane. Calculating with the lower value of 50%, in total 7,586,363 Nm^3 of biomethane could be produced and injected in the natural gas grid. This would account for 37,931,815 kWh. The income from injected biomethane in the natural gas grid is around 7.3 Cent/kWh. In total the income could reach app. 2.7 mln. EUR/year (37,931,815 kWh * 7.3 Cent/kWh). **The income for 20 years would reach 54 mln EUR without direct payments/bonus or any other additional financial support.** 255 EUR/ha direct payments/bonus can be calculated in addition. **This will lead to additional 31 mln EUR for 20 years. In total app. 85 mln EUR of income could be calculated.** Thus, the cultivation of Lucerne and sorghum for biogas production on the specific lignite reclamation sites does not show a profit for 20 years bearing in mind that low values for yields have been considered in this study.

Supply chain

For the supply chain at the lignite reclamation sites one option has been chosen for analysis. Figure 25 shows the selected supply chain for biomethane production. The CEN standards EN 16723-1 and EN 16723-2 for biomethane injection into the grid should be taken into account.

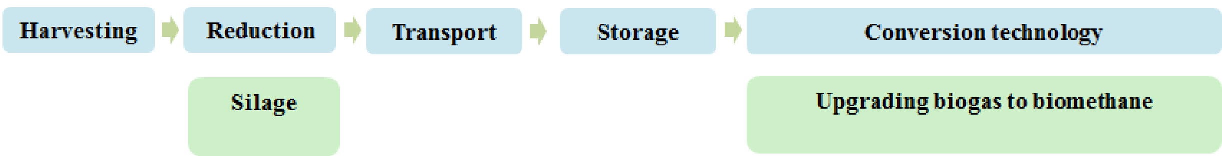

Figure 25: Possible supply chain for biomethane production from Lucerne and Sorghum

Contribution to biodiversity

Lucerne is worth mentioning in terms of positive impacts on the biodiversity. Lucerne fields have a positive impact on biological and landscape diversity. It is s shelter area and harbor for food resources (e.g. insects for bustards and other birds, field mice, partridges, hares, roe deer etc.). In addition Lucerne fields play an important role in the feeding of bees and the maintenance of bee populations on large cereal plantations.

The cultivation of Lucerne has a positive effect on water quality as it favors nitrite consumption in the soil. Therefore, Lucerne plays an important role in the reduction of nitrate-leaching.

Summary and conclusions

Biomethane production was chosen as an option to be further analysed for the lignite reclamation sites. Calculating 20 operating years for the operation of the biogas plant and upgrading facility. Total costs for 20 years would reach app. 85.1 mln EUR and income could reach 85 mln EUR. Therefore, the cultivation of Lucerne and sorghum for biogas production on the specific lignite reclamation sites does not show a profit for 20 years bearing in mind that low values for yields have been considered in this study. Considering that higher yields can be expected with increasing recultivation age and the prices of electricity increasing over the 20 years, profits can be higher making it economically feasible. Nevertheless, other value chains or conversion technologies must be further studied on lignite reclamation sites for better profitability. The calculations show that important factor for the economic feasibility is the cost for the feedstock supply.

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