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Potential, spatial distribution and economic performance of regional biomass chains; the North of the Netherlands as example

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Abstract

This work assesses the viability of regional biomass chains by comparing the economic performance of potential bioenergy crops with the performance of current agricultural land uses. The biomass chains assessed are ethanol production from Miscanthus and from sugar beet in the North of the Netherlands. The competitiveness of bioenergy crops is assessed by comparing the Net Present Value (NPV) of perennial crops, current rotations, and rotation schemes which include additional years of sugar beet. The current land use and soil suitability for present and bioenergy crops are mapped using a geographical information system (GIS) and the spatial distribution of economic profitability is used to indicate where land use change is most likely to occur. Bioethanol production costs are then compared with petrol costs. The productions costs comprise costs associated with cultivation, harvest, transport and conversion to ethanol. The NPVs and cost of feedstock production are calculated for seven soil suitability classes. The results show that bioenergy crops are not competitive with current cropping systems on soils classed as "suitable". On less suitable soils, the return on intensively managed crops is low and perennial crops achieve better NPVs than common rotations. Our results showed that minimum feedstock production costs are 5.4 €/GJ for Miscanthus and 9.7

€/GJ for sugar beet depending on soil suitability. Ethanol from Miscanthus (24 €/GJ) is a better option than ethanol from sugar beet (27 €/GJ) in terms of costs. The cost of bioethanol production from domestically cultivated crops is not competitive with petrol (12.34€/GJ) production under current circumstances. We propose that the method demonstrated in this study provides a generic approach for identifying viable locations for bioenergy crop production based on soil properties and current land use.

Key words: bioethanol, economic analysis, crop production, spatial distribution, sugar beet, Miscanthus

1 Introduction

Energy from biomass, including biofuels like ethanol, can play a major role in local, national and global energy supplies depending on land availability, costs, and supply. However, in both scientific and political arenas, it is seen that such bioenergy chains need to evolve in a way that is compatible with Sustainable Development.

In recent years, several studies (e.g. Hoogwijk, 2005; Dornburg 2008; Smeets 2007) have assessed the world bioenergy potential and the contribution to the world energy demand. Other studies have focused on bioenergy potential and related costs at a European level (EEA 2006; van Dam et al. 2007; de Wit and Faaij 2010; Fischer et al. 2010a; Fischer et al. 2010b) or national level (Broek et al. 2001; Batidzirai et al. 2006; Styles and Jones 2007). However, few studies describe the spatial variation of bioenergy production potential and the cost of bioenergy supply within a region. Since the physical environment is spatially heterogeneous, location is a key factor for the economic viability and environmental performance of bioenergy production. Because economic benefit is a major incentive for adoption, this paper focuses on the competitive advantage of bioenergy crops in relation to conventional land use in order to increase understanding of where, and on which types of soils, such land use changes might occur.

Ethanol production from Miscanthus (*Miscanthus* x *Giganteus)* and sugar beet *(Beta vulgaris L.)* in the North of the Netherlands is selected for our case study. This region is important as a test case, because of the high pressure on land for various uses including intensive agriculture. This enables an extensive analysis of the economic viability of regional biomass chains. Sugar beet and Miscanthus are selected because of their high potential yields and because they represent a typical first and second generation bioenergy chain. These are compared with current land use to determine their relative economic viability.

In Section 2, we elaborate on the design of the bioenergy chains, the characteristics of the region and the potential land availability in the region. In Section 3, the methods applied to asses the competitiveness of new bioenergy crops compared to current land use and the methods to calculate the cost of feedstock and ethanol production will be discussed. The approach to determine the soil suitability and the effect on the spatial variation of economic performance of potential and current land use is described in section 3.3. In Section 4 the results of the assessment are presented and the spatial variation is depicted in maps of the region. A sensitivity analysis shows the level of robustness of the results. In Section 5, the applied method, the data used and the results are discussed, and in Section 6, conclusions are drawn.

2 Case study description

2.1 Study region

The Northern region of the Netherlands (Groningen, Friesland and Drenthe) was selected as the area for our research for several reasons. Firstly, the Dutch government has provided clear targets for substitution of fossil fuel and green house gas emission reduction (Menkveld 2007; Ministerie van VROM 2007; Ministerie van Economische zaken 2008). Secondly, the pressure on land is relatively high due to a high population density, diverse land uses and an intensive agricultural sector, resulting in intense competition between different land uses. Thirdly, access to sea transport through the Eemshaven ports facilitates the possible transport of biomass feedstock and intermediate- or end-products to and from the rest of the world. Fourthly, this is a highly productive agricultural area with fertile soils, favourable climatic conditions, and advanced agricultural management (Romkes and Oenema 2004) with a farming population that is interested in alternative economic activities for the agricultural sector. Finally, several regional stakeholders have also articulated on the need for sustainable development in the region (Costa Due 2009; Energy Valley 2009).

The region has a mild maritime climate with average temperatures of 16 ºC during summer and 3 ºC degrees during winter (KNMI 2002). The most common soil types in the Northern region of the Netherlands are sand, clay, sandy clay and peat, and soils are generally fertile. Precipitation is relatively high as are ground water levels. The climate and soils are suitable for a wide range of crops (Christian et al. 2001)

Land use in the region (1.1 Mha) is dominated by agricultural activities: 68% of the total area is agricultural land of which 41% is used for agricultural crops and 57% for pastures. On parts of the pasture areas, silage maize is continuously cultivated by intensive cattle breeders. Cereals, potatoes, sugar beet and silage maize are the most dominant crops cultivated in rotation. Two common rotations schemes for sandy soils and two rotations schemes for clay soils are selected to represent current land use of arable land in the region and are depicted in Table 1.

Table 1

Due to intensive livestock production, the Netherlands faces a manure surplus. Because of the costs of managing this surplus, the application of manure on agricultural land has negative costs. Therefore, application rates are high in pasture areas with intensive cattle breeding.

Transport infrastructure in the region is well developed. Whilst waterways and railways are available, road transport is most convenient way of transporting agricultural goods within the region due to the relatively short distances and the flexibility that multiple production sites require (Hamelinck et al. 2005b). Rail and waterways and the Northern ports, connect this region to the rest of Europe and beyond.

2.2 Biomass potential in the region

The introduction of bioenergy crops to large areas of land would create competition with the food and feed crops already being grown in the region. Thus, in order to define a limit to the arable land available for bioenergy production, information provided by the EU Refuel project is used (de Wit and Faaij 2010). One of the objectives of the Refuel project was to map the potential production and costs of biomass crops in the EU for different time frames and for several land use scenarios. The method used in this study is comparable the approaches used by (Smeets et al. 2007) and (van Dam et al. 2007). In the Refuel approach, projections are used to describe the future dynamics of population growth, food intake per capita, agricultural production intensity, livestock intensity and land requirements for the growth of cities, villages and infrastructure

(Fischer et al. 2010a; Fischer et al. 2010b). The land available for biomass production is calculated by subtracting the land needed for other land use functions (including nature) from the total available land, assuming the self-sufficiency in food production in the region remains constant. In the Refuel study it is assumed that typical agricultural crops are only produced on arable land, while for herbaceous crops like Miscanthus it is assumed that pasture could also become available.

The base case scenario of the Refuel assessment is derived from the Common Agricultural Policy (CAP) of the EU. In addition, a more optimistic (high land availability) and a more pessimistic (low land availability) variant have been developed.
In Table 2, the amount of agricultural land that according to the Refuel results could become available for biomass production in the North of the Netherlands in 2015 and 2030 is depicted. The Refuel projections of land availability for biomass production in the North of the Netherlands are somewhat higher but in the same order of magnitude as the projected land availability of the Eururalis project (Westhoek et al. 2006; Eickhout and Prins 2008)

Table 2

In this study, the Refuel project is used to indicate what proportion of land could be converted for bioenergy production without diminishing the region's current self-sufficiency in food. In addition, data in the Refuel project are used to estimate the appropriate scale of conversion plants for the region.

2.3 Bioenergy chains

In this study, we investigate ethanol production from sugar beet and Miscanthus. These two bioenergy chains are selected because of their potential for high yields (Huisman et al. 1997;

Elbersen et al. 2005; PPO et al. 2006; van der Voort et al. 2008) and because of the developing market for ethanol in the Netherlands created by European biofuel policies. In addition, the two bioenergy chains are chosen because they have very different cultivation requirements and conversion technologies, since they are typical of first and second generation bioethanol supply chains.

Sugar beet

Sugar beet requires good quality soils and high inputs and is generally grown in rotation with cereals and potatoes. In our study, it is assumed that sugar beet for ethanol production is cultivated on land currently in use as arable land (as in the Refuel study, pasture is excluded for typical agricultural crops). This implies that the proportion of sugar beet needs to be increased within the current rotation schemes. Because the excessive use of beet or other intensive crops increases the risks of diseases and yield loss (Kempenaar et al. 2003), it is assumed that the proportion of sugar beet does not exceed 25% of the rotation, and that the total proportion of land assigned to intensively managed crops does not increase from current levels.

Current CAP regulations for sugar comprise of a quota and a price regime. The quota limits the production of sugar per county and the price regime sets a guaranteed intervention price for this quota. Sugar produced over the quota is sold on the world market, at considerably lower prices than EU quota prices. Since extra beet exceeds the quota for sugar production, sugar beet for ethanol production is less profitable than for sugar production. For this reason, it is assumed that the growth of sugar beet for ethanol is additional to that sold in sugar beet quota. Management and transport of sugar beet for ethanol production is assumed to be similar to current practice in this region. Once harvested, sugar beet cannot be preserved. The harvest window lasts from September until the end of December, thus maximizing the load factor of the beet processing plant. It is assumed the sugar beet, including 15% tare (soil attached to the beet), is transported by truck to a newly built ethanol plant close to the current sugar plant centrally located within the agricultural area. Since long distance transport of sugar beet is not economically attractive, the conversion plant is assumed to be of a size appropriate for the expected supply of sugar beets in the region, i.e. 700 kton (fresh weight) input per year (90 MW_{input}, 1.5 $PJ_{ethanol}$). This figure is derived from predictions made in the Refuel project on the maximum land available for arable bioenergy crops in 2015 (9.6 kha, see section 2.2) and the attainable yield on very suitable soils (73 ton_{fresh} $ha^{-1}y^{-1}$, 23% dm, 16% sugar). In the ethanol plant, sugar beet is shredded into cossettes and diffused in water to produce raw sugar beet juice and pulp. Pulp is further processed for animal feed and put on the market as a co-product. The raw juice is pasteurized, fermented, and distilled in order to produce ethanol.

Miscanthus

Miscanthus is a perennial crop with a rotation of 20 years. It requires few inputs and is relatively insensitive to soil conditions (Venturi et al. 1999; Bullard 2001; Bullard and Matcalfe 2001; Lewandowski and Heinz 2003; Lewandowski et al. 2003; Khanna et al. 2008).

In our study, it is assumed that Miscanthus can be cultivated on agricultural land that is currently in use as arable land and as pasture (as in the Refuel study)(de Wit and Faaij 2010). Although the highest yields are achieved when Miscanthus is harvested in autumn, harvest does not take place until spring, when the highest dry matter content and quality is achieved. Due to nutrient remobilization during winter, the removal of nutrients from the soil is lower in delayed harvests (Himken et al. 1997; Ercoli et al. 1999; Lewandowski and Heinz 2003; Monti et al. 2008) and this is preferable, since lower moisture, nutrient and ash contents are also beneficial for processing. It is assumed that harvesting takes place using a self propelled chopper, as this has been identified as the cheapest option in other studies (Smeets et al. 2009). In addition, chopped Miscanthus dries more easily and this improves future processing. Because ethanol production is assumed for the entire year, a continuous biomass supply is required. Therefore, an average storage time of 6 months is assumed, with an average dry matter loss of 2% over this 6 months (Smeets et al. 2009). The ‘chips’ are assumed to be transported to a lignocellulose ethanol plant by truck.

After physical size reduction, the cellulose is broken down into free glucose molecules by enzymatic hydrolysis (Hamelinck and Faaij 2006). In the fermentation step, the free sugars are converted to ethanol. Within the timeframe considered by this study, dilute acid pre-treatment, on-site enzyme production, enzymatic cellulose hydrolysis, and an Simultaneous Saccharification and Fermentation (SSF) configuration boiler and steam turbine, are expected to be the most prominent technologies for converting lignocellose crops to ethanol (Hamelinck et al. 2005a). The characteristics of this conversion pathway are therefore assumed for this study. From an economic perspective, large scale facilities are preferable to small scale facilities and a capacity of 400 MW is generally required to achieve reasonable production costs (Hamelinck et al. 2005a). Therefore, it is assumed that Miscanthus is processed in a 400MW ethanol plant (640 kton odt annual input, 4 $PJ_{ethanol}$) that is located close to the port of Eemshaven. Since the expected regional feedstock supply does not meet the input requirements of a plant of this size, it is assumed that 70% of the lignocellulosic material will have to come from international supply chains. It is assumed that the import of lignocellulose material from abroad is feasible because of relatively low production costs, because pre-treatment can be applied, and because of the relatively low cost of international sea transport (Hamelinck et al. 2005b).

In order to put these two bioenergy chains into context, other ethanol production chains are also assessed. Ethanol from currently cultivated annual crops such as wheat and maize are considered as are perennial crops like switchgrass and willow.

Specific data regarding required field operations, seed fertilizer and pesticide application, yield levels and dry matter content, transport of biomass and conversion to ethanol are provided in the supplementary on-line material.

3 Method

The competitiveness of the bioenergy chains is assessed by comparison of the economic performance of the bioenergy crops with the current use of agricultural land and by comparison of the production cost of bioethanol with average petrol prices. The way the spatial distribution of soil suitability and current agricultural land use affect competitiveness of bioethanol chains will be addressed. First, calculation methods for the economic competiveness of crops and the production costs are discussed. Thereafter, the method to determine the spatial distribution of soil suitability for individual crops and the effect on economic performance is considered.

3.1 NPV calculations for crop production

In order to compare both annual and perennial crops, all costs and benefits during the cultivation phase are discounted and aggregated to provide their Net Present Value (NPV) (Equation 1). The NPV of the various rotations are calculated by multiplying the NPV of the individual crops by their proportional share in the rotation (see Table 1).

$$NPV_{cr} = \sum_{Y=1}^{Y=x} \frac{\sum_{n=1}^{N} \left(I_{ny} \cdot B_n \right) - \sum_{m=1}^{M} \left(J_{my} \cdot C_m \right)}{(1+a)^y}$$ **(Equation 1)**

NPV_{cr}	= Net Present Value of crop per ha	[€/ha]
I	= occurrence positive monetary flow *n* in year y	[#]

B	= revenues of monetary flow n per ha	[€/ha]
J	= occurrence of negative monetary flow *m* in year *y*	[#]
C	= cost of monetary flow m per ha	[€/ha]
a	= discount rate	[%]
y	= annuity period	[y]

The annuity time period considered here is 20 years, which is in line with the lifetime of the perennial crops and the lifetime of conversion plants (see Table A7 of the online supplementary material). A discount rate of 5.5% is assumed. This is a realistic interest rate for farmer loans (Wolf and Klooster 2006; personal communication, J. Houtsma, da Vinci Finance Friesland) but is considered to be low for commercial investment projects.

For pasture, the NPV of grassland is compared to the NPV of Miscanthus. The revenue from pasture is represented by the avoided cost of fodder and the benefits related to manure application. For arable land, the best rotation for the specific soil type (clay/sand) is compared to a rotation with an increased proportion of sugar beet and to Miscanthus.

The costs and revenues of crop production depend on soil and climate, the economic environment, and the farm management system. All these parameters are regionally specific. For the calculation of the economic performance of crop production, only costs and benefits directly related to cultivation are taken into account. Overhead costs and general farm activities (e.g. maintenance of barns and farm area, cleaning, and administration) are not considered in this study.

The costs related to crop production generally include four main categories of expenses:

- land costs

- field operation costs (contractor, machinery, labour and diesel costs)
- input costs (seeds, fertilizers and pesticides)
- fixed costs (insurance, soil sample assessment, etc).

The benefits of crop production are the revenue from:

- selling the main product
- selling the co-product
- CAP subsidies for crop production

In our study, all costs and revenue are based on price levels for 2006 and are included in the supplementary on-line material. The lease price of land is used to reflect the land cost for farmers. A large variety of field operations need to be carried out for the production of crops: soil preparation, seeding/planting, fertilization, weed and disease control, harvesting, storage, and drying. Machine costs for field operations are derived from (PPO et al. 2006) and account for purchase price, salvage value, lifetime, interest rate, average annual operating hours, maintenance and repair, storage, insurance cost, and work rate of the specific field operation. The fuel use per field operation is related to the type of machine used for the operation and the work rate. The most commonly used tractor capacities for specific field activities are based on (Wolf and Klooster 2006). For field operations that are commonly outsourced in this region (e.g. seeding and harvesting beet and maize), contractor prices are incorporated. The contractor prices include costs for machinery, labour and fuel. For non-outsourced field activities, farmers' labour costs are assumed for the first worker, while for every additional worker, labour costs for an average employee are assumed.

The cost of harvesting perennial crops are related to the per hectare yield levels. The relationship between yield levels and harvest costs is non-linear and is described for willow by the Wood

Supply research Group of the University of Aberdeen (WSRG 1994). It is assumed that this relationship also applies for other perennial crops (Smeets et al. 2009).

$$HC = 4.33 \cdot Y^{1-0,589}$$ **(Equation 2)**

HC	=Harvest costs	[€/ha]
Y	= Yield	[odt/ha]

The fixed costs are a compilation of several costs that occur annually. These depend on the crop type, and include the costs for insurance, soil sample assessment, certifying and crop testing, tare, prevention of erosion, and national product levy. The input costs consist of the cost for planting material, fertilizers, and pesticides and are determined by the application rates and costs per unit. The revenue for the farmer consists of the sale of products and CAP subsidies. For cereals, both main- and co-products have market value.

3.2 Cost of ethanol

In order to calculate the ethanol production costs, all costs and benefits during all stages of the supply chain need to be taken into account. The specified cost calculation for perennial crops making use of the NPV has been demonstrated by (Broek et al. 2000b). In general, only monetary flows can be discounted. However, since the yield represents a monetary flow, it is legitimate to discount this output too (Broek et al. 2000a). The allocation of feedstock production costs is based on the economic value of the main- and co-product (e.g. straw).

All costs related to loading, unloading and transport need to be calculated per ton of product. This includes the cost of labour, fuel and depreciation of machinery. Finally, the costs and revenue for ethanol production need to be taken into account. This includes investment costs (depreciated over the lifetime), operations and maintenance (O&M) costs and the costs for fuel, gas, electricity and other inputs needed for the process. Benefits include revenue from co-products or electricity produced during processing. The scale, load factor and efficiency determine the annual input (feedstock) and output (ethanol). Equation 3 shows how the ethanol production costs are calculated.

$$C_{eth} = \frac{(Fs + Tr \cdot D)/(Dm \cdot E)}{\eta_{plant}} + \frac{\left(\frac{CC \cdot a}{1-(1+a)^{y}} + OM + EC - CP\right)}{AO_{eth}}$$ (**Equation 3)**

C_{eth}	= Cost of ethanol	[€/GJ]
Fs	= Feedstock costs	[€/ton (fresh)]
Tr	= Feedstock specific transport costs	[€/ton/km (fresh)]
D	= Distance to plant	[km]
Dm	= Dry matter content of feedstock	[%]
E	= LHV_{dm} feedstock	[GJ/odn]
η_{plant}	= Efficiency plant (GJ_{input}/GJ_{output})	[%]
CC	= Capital costs	[€]
a	= Discount rate	[%]
y	= Lifetime	[y]
OM	= Annual O&M costs	[€/y]
EC	= Annual energy input costs	[€/y]
CP	= Annual revenues co-products	[€/y]
AO_{eth}	= Annual output ethanol	[GJ/y]

3.3 NPV and costs of feedstock differentiated for soil suitability

Crop yields vary within the region due to different soil qualities. Therefore, the NPV of crops and the costs of feedstock are differentiated for different soil quality classes.

To map the soil suitability and the related yield for the different crops in our assessment, we use the most recent HELP (*Her-EvaluatieLandinrichtingsProject*) system (Brouwer and Huinink 2002; Brouwer et al. 2003). In this method, physical yields are determined by a combination of soil characteristics (e.g. water holding capacity, clay-sand-peat contents, rooting depth and stoniness) and water tables in summer and winter. The total yield reduction (D_{tot}) relative to the maximum potential yield is determined by the yield reduction caused by drought (D_{dr}) (mostly in summer) and the yield reduction caused by water surplus (D_{wa}) (mostly in winter) assuming no irrigation. See equation 4.

$$D_{tot} = D_{wa} + \left(\frac{100 - D_{wa}}{100} \cdot D_{dr} \right) \qquad \textbf{(Equation 4)}$$

The yield level reductions were produced for the most common arable crops and mapped by (Brouwer and Huinink 2002) onto 25 x 25m grid using GIS (Geographic Information System).

In the present HELP system a large selection of crops is included, but perennial biomass crops are missing and so are seed potatoes, summer wheat, barley and rape seed (see table 3). Estimates of yields losses of the missing crops ware made based on existing tables in combination with crop need knowledge. The expected yield loss of Miscanthus due to water and drought is based on (Christian et al. 2001; Lewandowski et al. 2003) and personal communication with Wolter Elbersen A&F, Wageningen University and Research centre. The assumptions regarding yield reductions due to water and draught stress of annual and perennial crops are summarised in Table 3.

Table 3

The crop specific HELP tables are used to map the soil suitability for all individual crops. This results in separate map layers of crop specific yield reductions. The suitability classes used are depicted in Table 4. The potentially suitable area includes the whole agricultural area excluding land used for greenhouses and land within Natura 2000 conservation areas.

Table 4

Yield statistics provided by (LEI CBS 2007) and (PPO et al. 2006) present average yield levels for the region, differentiated to sand and clay soils. These average yield levels are translated to yield levels per suitability class by taking the yield reduction per suitability class and the relative share of suitability class per crop for current land use into account.

The management responses to yield reductions are not always clear. On the one hand, fertilizer inputs may be lower, due to reduced crop removal from the field during harvesting. On the other hand, the efficiency of fertilizer uptake may be decreased on poorer soils, resulting in increased application requirements. In the case of herbicides, applications may be higher on better soils, since weeds are likely to generate more biomass. However, since the crop canopies may close earlier in the growing season on better soils, the crop is better able to compete with weeds, which could reduce herbicide requirements. Because the management response to yield reductions can result either in an increase or a decrease of inputs, and because management is also dependent on local circumstances and individual decisions, no general rule regarding the level of input response to yield reductions can be made (personal communication A.J. Haverkort, J.G. Conijn and J.J. Schroder, 2008, Plant Research International, Wageningen University and Research centre). Therefore, we assume that input levels remain constant over soils of different quality and that the revenue achieved determines whether a crop is grown at a specific location.

The NPV of the crops for each soil suitability class are linked to the crop specific soil suitability maps. For the NPV of rotations, individual map layers of the crops are combined for a final NPV map and weighted by the proportion of that crop in the rotation (Table 1). In addition to the NPV, the cost of feedstock production of Miscanthus and Sugar beet for every soil suitability class are linked to the GIS maps.

All parameters used for the calculation of the competitiveness of bioenergy crops compared to current land use and the calculation of the cost of feedstock and ethanol production are provided in the supplementary on-line material.

4 Results

The NPV of most agricultural crops, especially cereals, are found to be negative when all costs are included. In Figure 1, the proportion of costs and benefits (excluding subsidies) in the NPV of conventional crops, rotations, and perennial crops are shown for “very suitable” soils. Large differences are evident between intensively managed crops like potatoes and sugar beet, for which revenues are high but investments are high too, and less intensive crops like wheat and barley, which require far lower inputs and labour but do not provide high revenue.

Figure 1

In Figure 2, the NPV of perennial crops, typical rotations, and rotations with an increased proportion of sugar beet are shown for the different soil suitability classes. This figure shows that NPVs always decrease on less suitable soils and that the rate of decrease is greater for the crop rotations than for the perennials. This is due to the intensive management requirements of annual crops compared to perennial crops. Because it is assumed that inputs and work rates do not decrease for less suitable soils (except for yield related costs like harvest and drying), the economic performance of intensively managed crops declines more rapidly than the performance of less intensively managed crops on less suitable soils.

Figure 2 shows that an increased share of sugar beet in rotations generally has no significant effect on the NPV, except for the 'Clay II' rotation. For this rotation, an increase in the proportion of sugar beet in the rotation causes a lower NPV on very suitable soils, but achieves a less negative NPV on less suitable soils, because sugar beet substitutes for potatoes, which have very high yield losses on less suitable soils. For less suitable soils (> 20% yield loss) the NPV of perennial crops exceeds the NPV of rotations. However, at this point the NPV of perennials is also low compared to keeping the land fallow.

Figure 2

Currently, most farmers receive CAP (Common Agricultural Policy) support for cultivating agricultural crops (up to 446€/ha). Since energy crops receive little support (45 €/ha) in contrast to food and feed crops, the gap between the NPV of conventional crops and energy crops would increase on suitable soils. Thus, when subsidies would be included, the intersection between perennial crops and conventional land use moves towards less suitable soils (> 30% yield loss). As noted previously, farmers often do not account for the cost of land, their own labour, and machinery. Omitting the cost of labour and machinery especially influences the NPV of intensively managed crops, and in these circumstances, perennials are only competitive on low and less suitable soils (> 50% yield reduction).

Since perennial crops are more tolerant to water and drought stress, it is possible that some areas could be suitable for perennial crops and less suitable for rotation crops. The significance of this can only be depicted spatially. Therefore, the NPV of all the crops (including all costs and excluding subsidies) were linked to the soil suitability maps for the individual crops. For the NPV of rotations, individual map layers of the crops were combined for a final NPV map and weighted by the proportion of that crop in the rotation. The mapped NPV of rotations on clay and sand, pasture and maize were then combined with a map of current land use and, for clay and sand, the best performing rotations were then selected. Then, over the whole agricultural area, the NPV of current land use was compared with the NPV of Miscanthus on a 25m x 25m grid map (Figure 3). The same was done for the increased sugar beet rotation, but since there is little difference between the economic performance of extended sugar beet rotation and the conventional rotations (see Figure 2), this map is not presented here.

Figure 3

The light areas in Figure 3 indicate where Miscanthus can compete with current land use because of a higher NPV. Most of these areas are currently in use for pasture and are often too wet for arable crops. The dark areas reflect those zones in which current land use is most profitable. These zones have fertile soils and are well suited for cultivation of profitable crops like potatoes and sugar beet. In these locations, it is very unlikely farmers will be willing to switch to energy cropping systems, at least, from an economic perspective.

Table 5 shows that cropping Miscanthus on land that is currently used for pasture is often more profitable than current practice, but that Miscanthus is almost never more profitable on land that is currently used for maize. Table 5 also shows that Miscanthus is more likely to be competitive with rotations on sandy soils than rotations on clayey soils.

Table 5

The distribution of those areas where Miscanthus is competitive with current land use is depicted as a function of the soil suitability classes in Table 6. Most of the land on which Miscanthus is competitive with current land use is moderately suitable for Miscanthus (90% of the total area is low to highly suitable for Miscanthus). This is plausible, since “very marginally suitable” and “marginally suitable” soils are very rare, and “very suitable” soils are often more suitable for conventional cropping systems, which achieve higher NPVs on these soils.

Table 6

Cost of biomass

The cost of biomass is expressed per GJ feedstock (Lower Heating Value of dm whole crop) at the farm gate, and is differentiated for each crop and soil suitability class (Figure 4a). In the Northern region of the Netherlands, Miscanthus has a total potential energy yield of 155 PJ, if the whole agricultural area is dedicated to this crop. The lowest production cost is 5.4 €/GJ on very suitable soils, the highest is 41.6 €/GJ on very marginally suitable soils. The potential energy yield from sugar beet for the whole agricultural land area (134 PJ) is smaller than for Miscanthus. Also, the cost of production (9.7 €/GJ and above) is higher than for Miscanthus, but lower than for most other annual crops. However, in case it is assumed sugar beet is only cultivated on land currently in use as arable land, as assumed in the Refuel study(de Wit and Faaij 2010), the potential would greatly decrease. In addition, only a maximum share of 25% in the rotation is permissible, which would decrease the potential even more. An additional issue is that biomass production costs in the North of the Netherlands are likely to greatly exceed the cost of biomass imported from abroad (Lewandowski and Faaij 2006), which in the case of lignocellulosic biomass, are expected to vary from 3.0 - 3.5 €/GJ for pellets from Latin America, 3.5 - 5.0 €/GJ for pellets from Eastern Europe, and 4.5 - 6.5 €/GJ for pellets from Scandinavia (Hamelinck et al. 2005b).

Figure 4a

Figure 4b

Taking into account the figures presented in Tables 5 and 6, a cost supply curve can be constructed for Miscanthus for the area where its cultivation is competitive with current land use (Figure 4b). The potential presented in the figure is relatively high. The data presented in the Refuel study regarding land availability for bioenergy crops (see Section 2.2) indicate that only a small part of this potential can be exploited for bioenergy crops, without diminishing the self-sufficiency of the region (the 'optimistic' scenario of Refuel is presented by black dots in Figure 4b). Assuming that only the least cost production areas are likely to be dedicated to bioenergy crops (Figure 4b), this results in a potential supply of 2.7 PJ at a cost of 5.4 to 5.9 €/GJ compared with a potential of 71 PJ at a cost of 5.4 to 9.4 €/GJ if all the land where Miscanthus is competitive with current land use is taken into account. A cost supply curve for bioenergy feedstock from sugar beet for the area where it is competitive with current land use can not be made, since rotations with out of quota sugar beet have lower returns than current rotations.

The cost of feedstock production is affected by the soil suitability. In Figures 5a and 5b, the spatial distribution of the cost of sugar beet and Miscanthus production are given. Both crops achieve lowest production costs in the Northern area of the region. A relatively large area achieves comparatively low production costs for Miscanthus. The production costs of sugar beet are generally higher and increase more rapidly in less suitable conditions. In Figure 5a, the potential cost of sugar beet cropping on land now used for pastures is depicted as well. However, these areas are considered to be unavailable for sugar beet production. In this figure, the land currently used for pasture is mainly coloured dark (very high production costs).

Comparing Figure 3 with Figure 5b shows that for some locations where Miscanthus performs better than current land use, production costs are very high. However, most areas where Miscanthus has a higher NPV than current land use have relatively low production costs. These are the most promising locations for Miscanthus production.

Figure 5a

Figure 5b

Costs of ethanol

In Figure 6, the cost of ethanol production [€/GJ] from sugar beet and Miscanthus are represented. This figure is based on the least cost feedstock produced on very suitable soils (all costs factors including land, labour and machinery are taken into account). For comparison, the cost of ethanol from wheat and maize and the cost of petrol are depicted as well. The petrol prices do not include VAT, excise and margins. The difference between the cost of bioethanol and petrol is significant (>182%) assuming an oil price level of 62 US$/barrel. However, when oil price levels increase to 100 US$/barrel (average level of 2008) (OECD and IEA 2008) or 150 US$/barrel (as projected for 2020 by OECD and IEA) (OECD and IEA 2008), bioethanol could become competitive to petrol.

The bioenergy feedstock costs vary for the various crops produced at suitable soils (range 5 - 10 €/GJ, see Figure 4a). Conversely, the cost range of ethanol production is relatively small (24 - 27

€/GJ, see figure 6). This is caused mainly by the fact that relatively expensive feedstock in the form of sugar and starch crops require less advanced technology for the conversion to ethanol. The contribution of capital and operations and maintenance (O&M) cost are relatively large for ethanol production from lignocellulosic crops. The distance from field to processing plant is assumed to be the same for all feedstock, but the share of transport costs for ethanol from sugar beet is large due to the high moisture content of sugar beet.

Figure 6

For production of ethanol from wheat, only the main product (grain) is used; straw is considered to be a co-product used for other purposes. Currently there is a relatively high demand for straw for several purposes (stables, crop coverage, etc). Allocation of costs for production of the ‘main products’ is based on economic value. Based on this allocation, the production cost of straw exceeds the cost of Miscanthus (euro/$GJ_{feedtock}$). Therefore the cost of ethanol production from straw will be higher than from Miscanthus and will not be profitable. For this reason, it is assumed that demand for straw for ethanol production is not yet an additional competitive factor in the market for straw. The leaves and crowns of sugar beet are assumed to be left on the field, and are therefore not considered to be co-products. For lignocellulose crops, the whole crop is used for conversion to ethanol. If the total area where Miscanthus is competitive with current land use is dedicated to Miscanthus for ethanol, 25 PJ ethanol could be produced annually. However, the Refuel study indicates that only a minor share can be used for bioenergy crops before compromising self-sufficiency. This results in an annual production of 1 PJ of ethanol at a cost between 24.4 and 25.9 €/GJ, equivalent to 0.7 % of the energy in the petrol used in the Netherlands (142 PJ) in 2006 (CBS, 2008).

4.1 Sensitivity analysis

In this section the sensitivity of the NPV, the cost of biomass and the cost of ethanol for various key parameters is assessed. These have been selected because of expected fluctuations or uncertainty in specific parameters (e.g. commodity prices, fuel prices and discount rate) and/or the expected effect of the key parameter on the final result (e.g. biomass yield and labour wages). In Figure 7, the sensitivity of the NPV of Miscanthus and sugar beet cultivated on very suitable soils is presented using spider diagrams.

The NPV of Miscanthus and sugar beet are very sensitive to changes in yield levels and market prices. The NPV of sugar beet is more sensitive to changes in labour and energy prices than Miscanthus due to the relatively intensive management that is required. Biomass costs are sensitive to changes in yield, especially in the case of lower yields, where costs increase significantly. Miscanthus production cost is sensitive to changes in the discount rate. This is due to the high initial investment required and to the relatively long period of time that it takes to achieve high yields. For sugar beet the discount rate has little effect, since costs and benefits are approximately equal every year. The cost of ethanol production is very susceptible to yield levels and efficiency. The impact of higher energy prices is different for the cost of ethanol production from Miscanthus and from sugar beet. When energy costs increase, the costs of ethanol production from sugar beet also increases, due to higher feedstock and transport costs. For Miscanthus these costs also increase, but the co-product of ethanol production of Miscanthus, electricity, increases in value too. Therefore, for lignocellulosic ethanol, the net effect is a decrease in ethanol production costs when energy prices increase. The sensitivity for yield level represents the sensitivity for changes in soil suitability.

Figure 7

5 Discussion

5.1 Method and input data

In this study it is assumed that economic performance is the main driver for the adoption of different agricultural crops by farmers. The personal preferences of farmers, which can also influence land use, are not included in our study. Other factors that can influence the economic performance of land use, such as previous investment in crop specific machinery and equipment, long-term agreements with procurers of processing chains, individual management and rotation choices, and additional costs or benefits of specific land use due to locally enforced policy measures and subsidies (e.g. to protect ecosystems and historic landscapes), are also not included in this study.

An important assumption is that here inputs of seeds, fertilizers, pesticides, and field operations do not change for different soil suitability classes. The main reason for this is that poorer soils can require both higher and lower levels of inputs and, that based on available data, no general trend can be distinguished. The contribution of input costs to the total feedstock costs is relatively low for perennial crops (about 6%) but more significant for annual crops (about 12% for barley and 30% for feeding potatoes). If it were to be assumed that fewer inputs would be applied to crops on less suitable soils, the feedstock costs would decrease for these poorer soils. A further issue lies in the scale of analysis used in this study, which here, is based on a one-hectare comparison of different crops. Farmers however, need to consider the whole farm business and the way in which individual enterprises link with each other. For example, this could have implications for the analysis of the pasture areas, since only the replacement value of fodder and the application of manure are considered as economic benefits, and other benefits, such as subsidies and revenue from cattle breeding have not been included. Although the NPV does not necessarily represent every individual farmer's perspective, it does present a broad economic picture of the relative profitability of different land uses and, as a result, provides an indication of how land use might change at a regional level. Therefore, we propose that those areas where bioenergy crop production has been found to be relatively profitable in this study, could serve as a starting point for economic analysis of bioenergy production at a farm level.

There is little experience with the cultivation of perennial bioenergy crops in the Netherlands and as a result, management practices have seen little development or optimisation in comparison with conventional crops, where management has been optimized over the decades. For perennials, there are uncertainties regarding input requirements (e.g. rhizomes and fertilizer needs) and attainable yield levels, which have large implications for economic performance. This uncertainty is also reflected by the large differences for input requirements in the literature. In addition, since ethanol plants based on lignocellulose feedstock are not commercially running yet, efficiency and investment costs used in this study come attached with some uncertainty.

5.2 Results

The NPV of crops are very sensitive to market prices of agricultural products. These prices have fluctuated to a large extent over last few years. The FAO food price index increased from 116 to 219 between 2006 and spring 2008 and then decreased to 148 in December 2008 (FAO 2009). Therefore, the results related to the prices used here need to be carefully interpreted.

Our assessment indicates that Miscanthus could be competitive with current land use in a relatively large area (given a level playing field in terms of subsidies). The maps show that the area where Miscanthus could be competitive with current land use, is dominated by pastures. However, since there are uncertainties regarding management data of pastures and additional benefits, and differences in NPVs are small, this result should be interpreted with care. The

Refuel study also indicates a marginal availability of land currently in use for pastures (de Wit and Faaij 2010). Therefore, the actual area where bioenergy crops are competitive with pasture is expected to be very limited. The maps in Figure 3 and 5b give an indication of which areas could become the most promising areas for energy crop production. These areas are likely to be the ones where the NPV of Miscanthus is higher than the NPV of current land use and the costs of feedstock production are low.

The European sugar market is protected by the European Union by a set quota and a guaranteed intervention price. Intervention prices of white sugar were reduced from 63 €/100kg sugar in 2006 to 42 €/100kg sugar in 2009 (Berkhout and van Berkum 2005). The economic value of 1 ton of sugar beet for sugar therefore decreased from 82 €/ton in 2006 to 55 €/ton in 2009 compared with an economic value of 53 €/ton for ethanol (assuming an ethanol price of 0.60 €/l). This shows that the production of sugar has become less profitable over the years, as a result of the reduced intervention prices for sugar. In addition, when the EU market opens to imports from abroad, ethanol production (and other uses of sugar beet) could become more attractive. For example, sugar beet can be used for (potential) applications in food, feed and the biochemistry industry. More advanced products (e.g. amino acids) with higher market value could be produced from sugar beet in combination with ethanol. This could also contribute to a larger greenhouse gas and fossil fuel mitigation potential (Brehmer et al. 2009).

Production costs of bioethanol from Miscanthus are relatively high (24 €/GJ) compared to current petrol prices (12 €/GJ). Feedstock production costs of domestic cultivated Miscanthus would need to be reduced by 38% to 3.33 €/GJ to be able to achieve ethanol production costs that could compete with petrol prices (oil price 62$/barrel). The ethanol production costs from Miscanthus in the Netherlands are equivalent to the prices of ethanol imported form Brazil, mainly due to a high import duty of almost 5 €/GJ. With improvement in technology and management, ethanol production costs could be reduced to about 13.5 €/GJ in the future (Hamelinck et al. 2005a; Hamelinck and Hoogwijk 2007; de Wit and Faaij 2010). In addition, according to the World Energy Outlook, oil prices are likely to increase (OECD and IEA 2008). Therefore, bioethanol is expected to become more competitive with petrol in the future.

In this study, we have compared the economic performance between current land use and bioenergy crops. Although the influence of subsidies has been assessed, the main comparison is based on cost calculations that exclude subsidies. It should be noted however, that the current land use is a result of (historical and current) agricultural policies and subsidies. In order to achieve the feedstock production cost of 3.33 €/GJ for Miscanthus (at which ethanol production could compete with petrol prices), a subsidy of 600 €/ha is required. At that subsidy level, Miscanthus is more profitable than pasture and all crop rotations (including subsidies) on every soil suitability class, except for clay rotations on very high and high suitability soils. For sugar beet, a subsidy of 1080 €/ha is required to achieve a feedstock production cost (5.68 €/GJ) at which ethanol production costs could compete with petrol prices. At this subsidy level it is economically attractive to increase the share of sugar beet in all rotations for all soil suitability classes.

The potential contribution of domestically produced ethanol from Miscanthus and/or sugar beet is relatively small (<1% of total energy use in the transport sector) assuming that only the ‘available land’ as indicated by the Refuel study can be used for bioenergy crops. Therefore, the Netherlands will have to rely on imported biomass/bioenergy to meet its targets for biofuel use in transport (10% in 2020) and renewable energy (20% in 2020) (Projectgroep 'Duurzame productie van Biomassa' 2006).

6 Conclusions

In this paper, the potential and economic viability of bioethanol chains in the Northern region of the Netherlands has been assessed for different soil suitability classes. The results have been compared to current agricultural land use. In addition, the spatial distribution of feedstock production and the production costs have been mapped. With this approach, we have assessed where land use changes in favour of bioenergy crops are most likely to occur.

The results of the NPV calculations show that an increased share of sugar beet for ethanol production cannot compete with current cropping systems under present quota conditions and commodity prices. The potential biomass production from sugar beet is lower than from Miscanthus, since only arable land is assumed to be appropriate and less well suitable land is available for sugar beet cultivation. Most cost effective sugar beet production is on very suitable soils in the coastal area in the North and the East of the region. Ethanol from domestic produced sugar beet is significantly more expensive than petrol or ethanol produced from feedstock imported from abroad. Therefore, there are no economic incentives to produce sugar beet for ethanol production in the North of the Netherlands under current circumstances. However, when oil prices increase and ethanol production is combined with the production of more advanced products (e.g. bulk chemicals), the competitiveness could increase.

The spatial analysis shows a large area in the North of the Netherlands where cultivation of Miscanthus could compete with current land use when a level playing field is established (i.e. when subsides are excluded). Ethanol production of Miscanthus appeared to be the least cost option of bioenethanol production of domestically cultivated feedstock in this region, but is still almost twice as expensive (24.4 €/GJ ethanol) than petrol (12.3 €/GJ, at an oil price level of

62US$/barrel) or ethanol produced from feedstock imported from abroad. Therefore, there are no economic incentives for the production of Miscanthus is the North of the Netherlands for ethanol production under current circumstances. However, if bioenethaol production costs decrease because of technological learning and crude oil prices increase, bioethanol could become competitive.

Taking the land availability of the Refuel study into account, the contribution of ethanol from domestic cultivated feedstock would be less than 1% of the petrol use in the Dutch transport sector. This indicates a marginal potential for biofuel chains in this particular region, but this can still contribute to meeting the fuel blending targets in the Netherlands for the near future.

In the analysis of the competitiveness of Miscanthus production with current land use, current pasture land appeared to be an important potential area for Miscanthus cultivation. However, as indicated in the discussion, there are uncertainties regarding the economic performance of pastures at a farm level and additional research is required. Also a more in depth assessment regarding the relation between management, soil suitability and yield levels is needed in order to draw firmer conclusions concerning the economic and practical viability of cultivation of bioenergy crops in the identified promising areas. Since combined production of advanced products and ethanol from biomass feedstock could be more beneficial than ethanol production alone in terms of economic performance and greenhouse gas mitigation potential, innovative biomass supply chains could be an interesting topic for further research.

This study provides a generic methodology to identify promising locations for bioenergy crop production based on soil properties and current land use. The method can therefore be applied in other geographical regions and at higher levels of analysis. The most important conclusion from this assessment is that the spatial variation of economic viability of bioethanol production chains indicates where land use changes are most likely to occur. However, economic performance is just one of the criteria needed to investigate the sustainability of bioenergy production. The environmental impacts in relation to the spatial characteristics of regional bioenergy chains are also very important and need further investigation.

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Tables

Table 1: Two typical rotation schemes for sandy soils and two typical rotation schemes for clay soils for Northern region of the Netherlands derived from (LEI CBS 2007; van der Voort et al. 2008) expressed in share of individual crop in each of the rotations.

Share of crop in rotation	Clay rotation I	Clay rotation II	Sand rotation I	Sand rotation II
winter wheat	0.57	0.20		0.05
summer barley		0.10	0.28	0.25
winter barley	0.20		0.06	
seed potato		0.15	0.03	0.05
industrial potato		0.15	0.30	0.45
sugar beet	0.14	0.10	0.20	0.20
maize		0.25	0.04	
other			0.06	
fallow	0.09	0.05	0.04	
Total	1.00	1.00	1.00	1.00

Table 2: Share of land that could become available for biomass production in North of the Netherlands according to three Refuel scenarios.

Type of land	Availability in % of land					
	Low		Medium		High	
	2015	2030	2015	2030	2015	2030
Arable	1.9	6.1	2.7	7.4	4.3	10.2
Pastures	0.5	8.6	0.5	8.6	0.5	8.6

Table 3: Crops included in the HELP system (Her-Evaluatie van LandinrichtingsPlannen – Re-evaluation of spatial planning) and new crops introduced including their relative sensitivity to drought and water damage

	Crop	Included in HELP	Assumed water and drought sensitivity
Annuals	summer wheat	No	The same as winter wheat, but more sensitive to drought.
	winter wheat	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)
	summer barley	No	The same specifications as winter wheat, but more sensitive to drought.
	winter barley	No	The same specifications as winter wheat
	feeding potatoes	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)
	seed potatoes	No	More sensitive to both drought and water damage then feeding potato
	industrial potatoes	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)
	sugar beet	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)
	rape seed	No	The same specifications as summer wheat
	maize	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)
perennials	Miscanthus	No	The same sensitivity to excess water as maize (Christian et al. 2001), but with slightly lower yield losses for dry conditions because of its deeper rooting system.
	switchgrass	No	It has a high tolerance to severe water stress conditions (Monti et al. 2008). Therefore it is expected to be more drought tolerant then Miscanthus (and certainly willow) and similarly tolerant to wet circumstances as Miscanthus.
	willow	No	Willow can withstand seasonal flooding but not permanent water-logging (DEFRA 2002). It is expected to be more tolerant to wet circumstances and more sensitive to drought then Miscanthus and switchgrass.
	grass	Yes	Derived from (Brouwer and Huinink 2002; Brouwer et al. 2003)

Table 4: Classification soil suitability as function of yield reduction due to water and drought stress.

Suitability classification	Yield reduction
very suitable	0-10%
high suitable	10-20%
suitable	20-30%
medium suitable	30-40%
low suitable	40-60%
marginally suitable	60-80%
very marginally suitable	80-100%

Table 5: The proportion of land that is more profitable under Miscanthus or more profitable under the current land uses of arable crop rotations on clayey soils and sandy soils, maize and grass

Current land use	Rotation Clay I	Rotation Clay II	Rotation Sand I	Rotation Sand II	Maize	Grass	Miscanthus
Rotation clay	0.00	0.85					0.15
Rotation sand			0.58	0.00			0.42
Maize					0.97		0.03
Grass						0.12	0.88
Total share of land of highest NPV	0.00	0.15	0.17	0.00	0.01	0.06	0.61

Table 6: Share of area where Miscanthus has better Net Present Value than current land use (ΔNPV is negative) in total and for different suitability classes.

Miscanthus on land currently in use for	very marginally suitable	marginally suitable	low suitable	moderately suitable	suitable	high suitable	very suitable	share of area where NPV Miscanthus> NPV current land use
Miscanthus-clay rotation	0.000	0.000	0.018	0.011	0.014	0.000	0.000	0.044
Miscanthus-sand rotation	0.000	0.002	0.045	0.019	0.052	0.082	0.004	0.203
Miscanthus-maize	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Miscanthus-pastures	0.005	0.007	0.196	0.079	0.191	0.192	0.083	0.753
Miscanthus Total	0.005	0.010	0.259	0.109	0.257	0.273	0.087	1[1]

[1] total share of land where Miscanthus has better Net Present Value (NPV) than current land use corresponds with 0.61 of total agricultural area (see total table 5).

Figure captions

Figure 1: Individual contributions of cost items and benefits to Net present Value (NPV) of individual crops, crop rotations, and perennial energy crops excluding subsidies

Figure 2: Net present value of perennials, typical rotation schemes and rotations schemes including an extra share of sugar beet (ES) for different soil suitability classes (excluding subsidies).

Figure 3: Map of ΔNPV (= NPV of current land use - NPV perennial energy crops) for the whole agricultural area of the North of the Netherlands. Negative value (light area) indicates where Miscanthus has a higher NPV than current land use. All cost items are included and subsidies are omitted.

Figure 4a: Cost supply curves for various crops in the North of the Netherlands for the total of agricultural land in the region. The first 'step' in the curves indicate the cost of biomass produced on very suitable soils, the second for high suitable…the last step of each curve indicates the cost of biomass produced on very marginally soils

Figure 4b: Cost supply curve of Miscanthus based on land availability from ΔNPV (Net present value) and distribution over soil suitability and the potential related to the land availability according to the Refuel study.

Figure 5a: spatial distribution of sugar beet production costs in €/GJ

Figure 5b: spatial distribution of Miscanthus production costs in €/GJ

Figure 6: Cost of ethanol production form various feedstock in the North of the Netherlands compared to petrol prices for various oil price levels (US$/Barrel). Least cost feedstock produced on very suitable soils are incorporated.

Figure 7: Sensitivity analysis for Net present value (NPV), cost of biomass and cost of ethanol of Miscanthus and sugar beet. Key parameters, discount rate, energy prices, labour wages, yield levels, commodity prices and efficiency of conversion, are varied between -100% and +100% of the original value

Potential, spatial distribution and economic performance of regional biomass chains: The North of the Netherlands as example

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