Modelling of the Potential for Energy Crop Utilisation in Northern Sweden

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Abstract

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Within this thesis, a methodology for estimation of the potential supply of biomass feedstock from the energy crop reed canary grass *(Phalaris arundinacea* L.*)* is summarized and discussed. In the studied area, Västerbotten County in northern Sweden, agriculture is dominated by dairy and beef production, abandoned farmland constitutes 23% of the total arable land area, and EU subsidies have a strong influence on the profitability of different agricultural branches.

A partial equilibrium model with a break-even price approach was used to create supply curves for reed canary grass under the assumption that reed canary grass would be produced if the net return equalled or exceeded the current land use. Supply curves were created for three different scenarios; current EU subsidy scheme, proposed subsidy scheme of 2004, and without EU subsidies.

To quantify the restoration costs for making abandoned farmland available for energy crop cultivation, an orthophoto interpretation method was developed, and the real restoration costs for a sample of fields was determined by a fieldwork inventory. From orthophoto interpretation abandoned fields could be divided into two different classes with a mean estimated restoration cost per hectare of 173 SEK and 3990 SEK, respectively. The mean annual restoration costs of abandoned fields were used as an opportunity price for reed canary grass production on abandoned farmland.

Under the current subsidy scheme, the lowest reed canary grass farmgate fuel price was 56 SEK MWh^{-1} for a feedstock production equalling 0.36 TWh. Under the proposed subsidy scheme of 2004, a farmgate fuel price of 99 SEK MWh^{-1} was required for 1.1 TWh of feedstock. With no subsidies, the lowest break-even price was 115 SEK MWh^{-1}. In all scenarios, a biofuel feedstock production from reed canary grass equal to 1.3 TWh would be available at a farmgate fuel price of 116 SEK MWh^{-1}.

By the use of GIS tools, the spatial distribution of feedstock supplies was illustrated and analysed. The reed canary grass supply would be concentrated to the coastal area of the county, which also has the most developed infrastructure and the highest population density.

Keywords: reed canary grass, supply curves, biomass feedstock, potential, abandoned farmland

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Appendix

Papers I-II

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Larsson, S. & Nilsson, C. Farmland restoration costs for energy grass cultivation in northern Sweden. (Submitted to Biomass and Bioenergy)

II. Larsson, S. Supply curves of reed canary grass (*Phalaris arundinacea* L.) in Västerbotten County, northern Sweden under different EU subsidy schemes. (Manuscript)

Introduction

The European Commission's White Paper on energy set out a goal to double the share of renewable energies in gross domestic energy consumption in the European Union by 2010 from 6% to 12% (European Commission, 1997). Biomass resources are proposed to produce more than 80% (1,050 out of 1,250 TWh) of the total additional contribution of renewables. Within the strategy, an increased energy crop production of 525 TWh will make half of the additional biomass resources.

In 2001, the use of biofuels in Sweden was approximately 97 TWh; equalling 24% of the total domestic energy uses (Swedish Energy Agency, 2002). Biofuels are mainly used for heating purposes and within the forest industry. Biofuels from agricultural crops constituted around 0.9 TWh in 2001, where the main part came from straw and short rotation forestry, i.e. willow (*Salix spp*.) used in district heating plants and combined heat and power plants.

The main energy crops suitable for Swedish conditions are *Salix* and reed canary grass (*Phalaris arundinacea* L.). The current production is dominated by *Salix* for which the cultivation in Sweden in 2001 amounted to approximately 14,500 ha (Hillring *et al.*, 2001). Due to climatic factors, *Salix* production is concentrated to southern and central Sweden, since production in northern Sweden is unsuitable (Rosenqvist *et al.*, 2000). In northern Sweden, reed canary grass (RCG) is considered to be the most suitable energy crop (Landström *et al.*, 1996). The current production of RCG in Sweden amounts to less then 1,000 ha (Hillring *et al.*, 2001; Statistics Sweden, 2001).

The Swedish potential for dedicated energy crops has been estimated in several studies, for example (Axenbom *et al.*, 1992; Swedish Biomass Commission, 1992; Swedish Farmers Association, 1995). Within these studies, the potential for bioenergy crop production (*Salix* and reed canary grass) has been estimated from the agricultural land area not needed for food and fodder production and the long-term potential is estimated to 20-48 TWh. Depending on differences in the assumptions made, there is a great variety in the estimations of the potential supplies which also have been further discussed by Börjesson *et al.* (1997) and Johansson & Lundqvist (1999).

Reed canary grass as a biofuel feedstock

Production prerequisites

RCG is a perennial herbaceous crop suitable for cultivation on most soils and in most agricultural regions (Hadders & Olsson, 1997) and is considered to be the most suitable energy crop for cold climates (Landström *et al.*, 1996; Venendaal *et al.*, 1997). In middle and southern Europe, C4 grasses like Miscanthus spp. and sweet sorghum (Sorghum bicolour L.) are mainly produced. In North America, switchgrass (Panicum virgatum L.) is the dominating herbaceous energy crop and a lot of R&D is put into the development of switchgrass as an energy crop, for example (Cundiff *et al.*, 1997; Bransby *et al.*, 1998; McLaughlin & Walsh, 1998; Sanderson *et al.*, 1999; Ma *et al.*, 2000; Jannasch *et al.*, 2001).

RCG can be grown on most soil types but thrives particularly on wet humus-rich soils, while soils with more than 40% clay seem to hamper establishment (Venendaal *et al.*, 1997). It reaches a height of about 2 m in autumn. As the grass is established, it develops a dense rhizome system which increases the competitiveness and sustainability of the cultivation. Carbon and nitrogen is also recycled in the rhizome system, which increases the nutrient efficiency, decreases the risk of nutrient leaching from the cultivations, and increases the sequestration of carbon in the soil (Katterer & Andren, 1999; Partala *et al.*, 2001).

When RCG is produced for energy purposes, the delayed harvest system, in which, under Nordic conditions, the harvest takes place in spring, is preferable. Delayed harvest has been shown to be beneficial both for the biological production as well as the quality of the material harvested for energy purposes (Landström *et al.*, 1996; Burvall, 1997; Hadders & Olsson, 1997). RCG is sown in spring the first year and the first harvest is made in spring the third year. Fertilization is made the first year before sowing and the following years after harvest. The mean harvest level of delayed harvested RCG is approximately 6-8 ton DM ha^{-1} (Landström *et al.*, 1996; Venendaal *et al.*, 1997) and the mean net calorific heat value of RCG is 4.9 MWh ton DM^{-1} (Burvall, 1997) yielding a mean energy production of 34.2 MWh ha^{-1}. For comparison, *Salix* cultivations yield approximately 6–9 ton DM ha^{-1} yr^{-1}, with a mean net calorific heat value of 4.5 MWh, entailing a mean energy production of 27 – 41 MWh ha^{-1} yr^{-1}.

Fuel characteristics

If comparing the fuel characteristics for wood and RCG, RCG generally has a higher ash content, lower net calorific heat value (mostly due to the higher ash content), and higher levels of alkali, chlorine and sulphur (Table 1). The ash is also more voluminous than wooden ash and therefore RCG combustion equipment has to be able to handle high ash contents (Paulrud & Nilsson, 2001).

Table 1. The fuel characteristics for delayed harvested reed canary grass and for four wood fuels as a comparison (Burvall, 1997)

Parameter in % of dry matter	Reed canary grass (delayed harvest)	Wood fuels (bark, stem wood, forest waste)
Net calorific heat value (MJ/kg)	17.6 (0.85)	19.2 (0.46)
Ash	5.6 (1.82)	2.0 (1.4)
Carbon	46 (1.53)	52 (0.9)
Hydrogen	5.5 (0.26)	6.0 (0.3)
Nitrogen	0.88 (0.22)	0.3 (0.19)
Initial ash deformation (° C)	1404 (183)	1160 (50)
Sulfur	0.09 (0.02)	0.04 (0.018)
Chlorine	0.09 (0.07)	0.01
Potassium	0.27 (0.17)	0.2 (0.09)
Calcium	0.20 (0.06)	0.5 (0.23)
Phosphorus	0.11 (0.04)	0.04 (0.026)
Silicon	1.85 (0.77)	0.2 (0.22)
Sodium	0.02 (0.012)	0.01 (0.016)

The figures are mean values and standard deviations (in brackets), n_{grass} = 14, n_{wood}= 4.

Market development

In the beginning of the 90's, adjustments for a decrease in food production within the Swedish agricultural policy increased the cultivation of energy crops. The interest for RCG cultivation was high because the cultivation and harvesting technique was similar to conventional cropping. In 1991, approximately 4,000 hectares of RCG was established in Sweden (Johansson, 1997). RCG was then produced for direct combustion in specially adopted boiling plants, giving rise to asset specificity; *cf.* (Williamson, 1981). The utilisation decreased because producers had marketing problems and boiling plants were not getting enough feedstock for an adaptation to continuous RCG combustion.

Since the beginning of the 90's, the Swedish utilisation of upgraded biofuel (pellets, briquettes and powder) has increased substantially. In the years 1993-2002, the delivered quantities increased by approximately 250%, from 1.5 to 5.2 TWh (Ilskog *et al.*, 2003). So far, the production has been based on residues from the forest industry, mainly sawdust and cutter shavings. However, the expansion has now reached a point where, if the full capacity of existing facilities should be used, the forest industry residues would be fully utilised and a further expansion would be prevented by a shortage of feedstock. Hence, additional feedstocks are needed for the Swedish production of upgraded biofuels and an inventory of additional feedstock supplies has become a topical question.

Spring harvested RCG gives a dry (85% dry matter content) and storable material that can be directly briquetted or pelleted without artificial drying (Paulrud & Nilsson, 2001). With a conversion of RCG to pellets or briquettes, handling at combustion sites is more or less equal to that of wooden pellets and the asset specificity of the RCG chain is reduced.

Potential for reed canary grass production in northern Sweden

Currently used farmland

In areas with only a few economically viable landuse alternatives, the agricultural risk is higher than when the farmland can support a larger number of viable uses. Agricultural areas with only a few viable uses are defined by Smit *et al.* (1991) as marginal farmland, which when the profitability is low, is most likely to be abandoned because there are no economically viable alternatives. However, even if the number of viable landuses is low, a high flexibility between viable options can reduce the agricultural risk (Smit *et al.*, 1984). Then the landuses can be altered and adapted to the most profitable alternative.

Due to climatic factors, there are only a few different economically viable farmland uses in northern Sweden. The agriculture is dominated by dairy and meat production and a majority of the farmland is used for production of on farm consumed fodder, mainly forage and barley. With a high percentage of dairy and feedstock production, the flexibility of agricultural landuse in northern Sweden is low and farmland devoted to forage, and pasture for fodder production is tightly connected to the current farm structure. Even if RCG is shown to be an economically viable alternative, the availability of farmland is limited since the agricultural risk when changing the current production based on livestock holdings to energy cropping is substantial. On the other hand, farmland not required for fodder production has few viable uses, and there, RCG could be a competitive crop.

Since the mid-sixties, the agriculture in northern Sweden has been subject for regional policy and governmental financial support, for the most part aimed to compensate for the climatically less favourable conditions (Persson, 1989). Since the EU entrance in 1995, subsidies within the EU’s Common Agricultural Policy (CAP) have a strong influence on the economy of different agricultural branches in northern Sweden. Under the current EU subsidy scheme, there are generally three types of subsidies that affect the profit of different crops: area payments, regional subsidies, and environmental subsidies for an open and varied landscape (Swedish Board of Agriculture, 2002a, b, c). The European Commission is currently working on a revision of CAP for implementation in 2004, and within the proposal for a new agricultural policy the direct support for different crops is removed (European Commission, 2003). Instead a single farm payment will be disbursed to the farmer, based on the amount of subsidies received in the years 2000-2001. The single farm payment will be received irrespective of the crops cultivated. An additional support for cultivation of energy crops of 45 euro ha^{-1} is proposed to stimulate an increased bioenergy feedstock production.

The revision of CAP will not alter the regulations for regional and environmental subsidies. In northern Sweden, these subsidies are directly connected to livestock holdings and the number of livestock is used for calculation of the area for which regional and environmental support can be disbursed (Swedish Board of Agriculture, 2002b, c). The environmental support for an open and varied landscape is aimed to support an extensive use of forage and pasture farmland. Hence, it can be assumed that the area for which environmental subsidies can be received is enough to fulfil the demand for forage.

In paper II, the forage area for which environmental subsidies could be received was excluded from the farmland resource available for RCG cultivation, since it was assumed that this area was not actually available unless major structural changes of the existing agriculture were to be made.

Abandoned farmland

Farmland abandonment is mainly caused by social, structural or natural factors such as a low earning potential, structural weakness or unbeneficial physical conditions (Baldock, 1996). In regions of extensive forest cover relative to agricultural open ground, such as the northern Scandinavia, farmland abandonment makes great changes in the landscape pattern. A mixture of forest and farmland is considered important for the scenic value of landscapes (Tahvananinen *et al.*, 1996) and in marginal areas, where farmland abandonment usually occurs, it generally has a negative influence on biodiversity and the landscape (MacDonald *et al.*, 2000). An increasing rarity of open space may also cause increasing rural decline and contribute to out-migration (Smit *et al.*, 1991).

Where no active conversion towards forestry has been undertaken, abandoned fields are in different stages of natural succession (Hansson & Fogelfors, 1998) and the economical value of abandoned fields is low. Hence, the abandoned farmland could be considered as a poorly utilized land resource, which in northern Sweden constitutes a substantial share of the potential energy crop production area.

The state of woodland invasion and drainage is of vital importance if the abandoned farmland is considered to be recultivated. The rate of succession and loss of drainage is dependent on numerous factors, e.g. ground moisture, field size, and vegetation cover. Staaland *et al.* (1998) approximate the time for an abandoned open-grass and herb-dominated landscape to become a bush and forest system to 20-30 years, in southern Norway. Thus, the actual point of time for abandonment of different fields is often difficult to state since cultivation may have ceased gradually, and because of lack of data on the time for abandonment.

Remote sensing of landscape patterns can be done by interpretation of aerial photographs or satellite images. Previous studies for evaluation of abandoned arable land by remote sensing of Landsat MSS imagery have been done by Peterson & Aunap (1998) and Feranec *et al.* (2000). In these studies, difficulties with the distinction between grassland and old fields with bushes were experienced. Moreover, a spatial resolution of approximately 80 m at ground level, as in Landsat MSS, requires fields of at least some hectares in size, but for smaller fields the resolution is too coarse.

For detailed studies of landscape patterns, aerial photograph interpretation is to prefer even though the interpretation process often have to be managed manually and is more time consuming. Comparison of aerial photos from different time periods is one of the most common methods for studies of land use changes, for example (Ihse, 1995; Staaland *et al.*, 1998; Fjellstad & Dramstad, 1999; Lipsky *et al.*, 1999).

In paper I, a method was developed where black and white aerial photographs were used for interpretation of the restoration requirements of abandoned farmland. Colour infrared aerial photographs have been shown to give more information especially for ground moisture (Cousins & Ihse, 1998) and could have been preferable for an improved identification of ditching requirements. However, availability of digital infrared photos was sparse and hence, black and white digital orthophotos, being more commonly available, were chosen which also increases the chances for implementation of the method. By orthophoto interpretation, the abandoned fields were separated into two classes; A and B, according to the amount of visible woodland invasion. The restoration costs of the abandoned fields were determined by fieldwork inventories of a sample where the restoration requirements were recorded and the costs for required restoration actions were summed up to for each field. For the fields in class A, the mean estimated restoration cost was 173 SEK ha^{-1} (RMSE=93) and in class B 3990 SEK ha^{-1} (RMSE=451). If the restoration costs should be covered by RCG production, the corresponding increase of the fuel price on class A fields is 1 SEK MWh^{-1} and in class B 21 SEK MWh^{-1}.

The method developed in paper I should be regarded as a tool in a planning process where the state of abandoned farmland in a region is inquired. Thus, the actual restoration cost of fields in the two classes can differ both over time and between different regions, but the magnitude of the difference between restoration costs in the two classes can be expected to last.

Modelling of bioenergy feedstock supplies

Supply curve methods

Supply curves define the relationship of the potential quantities of a resource that could be available for a given market price. Methods for estimation of energy crop supply curves have been developed and described by Downing (1996) and Walsh (1998; 2000). By using a partial equilibrium approach, break-even prices for various energy crops was identified where the profitability of energy cropping was equal to or higher than for the current agricultural landuse. From these results supply curves of the different energy crops was created.

In a partial equilibrium analysis all parameters are kept constant except for the one that is being varied and no feedback mechanisms are included. It is also assumed that the market being studied is an isolated phenomenon with a negligible effect on the surrounding economy (Found, 1971).

In paper II, partial equilibrium methodology was used to create supply curves for RCG in Västerbotten County in northern Sweden. The aim was to provide information on how much RCG could be available at certain farmgate price levels under different EU subsidy schemes.

The farmland required for cultivation of forage and pasture to supply the demands of current livestock holdings was excluded from the analysis on beforehand, because this area was judged to be unavailable for other agricultural uses. Landuses included in the analysis were cereal production, surplus forage farmland, set-aside farmland, and abandoned farmland. If cereal production would be replaced by energy cropping, the demand for purchased cereals for fodder purposes would rise, but this increase is not likely to affect cereal prices, since the volumes in question, as compared to the total market of cereals, are small. The other landuses are not connected to market products. An exception could be the production of forage for sale on surplus forage farmland. Under these conditions, the partial equilibrium approach was considered to be an efficient analysis tool. The influence of different EU subsidy schemes on RCG break-even prices could also be well handled by the model.

In paper II, it was shown that the lowest RCG farmgate break-even price (56 SEK MWh^{-1}) is found under the current subsidy scheme when RCG is cultivated on surplus forage farmland. Surplus forage farmland was assumed to have a zero opportunity cost, because it does not entitle to any EU subsidies and the required amount of forage would be satisfied by forage farmland for which environmental subsidies could be received. RCG cultivation would, on the other hand, entitle to set-aside subsidies and thus, lower the RCG break-even price substantially. In Västerbotten County, there are currently 10,500 ha of surplus forage farmland equalling approximately 10% of the total farmland area. The current use is probably a mix of extensive forage and pasture, cutting for maintenance of an open landscape, out leasing of pasture to horse owners, and production of hay for sale to horse and reindeer owners. Accordingly, for some of the current landuses there is an existing opportunity cost in the market of hay sales and pasture leasing, but these are very difficult to get hold of and quantify. The pricing of these products vary a lot and some of the transactions can be suspected to be made on the black market. Hence, these alternate uses will have to be considered as an uncertainty factor in the calculations of the RCG break-even price on surplus forage farmland.

Another thing to consider is that the set-aside subsidy will be disbursed whether or not the RCG is harvested and sold. Accordingly, RCG cultivation only for set-aside purposes, where the grass is mowed each year to fulfil the set-aside regulations but not harvested, is an alternate landuse of surplus forage farmland. Depending on fertilization management, an estimated opportunity cost of this type of set-aside RCG cultivation is 500-750 SEK ha^{-1}. Compared to this, the corresponding RCG farmgate break-even price is 75-85 SEK MWh^{-1}.

Under the proposed subsidy scheme of 2004, the lowest RCG farmgate break-even price will be 99 SEK MWh^{-1} for production on farmland currently used for surplus forage, set-aside, and cereals (unless production on set-aside farmland is prohibited). The amount of RCG available at this price is about three times the amount available at 56 SEK MWh^{-1} under the current subsidy scheme. To reach the same feedstock supply under the current subsidy scheme, a fuel price of 115-116 SEK MWh^{-1} is required. Hence, if the demand for RCG is high, the supply situation in 2004 will be more beneficial than the current.

Spatial data – GIS applications

The use of GIS tools has become a common method for illustration and analysis of the geographical distribution of bioenergy feedstock supplies. Bioenergy feedstock is a bulky product, economically sensitive to transportation, and the spatial distribution of biomass is of vital importance for the availability of the resources. GIS tools can be used merely for illustration and analysis of the spatial distribution of biomass resources; see *e.g.* (Parikka, 2000; Roos *et al.*, 2000), but also in various ways were further spatial analysis is needed. Factors affecting the yield and production conditions of different biomass resources (e.g. soil type, humidity, altitude, etc.) can be handled efficiently by the use of GIS tools for estimation of feedstock potentials and has been used by *e.g.* Clifton-Brown *et al.* (2000) and Schneider *et al.* (2001). There are also several studies where transportation costs are included in the feedstock prices and the supply system of different biomass resources to conversion plants is optimised, for example (Noon & Daly, 1996; Graham *et al.*, 1997; Graham *et al.*, 2000; Voivontas *et al.*, 2001).

In paper I, data on abandoned fields was retrieved from a database and the orthophoto interpretation was made in an ArcView® environment. The ArcView® interface was useful because of its ability to combine orthophotos and a digitized field border layer, which simplified the identification of abandoned fields substantially. Study II was also performed on data retrieved from an ArcView® database. By the use of GIS tools the geographical distribution of different current land uses could be analyzed and the amount of region specific EU subsidies was calculated in relation to the number of livestock in different regions. By creation of maps showing the density of farmland available for RCG production, the spatial distribution of biomass resources was visualised.

The methods presented in paper I and II, for estimation of potential supplies of RCG, can be used in other areas with similar agricultural conditions. Due to the high resolution of data considering current land uses, the methods can be used for planning on various aggregation levels.

On municipal level, where the total area is approximately 500-10,000 km^2, the orthophoto interpretation of abandoned farmland can be done on all fields according to the method developed in paper I. The data is then kept on a field specific level. Within actively cultivated farmland, yearly crop rotation confuses the absolute accuracy of current land uses and data on surplus forage farmland will never be field specific. Data on surplus farmland could be obtained on farm level, but this would require farm specific data on livestock. Thus, for the methods developed, the highest resolution of data is achieved on municipality level, which for planning purposes probably would be sufficient. By creation of municipality maps, using GIS tools, areas with high densities of abandoned farmland with low restoration requirements and areas of currently used farmland that could be available for energy grass production can be identified.

When potential supplies are to be estimated on a regional level, the orthophoto interpretation of abandoned farmland becomes very time consuming. Hence, in paper II, the county was divided into three different altitude zones with distinct differences in the amount of farmland available for RCG cultivation. A sample of abandoned fields was picked from each zone for orthophoto interpretation. Under the assumption that the restoration cost distribution for the fields in the sample was equal to the real restoration cost distribution for the fields in paper I, the potential supplies of RCG fuel in each zone was derived. Still, the assumption of an equal restoration cost distribution between abandoned fields in paper I and the abandoned fields in each zone causes an uncertainty to the method.

Future research

Production of pellets or briquettes from new feedstock will alter the production conditions and the market of upgraded biofuels by an increased complexity of the feedstock supply system and a diversification of pellet qualities and prices.

Biomass feedstock supply systems have been modelled in several studies; see (Mitchell, 2000). However, to my knowledge, there are no previous studies on the supply system for production of upgraded biofuels from multiple biomass resources. The supply systems for pellet production will have great similarities with the biomass supply systems for direct combustion, but also important differences which should be addressed.

Generally, for all biomass supply systems, the spatial distribution of biomass resources has a strong influence on their economical viability, since transportation costs can account for a significant portion of the total biomass fuel costs. Also, the characteristics of the conversion site will put limits to the utilisation of different biomass sources. A GIS-based decision support system for allocation of biomass resources to power plants in the Tennessee Valley Authority has been developed by Noon & Daly (1996). In the model, biomass utilisation was optimized according to feedstock prices, feedstock supply, and transportation costs, and limited by the boiler capacities for biomass combustion. A feedstock supply system for production of upgraded biofuel could be studied in a similar way. In such a model it would be desirable to study the influence of feedstock prices, feedstock supply, transportation costs, storage costs, and the expected price of the upgraded fuel on the allocation of different biomass resources. As for direct combustion, the equipment at the conversion site will be limiting for the utilisation of different feedstock. Hence, a key issue in the modelling will be to specify the handling routines and technical equipment at the production sites of upgraded biofuel required for different feedstock types. Research on the technology of pellet production from a multiple range of feedstock is currently performed at many different places and data from those trials can hopefully be provided to a feedstock supply model.

Feedstock flexibility will be a trade-off against investment costs. This is illustrated by Thek & Obernberger (2002) on the subject of feedstock drying prior to pellet production. Feedstock drying (including investments) accounts for up to 30% of the total pellet production cost. On the other hand, compared to wet material dry material feedstock prices are generally higher. Also, a pellet mill without a dryer is less feedstock flexible, and thus, more sensitive to price fluctuations.

A GIS-based model will require detailed data regarding prices, supply, and geographical distribution of different biomass feedstock. The geographical distribution for forest industry residues (sawdust and cutter shavings) is known and, since a market for these products already exists, data on prices and supplies are more or less available.

By using the methods developed in paper I and II, potentials for reed canary grass at a certain farmgate break-even prices on a regional (county) or local (municipality) level is estimated. Also, a high resolution of the spatial data on the potential supplies is attained, making it suitable for incorporation in a GIS-model.

Other feedstocks of interest for production of upgraded biofuels that could be evaluated in the analysis are peat, pulpwood, and forest residues.

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