Polish Journal of Agronomy
2012, 9, 23–28

The sustainable agricultural land potential for energy crop production in Germany and Poland

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Abstract. Biomass is broadly applicable in the energy sector for power, heat and transport, but it is strongly restricted by its availability. If biomass is supposed to contribute to a more sustainable energy system, its limited potential needs to be respected. Especially energy crops are in heavy competition with food and fiber production, nature conservation and construction activity. This paper presents a model HEKTOR which helps to analyse the interdependencies between these various land uses. HEKTOR is a scenario tool that provides insight in the availability of agricultural land for the production of energy crops under sustainability restrictions on a national level. The model was applied to Poland and Germany. Two scenarios are presented: A 'business-as-usual' scenario is compared to a 'sustainability' scenario. On the one hand, the model quantifies the conflict of objectives between enhanced extensification in agriculture and increased area for nature conservation. On the other hand, the synergies in restricting construction activity are assessed. Our results show that the sustainable energy potential from energy crops is strongly restricted for Germany compared to its energy demand whereas in Poland domestic agricultural biomass provides a much higher potential for energy supply, even if sustainability is comprehensively considered. Still, strong interdependencies with other land use are found. For energy crops to remain a sustainable option in the energy sector, its influence on the food markets must be considered more thoroughly and a comprehensive approach to sustainable development in land use is a prerequisite.

key words: biomass, bioenergy potential, energy crops, available agricultural area, sustainability targets

INTRODUCTION

During the last years, biomass has been a key element in the strategy towards a higher share of renewable energy in Europe (EU-Kommission, 2005; EU-Commission, 2011), as biomass can be converted to power, to heat and to biofuels for transport. At the same time it has also become clear, that bioenergy use can pose a risk to sustainability, e.g. if no limits are set to its use (EU-Kommission, 2010; Chum et al., 2011). Especially energy crop production is in heavy competition with land use for food, which could be seen in 2007/2008, when biofuel support policies significantly added to food price increases (Doornbosch and Steenblik, 2007; HLPE, 2011). Land demand for fibre, nature conservation and construction activity increases this competition.

Thus bioenergy policies need to assess the share of available agricultural area, which can be allocated for energy crop production as well as its interdependencies with the above mentioned land uses. The complexity of this allocation problem is increased by the continuously increasing demand for food and fiber as well as yield improvements. Moreover, international trade dependencies can shift land use from the bioenergy consumer country towards the bioenergy producing country, resulting in land use change and associated CO_2-emissions that lead bioenergy use to the point of absurdity. The assessment of domestically available agricultural area is a prerequisite for further economic and trade related analysis. While there already exists a number of global modelling approaches that analyse various influence factors on the biomass potential (Berndes et al., 2003; Thrän et al., 2010; Beringer et al., 2011), national biomass potentials often only provide single estimations (EU-Commission, 2011) and modelling approaches are not yet available for all countries (Fritsche et al., 2004; Lewandowski et al., 2006).

This paper presents a model HEKTOR, which was developed for analysing these land use multi-interdependencies. It provides insights into the availability of agricultural land for the production of energy crops under sustainability restrictions on a national level. The model HEKTOR is a scenario tool for mid- to long-term analysis of sustainable biomass potential of the agricultural sector and has been in use for various studies (Fritsche et al., 2004; Si-

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Received 18 October 2011

mon, 2007). Due to the model's data basis it is easily adaptable and has so far been applied also to the Czech Republic, Hungary and partially to France (EEA, 2006; Simon and Wiegmann, 2009).

MATERIALS AND METHODS

The HEKTOR Model

The HEKTOR model (HEKtar-kalkulaTOR) allows analysing the interdependencies between land use for food demand, nature conservation and construction activity. It quantifies the availability of agricultural land for the production of energy crops under sustainability restrictions on a national level. The model was developed for several European countries including Germany and Poland. A detailed description of the model can be found in Simon (2007).

***Modelling approach*:** To disentangle the above described complexity of multi-inter-dependencies of land use, HEKTOR provides a bottom-up approach, starting with the regional interdependencies between economical restrictions and food demand as well as the political framework and its influence on agriculture. HEKTOR based on two major assumptions on land use change and land availability that account for sustainability restrictions:

Land use change can lead to additional CO_2 emissions that outweigh the CO_2 benefit of the energy crop, depending on the carbon sequestration of the previous land use. According to the IPCC the quality of land use in this respect is increasing from degraded or cropland over grassland to woody areas (Chum et al., 2011). Thus, HEKTOR restricts future agricultural biomass production to agricultural land. Land use change is only permitted from arable land towards grassland and perennials, while land use change from forest or grassland toward arable land is excluded. Due to the high nature value of grassland the current share of grassland is maintained. This also complies with the target of current agricultural policy to keep the share of permanent pasture at least constant (EU-Council, 2003).

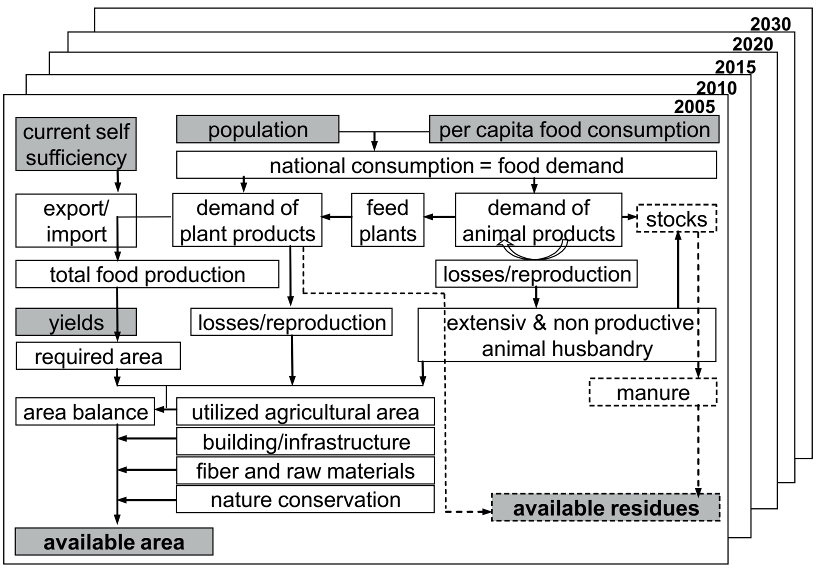

Figure 1. Flow chart for the potential model HEKTOR

The second basic assumption of the model is priority of food production on agricultural land. Other land use must be respected as well. Thus bioenergy can be produced on all agricultural lands, which are not in use for food and feed, raw materials, nature conservation and construction activity.

***Model structure*:** HEKTOR assesses agricultural land use for a time range until 2030, accounting for changes in food consumption, agricultural yield development as well as demographic changes. The model can be extended by a sub model, which assesses agricultural residue potential. HEKTOR is structured as a set of Excel-files. These files and detailed insight in the background data can be obtained from Simon (2007).

Figure 1 gives an overview over the model structure: Based on population and food demand per capita the model calculates total food demand of a country. Food consumption is converted to agricultural land use via crop yields and processes for animal production, based on the GEMIS Life Cycle Analysis Database (Öko-Institut, 2005) and additional agricultural data sources (see details in Simon, 2007; Simon and Wiegmann, 2009). The processes are available for various production intensities, including one organic process in each sector. The result is the required area for food demand which is then corrected via self-sufficiency rates towards national land use for food.

For the assessment of future food production, HEKTOR includes trends for the development of population, food consumption, yield increase and productivity in animal production. The trends are broadly based on statistical data on crops and animal production and food demand and population for the last decades from FAO and EU (FAOSTAT, 2004, 2005; EUROSTAT, 2006). Since the primary development of the model, statistical background data for population (with forecasts), yields and food consumption was continuously updated, based on European statistics (BMELV, 2009; EUROSTAT, 2011). The statistical basis and national focus make HEKTOR easily adaptable to other countries.

Besides trends in food consumption, HEKTOR also includes major aspects of the European common agricultural policy that influence the development of food production in the long term (DG AGRI, 2010).

In a next step, the required area for food demand is subtracted from the total utilized agricultural area of a country. The remaining area first covers land use for fiber and other raw materials, based on currently utilized area. Moreover, the additional land consumption for buildings and infrastructure is subtracted as well as additional land for nature conservation. The residual is the available area for energy crops.

This residual is highly variable over time. It strongly depends on technical developments in production and consumption – which are covered by the trends described above. Its variability is also strongly influenced by political decisions in the energy, food and nature conservation sectors. The latter cannot be assessed by trends, but can be analysed via scenarios, as described in the next section.

Scenarios

HEKTOR serves as a scenario tool for the assessment of future availability of agricultural land for energy crop production. Scenarios are if-then assumptions that can be used to assess future development pathways in a specific sector. They are tools to evaluate a set of uncertainties. A scenario is defined by a storyline, describing consistent specifications for the selected set of parameters.

Two scenarios are developed: The story line of the 'business-as-usual' scenario (BAU) follows a development along current trends without further political measures. This is compared to a sustainability scenario (SU), where a consistent set of sustainability targets is implemented for all considered land use. Both scenarios are applied to Poland and Germany.

Both scenarios follow current market prospects in the EU for the next decade: Meat production is shifting increasingly from beef to pork and even more to poultry, while the prospects for the milk sector are in general favourably. Self-sufficiency will remain constant, while stocks will decrease (DG AGRI 2010). The latter assumption ensures that food security is not compromised by increasing production of bioenergy.

Table 1 describes the distinctions between the two scenarios in both countries. These are made for the intensity of food production, land consumption and nature conservation targets. In the BAU scenario the area under organic farming is increasing slowly in both countries. Land consumption is currently much higher in Germany than in Poland, while the area under nature conservation restrictions is increasing only slowly (for details on the BAU scenario see also Simon (2007)).

For the sustainability scenario a set of targets was developed based on European sustainability targets. For organic farming the European action plan for organic farming (EU-Kommission, 2004) was translated into an increasing share in each country. In Germany the high intensity in agriculture demands a higher target of 30% for organic farming in 2030. For Poland the target is lower, however a conservation of currently existing high nature value farmland was additionally assumed.

Targets for land consumption and nature conservation for Germany were taken directly from the national sustainability strategy (Bundesregierung, 2003). In Poland the national environmental policy aims at afforestation (Polish Ministry of the Environment, 2009). For land consumption a slight decrease is assumed in Poland, based on the German sustainability target.

The scenarios were modelled with HEKTOR, calculating the available grass land and arable land. The primary energy potential is calculated from a cultivation mix. For arable land a mix of wheat, sugar beet, rape seed, short rotation coppice, maize silage and twin cultivation was assu-

Table 1. Description of the analysed Scenarios BAU and SU and targets for the year 2030.

Scenario	Business as usual Scenario (BAU)	Sustainability Scenario (SU)
Story line	Development along trends, no further measures	consistent sustainability targets in various sectors
Organic farming HNV farming#	Poland (PL) 8% Germandy (DE) 12%	PL10%, high share of HNV farming DE 30%
Land consumption for building activity	PL ~25 ha/d ↑ DE ~80 ha/d ↓	PL 20 ha/d DE 30 ha/d by 2020
Land for Nature conservation	trend	PL forest area ↑ + HNV farming DE 10% of land area
Market prospects	Shifting to pork and poultry; good prospects for milk + products	
Self sufficiency	stagnation	

HNV: High nature value (for details see EEA, 2007)

med with equal shares. Yield levels for energy crops were equal to food production. Further details are described in Simon (2007). For wheat, sugar beet and rape seed also the residues were considered, while maize silage and twin cultivation were accounted for through biogas yield. Also grassland was accounted for by the biogas yield of grass silage.

As a result the scenarios on the one hand quantify the increasing competition between enhanced extensification in agriculture, increased area for nature conservation and land for bioenergy. On the other hand, synergies for bioenergy by restricting land consumption for construction activity are assessed.

RESULTS AND DISCUSSION

Our results show, that in the BAU scenario the available arable area is increasing during the whole projection period to around 2.4 Million hectar (Mio. ha) in Poland and 2.1 Mio. ha in Germany. This provides an increasing potential for energy crops. In the SU scenario this is not the case. As arable land faces more restrictions, the available arable land in Poland stagnates around 1.8 Mio. ha until 2030, whereas in Germany only 0.9 Mio. ha are available in 2030. This development is mainly due to the increase in organic farming, which leads to a lower overall production intensity in animal and plant production and in turn a higher allocation of agricultural area towards food. However the availability of grass land is almost the same as in the BAU scenario, for Poland between 1.3–1.5 Mio ha in 2030 and for Germany around 1.1–1.2 Mio. ha.

Figure 2 shows the development of the available area in the two scenarios for Poland and Germany, as well as the development of land consumption for construction activity and additional land for nature conservation.

Figure 2 also shows that land use competition outside agriculture will have a large influence on the land availability. In the BAU scenario Poland will rededicate 0.6 Mio ha. and Germany 1.3 Mio. ha of agricultural land for other uses. In the SU scenario the rededicated area will be just slightly higher, as the reduced land consumption almost levels out the increasing nature conservation demand. Sustainability targets focusing on extensification thus need to be taken into account for national biomass potentials.

If the available agricultural area is converted into primary energy potentials as described above, the results show a slightly different picture (Figure 3). Even though land availability is higher in the BAU scenario in Poland, the primary energy potential for 2030 is lower at 540 PJ (Petajoule) compared to Germany with 550 PJ. This is due to lower intensity and thus lower yields in Poland. In the SU scenario Poland's primary bioenergy potential is still increasing to 420 PJ in 2030, while the potential in Germany stagnates around 280 PJ annually.

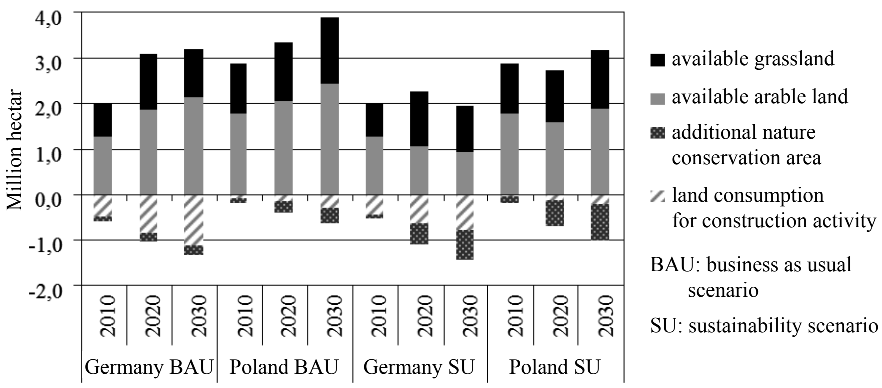

Figure 2. Available agricultural area for bioenergy and land demands for nature conservation and construction activity

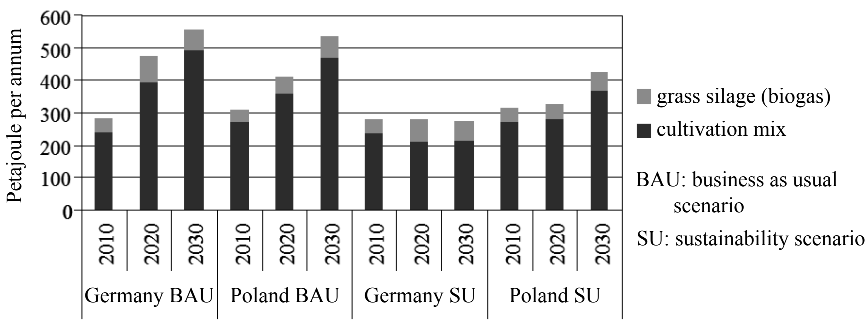

Figure 3. Primary energy potentials from agricultural area in the BAU and SU scenario for Poland and Germany.

To evaluate these primary energy potentials, they were compared to overall primary energy supply. Today's primary energy supply in Poland is around 4 EJ/a (Exajoule) (EUROSTAT, 2011). Thus primary energy supply from energy crops alone could serve 10% of Poland's current primary energy demand. For Germany this share is around 2–5% and thus much lower.

Compared to the agricultural biomass potential as assessed by the National Renewable Energy Action Plan (NREAP) for Poland (Polish Minister of the Economy, 2010), the biomass potential is higher than previously assumed. The National Renewable Energy Action Plan considers the primary energy potential from biomass for 2020 to be around 280 PJ, of which 120 PJ arise from agriculture. For 2020 the primary energy potential calculated from HEKTOR for energy crops alone varies from 325 PJ in the SU scenario to 410 PJ in the BAU scenario. Even under strong sustainability restrictions this is twice the amount of the National Renewable Energy Action Plan. This indicates that the sustainable biomass potential in Poland could be higher than previously assumed and biomass from agriculture could be mobilized even under strong sustainability restrictions and without endangering food security.

The variations in the results between the different scenarios as well as the comparison with the National Renewable Energy Action Plan show, how much biomass potentials from energy crops depend on assumptions of future developments and political measures in all land use sectors and vice versa. The much lower potential in the NREAP could result for example from a much higher estimation for future food exports or lower estimations on productivity increase. Single estimations of potentials always need to be reflected against the primary assumptions, which are not absolutely transparent in the case of the NREAP.

The large variations in results show, how strongly political measures e.g. in agricultural or nature conservation policy influence the biomass potential. A scenario approach thus helps to identify the band width of biomass potentials and models such as HEKTOR are necessary to quantify this corridor. If the bioenergy production in both countries exceeds the calculated values in both scenarios, this will be either on the cost of lower self-sufficiency for food, feed and fiber or on the cost of nature conservation. Restrictions on land use for construction activity will alleviate the competition.

For bioenergy from agricultural cultivation to remain a sustainable option in the energy sector, its influence on the food markets and nature conservation must be respected more thoroughly and a comprehensive approach to sustainable development in land use is necessary. Our results call for a more integrative approach in policy sectors that concern land use. Especially support schemes in agriculture and the energy sector need to be harmonized to avoid unsustainable developments, as seen in the past. Even though these harmonization efforts also need international agreements, they first need to start on national level. With HEKTOR we have provided a tool for such policy analysis.

CONCLUSION

The presented land use model HEKTOR provides the basis for scenario analysis for bioenergy potentials from energy crops on national level until 2030. Two scenarios develop a corridor for available agricultural area for energy crop production. Our results show that the sustainable energy potential from energy crops on agricultural land is restricted to 2–5% for Germany compared to its energy demand, whereas in Poland domestic agricultural biomass provides a much higher potential for energy supply of around 10%, even if sustainability is considered comprehensively. This indicates that bioenergy could play an even more important role in Poland in the future.

If the bioenergy production in both countries exceeds the calculated values in both scenarios, this will be on the cost of lower self-sufficiency for food, feed and fiber or on the cost of sustainability. For bioenergy from agricultural cultivation to remain a sustainable option in the energy sector, its influence on the food markets and nature conservation must be respected more thoroughly and a comprehensive approach to sustainable development in land use is necessary.

Our results call for a more integrative approach in policy sectors that concern land use, if biomass is supposed to remain a sustainable energy source. Especially support schemes in agriculture and the energy sector need to be harmonized to avoid unsustainable developments, as seen in the past.

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