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Spatial distribution of economic viability of regional biomass chains: a case study of bioethanol production in the North of the Netherlands

The objective of this work is to assess the viability of regional biomass chains. The economic performance of potential bioenergy cropping systems is compared to the performance of current agricultural land use. Furthermore, bioethanol production costs are compared to average gasoline prices. Spatial heterogeneity of physical conditions is taken into account to determine the spatial variation in economic viability of bioenergy chains.

The regional biomass chains assessed in this study are ethanol production from Miscanthus and from sugar beet in the North of the Netherlands. The competitiveness of bio energy crops is assessed by calculating the Net Present Value (NPV) of currently applied rotation schemes, rotation schemes including an additional share of sugar beet and of Miscanthus. Costs of ethanol production are calculated taking into account costs of domestically cultivated crops, transport and conversion. The NPV's and cost of ethanol are calculated for seven categories of soil suitability. The spatial distribution of soil properties and current land use is used to map the spatial variation in competiveness and production costs using GIS (Geographical information System). Such a detailed spatial distribution of economic viability of bioenergy chains indicates were land use changes are most likely to occur.

The results show that both perennial bioenergy crops as well as an increased share of sugar beet are not competitive with current cropping systems when soil is equally suitable. However, on soils less suitable for annual crops yet quite suitable for less intensive managed crops, Miscanthus achieves a better NPV than common rotations. As sugar beet has high soil suitability requirements, for less suitable soils the NPV of a rotation with an increased share of sugar beet for ethanol production does not exceed the NPV of common rotations. The cost of bioethanol production from domestically cultivated crops is not competitive with gasoline at current oil prices levels. Bioethanol could become competitive when (increased) support for energy crops is provided for, conversion technologies improve and/or ethanol receives (partial) excise exemption. The method applied in this paper contributes to the identification of promising locations for bioenergy crops and could be applied to several regions and/or levels of analysis.

Key words: bioethanol, land use changes, economic viability

1 Introduction

In recent years, several studies have assessed the bioenergy potential at a global level, (Hoogwijk, 2005; Dornburg 2008; Smeets 2007) European level, (van Dam 2004, Fischer 2007; de Wit, 2008; EEA, 2008) or at a national level (Broek et al. 2001; Batidzirai et al. 2006; Styles and Jones 2007a). However, a limited number of studies are available about the spatial variation of potential and cost of bioenergy supply within a region. Since the physical environment is spatially heterogeneous, the production location is a key factor for the economic viability and the 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 and production costs of biofuels compared to conventional fuels. This contributes to an increase in the understanding of where and on which types of soils 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 as a case study.

Section 2, will elaborate on the selected region and bioenergy chains. In section 3, the methods applied and the data used to asses the economic viability will be discussed. The results of the assessment are presented and the spatial variation is depicted in maps of the region in section 4. A sensitivity analysis shows the level of robustness of the results. In section 6, the applied method, the data used and the results are discussed and in the final section, conclusions are drawn.

2 Case

2.1 Region

In this study the production of bioethanol from sugar beet and Miscanthus cultivated in the Northern region of the Netherlands (the province of Groningen, Friesland and Drenthe) is investigated.
The Northern region of the Netherlands is selected because of the clear reduction targets of fossil fuel use and green house gas emissions (CDA et al. 2007; Menkveld 2007; Ministerie van VROM 2007; Ministerie van Economische zaken 2008), the high the pressure on land and related competition between land use functions; the availability of extended infrastructure; the productivity of the agricultural area due to fertile soils, favourable climate conditions and advanced agro management (Romkes and Oenema 2004). Additional reasons are the interest in alternative economic activities in the agricultural sector and the articulated the aspiration of stakeholders to contribute to sustainable development in the region (Costa Due 2009; Energy Valley 2009) and the availability of (spatial) data, which makes it a suitable region to demonstrate a spatial methodology to assess economic viability of regional biomass chains.

Land use in the region is dominated by agricultural activities. Main part (68%) of the total area is agricultural land of which 41% is used for agricultural crops and 57% for pastures. Cereals, potatoes and sugar beet 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. They are depicted in table 1.

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; Voort et al. 2008) expressed in share of individual crop in each of the rotations.

Share of crop	Clay rotation		Sand rotation	
in rotation	I	II	I	II
winter wheat	0.57	0.20		0.05
summer barley		0.10	0.28	0.25
winter barley	0.20			
rye			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

2.2 Biomass Potentials in the region

In order to set a range for the potential available arable land for bioenergy production, information provided by the Refuel study is used (Wit and Junginger 2008). In this method, projections are developed to describe dynamics in population growth, food intake per capita, agricultural production intensity, livestock intensity and land claims for the growth of cities, villages and infrastructure (Fischer et al. 2007). The availability of land for biomass production is calculated by subtracting land needed

for other land use functions (including nature) from the total available land, assuming the self sufficiency of food production in the region remains constant. The base case scenario of the Refuel assessment is derived from the Common Agricultural Policy (CAP) of the EU. In addition, a more optimistic and a more pessimistic variant have been developed. Figure 1 shows the amount of agricultural land that could become available for biomass production in the North of the Netherlands in 2015 and 2030 according to the Refuel results.

Figure 1

2.3 Bioenergy chains

Sugar beet

Sugar beet is a domestic crop which is cultivated in The Netherlands for centuries. It requires good quality soils and high input levels. It is grown in rotation with cereals and potatoes. In our study, it is assumed that sugar beet for ethanol production is cultivated on land that is currently in use as arable land (hence pastures are excluded for this crop, according to the Refuel study). Therefore, the share of sugar beet needs to be increased within the current applied rotation schemes but it is assumed that the share of sugar beet will not exceed 25% of the rotation.

Since sugar beet can not be preserved, the harvest window is extended from September until end of December in order to maximize the load factor of the beet processing plant. It is assumed that the sugar beet is transported by truck to a newly built ethanol plant close to the current sugar plant. The conversion plant is assumed to have a scale appropriate for the expected supply of sugar beets in the region i.e. 810 kton input per year.[1] In the ethanol plant, sugar beets are shredded to cossettes and diffused in water to in order to produce raw sugar beet juice and pulp. Pulp is further processed for animal feed and put on the market as co-product. The raw juice is pasteurized, fermented and distilled in order to produce ethanol.

Miscanthus

Miscanthus is a perennial crop with a lifetime of 20 years, which does not require high inputs rates or optimal soil conditions (Venturi et al. 1999; Bullard 2001; Bullard and Matcalfe 2001; Lewandowski and Heinz 2003; Lewandowski et al. 2003; Khanna et al. 2008).

Following the Refuel study, it is assumed that Miscanthus can be cultivated on agricultural land that is currently in use as arable land or pastures. Although highest yields are achieved when harvested in autumn, harvest will not take place until spring when the highest dry matter content and quality is achieved[2]. The chipped Miscanthus is transported to a newly built lignocellulose ethanol plant by truck. It is assumed that Miscanthus is processed in an ethanol plant of 400MW input (190 kton odt annually), located closely to the harbour. Feedstock supply of the plant is derived form a combination of domestically cultivated Miscanthus and lignocellulose material from international supply chains. After physical size reduction, the cellulose is broken down to free glucose molecules by means of enzymatic hydrolysis (Hamelinck, 2004). In the fermentation step, the free sugars are converted to ethanol. Within the considered timeframe of this study, dilute acid pre-treatment, on site enzyme production, enzymatic cellulose hydrolysis, SSF configuration boiler and steam turbine are expected to be the most prominent technologies for converting lignocellosic crops to ethanol (Hamelinck et al. 2005).

3 Method and input data

[1] This figure is derived from the maximum available land in 2015 according to the Refuel study (9.6 kha, see figure 1) and the attainable yield on very suitable soils (73 ton_{fresh}/ha/y, 23% dmc, 16% sugar).

[2] Due to nutrient remobilization during winter, nutrient removal from the soil is lower in case of delayed harvest (Monti et al.; Himken et al. 1997; Ercoli et al. 1999; Lewandowski and Heinz 2003). Lower moisture nutrient and ash content is more beneficial for further processing

3.1 NPV calculations for crop production

In order to compare both annual and perennial crops, all costs and benefits related to the cultivation phase of conventional and energy crops are discounted to the net present value (NPV), see formula 1. The NPVs of rotation schemes are calculated by multiplying the NPV of the individual crops by their share in the rotation scheme (see table 3).

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

Equation 1: Net present value

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 costs and revenues of crop production depend on soil and climatologically conditions, economic environment and farm management system applied. All these parameters are regionally specific.
The costs related to crop production generally include four main categories of expenses:

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

The benefits related to crop production are the revenues from:

- selling the main product
- selling the co-product
- (European) subsidies for crop production

Overhead costs and cost related to general farm activities are not included. The data on field operations and inputs are based on (Schreuder et al. 2008) (PPO et al. 2006) for annual crops, on (Animal science Group 2005) and (Evers 2008; Roelofs 2008) for pastures; and on (Smeets et al.; Huisman et al. 1997; Bullard 2001; Christian et al. 2001; DEFRA 2002; Heller et al. 2003; Lewandowski et al. 2003; Styles and Jones 2007b; Boehmel et al. 2008) for Miscanthus, switchgrass and willow. It is assumed that nutrient requirements are met by fertilizer (N, P2O5, K2O) application and that no lime or magnesium is needed. Crop specific subsidies of 2006 ware provided to farmers who produced a particular crop in the reference period 2000-2002 (PPO et al. 2006).

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 based on the NPV has been demonstrated by e.g. (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 the co-product (i.e. straw).

All costs related to biomass transport (including costs of labour, fuel and depreciation of machinery) are incorporated as well as the costs and revenues for ethanol production (investment costs, O&M costs, costs energy and other inputs needed for the process and benefits related to the production of co-products).

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 included in this assessment, the most recent HELP (*Her-EvaluatieLandinrichtingsProject*) system, developed by Brouwer et al (Brouwer and Huinink 2002; Brouwer et al. 2003), was used. In this method, yield levels are determined by a combination of soil characteristics and water table levels in summer and winter. Separate yield reduction tables based on water and drought damage were developed for the most common arable crops and have been linked with the surfaces having the same soil-water table characteristics (at a grid level of 25mx25m) using GIS (Geographical information system) (Brouwer and Huinink 2002). The suitability classes used are depicted in table 6. The potentially suitable area includes the whole agricultural area excluding land in use for greenhouses and land within Natura 2000 (Nature conservation areas).

Table 6: 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%

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 relative share of suitability class per crop for current land use into account.

Because the management response to expected lower yields could be an increase or decrease in terms of inputs (fertilizer, pesticides etc), and is dependent on local circumstances and individual decisions, no general statements regarding increases or decreases in inputs can be made (Haverkort et al. 2008). Therefore, in this case study it is assumed that the input levels remain constant over different soil qualities and that revenues achieved determines whether a crop is grown at a specific location.

The NPV values of the crops for each soil suitability class are linked to the crop specific soil suitability maps. For the NPV of rotations, the individual map layers of the crops are combined in a spatial weighted summation for a final NPV map (in which weights represent the share of the individual crop in the rotation, see table 1). In addition to the NPV, the cost of feedstock production of Miscanthus and Sugar beet are calculated for every soil suitability class and linked to GIS maps.

4 Results

In figure 2, the NPV of perennial crops, typical rotations for the North of the Netherlands, and rotations including an increased share of sugar beet are depicted for different soil suitability classes. This figure shows that the NPVs decline for less suitable soils at all times. Because inputs and work rate requirement do not decline for less suitable soils (except for yield related cost 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 (NPV for soil suitability's)

Since soil suitability characteristics are not equal for every crop and perennial crops are more tolerant to water and drought stress, some production sites could be suitable for perennial crops but less suitable for rotation crops. For the whole agricultural area, the NPV of current land use has been compared to the NPV of potential land use of Miscanthus. This results in a 25mx25m grid map of ΔNPV (current land use - potential land use), see figure 3.

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Figure 3 (map of ΔNPV)

The green areas point out where the NPV of Miscanthus is higher than current land use. Most of these areas are currently in use for pastures and often too wet for arable crops. The red areas reflect the zones in which current land use is most profitable. These zones have fertile soils and are well suitable for profitable crop cultivation like potatoes and sugar beet. At these locations, it is very unlikely farmers are willing to switch to energy cropping systems from an economic point of view.

Cost of biomass

Taking into account the results presented in figure 3, a cost supply curve can be constructed for Miscanthus for the area where its cultivation is competitive with current land use (see figure 4). The numbers presented by the Refuel study regarding land availability for bioenergy crops (see section 2.1) indicate that only a small part of this potential can be exploited for bioenergy crops, without diminishing the self sufficiency level in the region (presented by black dots in figure 4). The least costs production areas are likely to be dedicated to bioenergy crops (most left part of the graph in figure 7b). This results in a potential supply of 2.7 PJ at a cost of 5.4 to 5.9 €/GJ. Nevertheless, this is most probably above the costs of biomass imported from abroad (Lewandowski and Faaij 2006). A similar cost supply curve for sugar beet as a bioenergy feedstock can not be made, since an additional share of sugar beet for ethanol production is not competitive with current land use.

Figure 4 (cost supply curve Miscanthus)

In figure 5, the spatial distribution of Miscanthus production costs is given. Comparing figure 3 with figure 5 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 better NPV than current land use have relatively low production costs. These are the most promising locations for Miscanthus production.

Figure 5 (map of feedstock production costs)

Costs of ethanol

In figure 6, ethanol production costs from sugar beet and Miscanthus are represented [€/GJ]. This figure is based on the least cost feedstock produced on very suitable soils. For comparison, the cost of gasoline is depicted. The difference between cost of bioethanol and gasoline is significant (>182%, assuming a price level of 62 US$/barrel). The contribution of capital and O&M cost are relatively large for ethanol production from lignocellulosic crops. The share of transport costs for ethanol from sugar beet is large due to the high moisture content of sugar beet.

Figure 6

If all competitive areas are dedicated to Miscanthus for ethanol, 25 PJ ethanol could be produced annually. However, the Refuel study indicated that only a minor share could be used for bioenergy crops. This results in an annual production of 1 PJ ethanol at a cost of 22.5 to 24.0 €/GJ. This is equivalent to 0.7 % of the total gasoline use in the Netherlands of 142 PJ in 2006 (CBS, 2008).

5 Sensitivity analysis

The NPV of Miscanthus and sugar beet are very sensitive for changes in yield levels and market prices of Miscanthus and sugar beet. The NPV of sugar beet is more sensitive for changes in labour and energy prices than Miscanthus. This is due to the relative intensive management that is applied. The cost of biomass is quite sensitive to changes in yield, especially for yield decreases. The cost of Miscanthus production is sensitive for changes in the discount rate unlike the cost of sugar beet. This is due to the uneven distribution of costs and benefits of Miscanthus in time. The impact of higher energy prices is different for the cost of ethanol production from Miscanthus and from sugar beet. When energy costs increase, cost of ethanol production from sugar beet increase due to higher feedstock and transport cost. Although, these costs increase for Miscanthus as well, this is by far compensated by an increase of value of the co-product of ethanol production of Miscanthus: Electricity. Therefore, for lignocelluloses ethanol the net effect is a decrease in ethanol production costs when energy prices increase.

6 Discussion

6.1 Economic approach

Although, the economic performance is assumed to be a main driver for the adoption of other agricultural systems by farmers, physical or more personal drivers affect land use change as well . Also, economic factors that are very specific for the individual farmer are not included in this study.

6.2 Method

Although the NPV is a widely adopted method to assess viability of corporate investments, it is not often applied for agricultural systems. Generally individual farmers do not include long term economic assessments in their decision making process. Therefore, the NPV does not necessarily represent the farmers' perspective.

In this study, the feedstock costs are expressed in €/GJ_{LHV}. However, biomass products can be valued for other characteristics than their heating value (namely: nutrition-value or potential substitution for precious products like rare pharmaceuticals). In this assessment, yield levels are only related to the soil suitability. Yield levels decrease could however also be caused by other factors, for example the management applied. Since this plays a role at the level of the individual farmer, it is not included in this study.

6.3 Input data

Although much information about typical rotation schemes and general management practices for conventional crops in this region is available, large varieties occur since every farmer has his own individual practices. This is especially true for pastures and additional benefits like extra manure application. In addition benefits and subsidies from cattle breeding and local enforced subsidies are not taken into account. Therefore, assuming general practices for pastures is a theoretical assessment.

Due to a lack of experience, there are uncertainties regarding input requirements (like rhizomes and fertilizer needs) and attainable yield levels of perennials and the performance of lignocellulose conversion technologies which can have large effects on the economic performance. This is also reflected by large inconsistencies found in literature.

Since the benefits of manure application depend on local circumstances and preferences, fertilizer costs are incorporated in our study for consistency reasons. This may possibly give an underestimation of the NPV and an overestimation of the production costs.

A very significant assumption in this study is that management is not altered for different soil suitability classes. Main reasoning here is that poorer soil qualities could require both higher and lower input rates (see section 3.3), since no general trend could be distinguished.

6.4 Results

The NPV's of crop production are very sensitive to market prices of agricultural products. These prices have fluctuated to a large extent last few years as is demonstrated by the FAO food price index (FAO 2009). Therefore, the results related to these prices need to be carefully interpreted.

As there are large uncertainties regarding management data of pastures and additional benefits, and differences in NPV's are small, the competitiveness of Miscanthus with pastures should be interpreted with care.

Since in our assessment a level playing field (in terms of subsidies) is assumed, the maps do not represent the actual situation but give an indication of which areas could become the most promising ones for energy crop production.

7 Conclusions

In this paper, the potential and economic viability of bioethanol chains in the northern region of the Netherlands differentiated for different soil suitability classes has been assessed. By these assessments it is explored which areas are most favourable for bioenergy crops.

The results of the NPV calculations show that an increased share of sugar beet for ethanol production can not compete with current cropping systems under present quota conditions and commodity prices. Most cost effective sugar beet production is on very suitable soils in the coastal area in the North of the region, but feedstock costs appear to be more expensive than Miscanthus. Lower investment costs of the ethanol production plant and higher conversion efficiencies of ethanol from sugar beet compared to ethanol from Miscanthus reduces the relative difference in bioethanol production costs. Nevertheless, ethanol from domestic produced sugar beet is significantly more expensive than gasoline 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.

The spatial analysis shows that Miscanthus could compete with current land use in areas where soils are suitable for Miscanthus yet less suitable for intensive-managed annual crops. However, this is only true when a level playing field is established (in terms of subsidies). Ethanol production of Miscanthus appeared to be the least cost option in this region, but is still far more expensive than gasoline (at a oil price level of 62$/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. Taken the land availability of the Refuel study into account, the contribution of ethanol from domestic cultivated feedstock would be less than 1% of the gasoline use in the Dutch Transport sector. This indicates a marginal potential for biofuel chains in this particular region, but it could contribute to meet the blending targets in the Netherlands for the near future.

The methodology applied in this study could be further improved by additional research regarding economic performance of pastures and new bioenergy crops. In addition, a more in depth assessment regarding the relation between management, soil suitability and yield levels is needed to comprehend the individual and location specific management choices.

This study provides a methodology to assess the economic viability of regional biomass chains by analysing the competitiveness of bioenergy crops compared to conventional agricultural land use and the spatial specific feedstock production costs taken into account the region specific parameters like yield levels, commodity prices and chain design. This methodology is also applicable to other regions and it could be applied to higher scale levels.

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