Universität für Bodenkultur Wien
Department für Wirtschafts- und
Sozialwissenschaften

A modeling framework for the analysis of biomass production in a land constrained economy – the example of Austria

Bernhard Stürmer
Johannes Schmidt
Erwin Schmid
Franz Sinabell

Diskussionspapier
DP-51-2011
Institut für nachhaltige Wirtschaftsentwicklung

Mai 2011

University of Natural Resources and Applied Life Sciences, Vienna
Department of Economics and Social Sciences

A modeling framework for the ana lysis of biomass production in a land constrained economy – the example of Austria

Stürmer, B.[1], Schmidt, J.[1], Schmid, E.[1], Sinabell, F. [2]

Abstract

Ambitious renewable energy targets have been implemented in the EU that can only be attained if further measures are taken to boost biomass production for energy uses on agricultural land. The aim of this discussion paper is to explore consequences for land use and environment if biomass production will be expanded for non-food purposes in Austria. We assess the bio-physical and economic production potentials of energy crops and explore the trade-offs between bioenergy and food production on arable lands in Austria. In a policy experiment, we analyze how costly it is to expand domestic non-food biomass production by employing an integrated modeling framework using an elaborated set of bio-physical and economic data. The results indicate that an expansion of biomass production for first and second generation biofuels would imply significant adjustment costs for the agricultural sector. Furthermore, increasing feedstock production would have significant impacts on land use and fertilizer intensity levels. The economic analysis considers differences of regions and site conditions, which lead to higher opportunity costs, and hence, higher feedstock costs as assumed in previous studies. Subsidizing domestic biomass production likely leads to rising regional food and feed prices as well as factor prices (e.g. land renting) in a land constrained economy.

Keywords: land use competition, bioenergy, non-food and food crops, integrated modeling

[1] Department of Economics and Social Sciences, University of Natural Resources and Life Sciences (BOKU), bernhard.stuermer@boku.ac.at, johannes.schmidt@boku.ac.at, erwin.schmid@boku.ac.at
[2] Austrian Institute of Economic Research (WIFO), franz.sinabell@wifo.ac.at

1 Introduction

The topic of this discussion paper is to explore the conditions under which an expansion of bioenergy crops on agricultural land is a viable option in a land constrained economy. Such a scenario is analyzed for the case of Austria. Agricultural production conditions in this country are typical for central Europe. In Austria, land is constrained because of two major factors: a) settlement areas are expanding (at a rate of approximately 20 hectares per day) thus continually reducing land available for agricultural production, and b) strict forest laws make it virtually impossible to reclaim land that has turned to forest land.

In such a setting, the options to produce more biomass are to (i) mobilize fallow land, (ii) change agricultural land covers e.g. from grassland to arable land, (iii) use previously abandoned residues or waste products, (iv) reduce losses at field and storage, (v) plant crops with higher yields, and (vi) employ more intensive production methods. All these options imply opportunity costs that vary across the country because natural and economic conditions are heterogeneous. We have developed an integrated modeling framework that is capable to account for both, natural and economic heterogeneity and which can be used to derive supply functions for bioenergy crops at regional to national levels.

The implementation of policies to promote biofuels has triggered a large number of studies that explore the production potential on agricultural land as well as the consequences for land uses at a continental scale. Several studies show that there are considerable resources available for an expansion of biomass production in Europe without significantly affecting the supply of food crops (e.g. HENZE and ZEDDIES, 2007; VAN DAM et al., 2007; KRASUSKA et al., 2010; FISCHER et al., 2010a,b; DE WIT and FAAIJ, 2010). Austria is among the countries covered in these studies. We make an attempt to identify the concrete conditions under which an expansion of bioenergy crop production is a viable policy option. We demonstrate a bottom-up approach to quantify the bio-physical and economic production potentials at municipality level using a detailed set of administrative data on agricultural land uses. By taking into account the observed agricultural production structure, we are able to identify the activities that have to be abandoned or scaled down to provide land for bioenergy crop production. This approach is complementary to the bird's eye view taken in the studies cited above. The economic potential is assessed by considering spatially explicit opportunity costs in expanding domestic bioenergy crop production.

Given that global markets of agricultural commodities are linked by trade, it is evident that market interventions at a national level have spill-overs on other countries. Several studies have already shown the likely direct and indirect land use changes triggered by the implementation of biofuel policies in the EU (BANSE et. al. 2008) and the U.S. (SEARCHINGER et al., 2008). The debate following the publication of SEARCHINGER et al. (2008) shows that disentangling the intricate consequences of bioenergy policies is difficult and controversial (MATHEWS and TAN, 2009). Even at the national level, bioenergy policies from different fields often interact in a non-anticipated way. An example is Germany where a subsidy on electricity generated by biogas has resulted in surging land rents, limiting the production of food crops (GÖMANN et al., 2007) and the availability of crops for biofuels (BREUER and HOLM-MÜLLER, 2007).

In this strain of literature, our discussion paper is addressing four different aspects using Austria as an example:

- The integrated modeling framework: In order to quantify many of these unintended side effects, we have developed an integrated modeling framework to analyze bio-physical and economic biomass production potentials and consequences at site as well as municipality to national levels.
- The trade-off between food and non-food crop production: We present a policy experiment that allows a quantification of the consequences of a scheme promoting bioenergy crops on the local supply of crops for food production. Aggregated at the national scale, the consequences for the supply balances of food production become evident.
- The potential benefits of advanced technologies to mitigate trade-offs: The introduction of new technologies i.e. second generation biofuels is widely seen as an opportunity to a) make available resources which cannot be used to date, and b) make use of crops with higher biomass yields. The effects of such technologies on land use change at global scale have recently been investigated by HAVLIK et al. (2010). For the case of Austria, we explore a possible scenario for the production of feedstock of second generation biofuels on agricultural land focusing on b).
- The impacts on land use and crop management intensity: The expansion of bioenergy crop production does not only change land use patterns but also changes the intensity of crop production and management variants.

The discussion paper is structured as follows: In the next section, we briefly review the policies that are implemented to stimulate the use of biomass for renewable energy production. Without policy intervention, the production of bioenergy would be at a much lower scale than currently observed. We describe a policy scenario to stimulate bioenergy crop production and we explore the difference between this scenario and actual policies in place. In the following section, we describe data and the modeling framework, which is a link of the models CropRota, EPIC and BiomAT. Results are presented in the subsequent section. The final section summarizes and concludes.

2 The context of the study

In Europe, the production of first generation (1G) biofuel based on cereals, sugar and oil crops is not commercially viable without policy intervention. The transportation sector of the European Union is mainly dependent on non-renewable fuels (EACI, 2008). In an attempt to reduce the EU greenhouse gas emissions, the European Commission has set a binding minimum target of 10% of total transport energy consumption for the use of renewable energy sources by 2020 (Directive 2009/28/EC). EU Member States are required to implement regulations in order to attain these targets. The main purpose of mandatory national targets is to provide planning certainty for investors and to encourage continuous development of technologies which generate energy from all types of renewable sources.

High investments are necessary to produce second generation (2G) biofuels. They are mainly produced from lignocellulosic non-food crops and are therefore considered as sustainable alternative to 1G biofuels which are produced from food and feed crops. The latter ones have caused the development of a food-versus-fuel debate particularly in the food crises of 2007/2008 (SIMS et al., 2010; NAIK et al., 2010).

2G biofuels are expected to avoid several problems associated with 1G biofuels (e.g. direct competition with food and feed), because waste and forest products can be used as primary resource (IEA and OECD, 2009). The consequences for direct and indirect land use and environmental impacts remain unclear, particularly if 2G feedstock is produced on agricultural land. Although the main feedstock for 2G production is expected to come from wastes and forest residues, agriculture is likely to supply biomass such as straw, grass or wood from short rotational plantations.

Currently, 2G ethanol and diesel are only produced in pilot facilities. Technical problems and high production costs pose barriers to commercial production (NAIK et al., 2010; LONDO et al., 2010). Several authors expect lower unit costs, less direct and indirect land use change effects as well as higher CO_2 reduction potentials, once 2G biofuel production is widely adopted (NAIK et al., 2010; SUURS and HEKKERT, 2009). SIMS et al. (2010) expect considerable cost reduction for 2G biofuels by 2030. Political regulation also fosters the development of 2G biofuels.

In 2008, a blend of 5.75% biofuels was required by the Austrian regulation (Kraftstoffverordnung 1999 i.d.f. BGBl. II Nr. 168/2009). In Austria, biodiesel is produced in several processing plants with an annual capacity of 650,000 t. Ethanol is produced in a plant with an annual capacity of 190,000 t (BIOKRAFT AUSTRIA, 2010). Rapeseed is the main feedstock for biodiesel, whereas corn, wheat and sugar beets are used for ethanol production. Only 10% of biodiesel is produced from domestically harvested rapeseeds, while most of the feedstock of ethanol is grown in Austria.

3 Materials and Methods

3.1 The bio-physical data

Deterministic bio-physical process simulation models usually require homogeneity with respect to data inputs i.e. soils, climates, topography, and land use management. Therefore, a set of homogeneous response units (HRU) have been derived to capture the heterogeneity in the natural production conditions of Austrian agriculture (Figure 1). In particular, data on elevation, slope and soil types have been classified to delineate 443 HRU for Austria. Climate and land use data are not directly part of the HRU, but have been merged with the 1 km² HRU raster layer in a consecutive data processing step. Consequently, only those parameters of landscape have been used in the HRU delineation, which are relatively stable over time and hardly adjustable by farmers. It allows assessments of climate change impacts as well as consistent integration in economic land use optimization models (see chapter 3.3). The HRU delineation classes are as follows and correspond with the HRU coding in Figure 1:

Elevation classes: 1 (≤300 m), 2 (>300 m – ≤600 m), 3 (>600 m – ≤1100 m), 4 (>1100 m – ≤1600 m), 5 (>1600 m – ≤2100 m), and 6 (>2100 m);

Slope classes: 1 (≤5%), 2 (>5% – ≤10%), 3 (>10% – ≤15%), 4 (>15% – ≤30%), 5 (>30% – ≤50%), 6 (>50% – ≤100%), and 7 (>100%);

Soil classes: 1 (Auboden), 2 (Braunerde), 3 (Gley), 4 (Bodenformkomplex), 5 (Moor), 6 (Anmoor), 7 (Pseudogley), 8 (Rendsina, Ranker), 9 (Reliktboden), 10 (untypischer Boden), 11 (Schwarzerde), 12 (Salzboden), 13 (undefinierter Boden), 14 (Rohboden), 15 (Podsol), and 99 (soil information is supplemented from the EU soil database);

The elevation and slope data are extracted from the global Shuttle Radar Topography Mission digital elevation model (SRTM) developed by NASA (http://www2.jpl.nasa.gov/srtm). SRTM is available in 3'' horizontal resolution (approximately 90 m at the equator) and the altitude measure units are meters above sea level. The soil data is extracted from the Austrian Soil Map (eBOD, 2009) provided by the ministry of agriculture and the Federal Research and Training Centre for Forests, Natural Hazards and Landscape. The soil database contains data on soil attributes by soil layer including silt, sand and clay contents, humus content, pH, calcium carbonate content, and coarse fragment content. Since the Austrian Soil Map does not cover all areas it has been supplemented with data from the EU soil database (Balkovic et al., 2009a, 2009b). The agricultural land use data is extracted from the IACS database (BMLFUW, 2008a). It has been processed to provide average crop shares, which are input to CropRota to delineate typical crop rotations at municipal level.

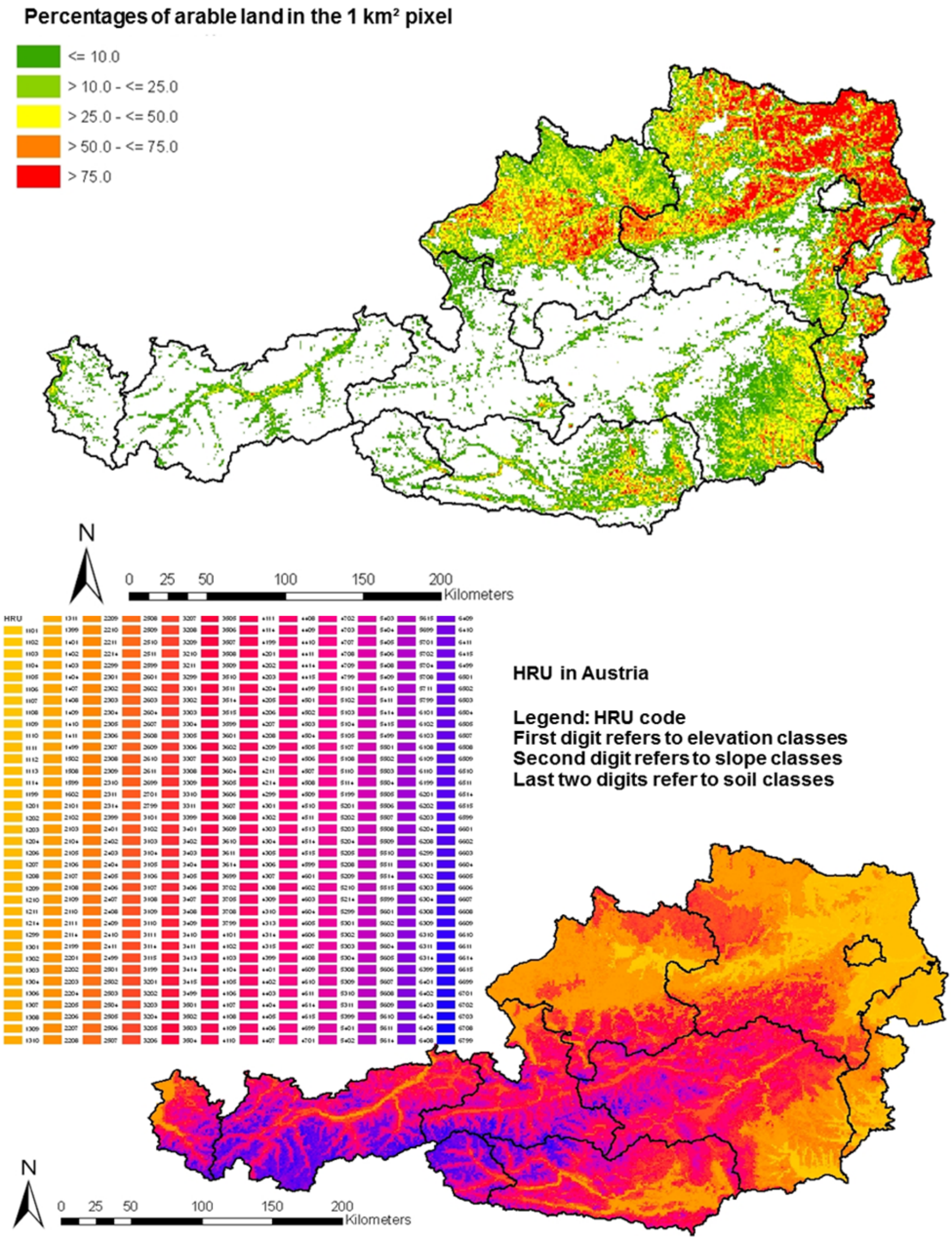

Figure 1: Percentages of arable land in the 1 km² pixel and Homogeneous Response Units (HRU) in Austria

The daily weather data for temperature, precipitation, solar radiation, relative humidity, and wind speed are provided from ZAMG (Central Institute of Meteorology and Geodynamics) for 30 Austrian weather stations from 1975 to 2007. The data have been processed to delineate 60 climate clusters for Austria (STRAUSS et al., 2010). Furthermore, STRAUSS et al. 2010 have developed a statistical climate change model to produce climate change data for all 60 climate clusters until 2040. Figure 1 shows the Homogeneous Response Units for Austria as well as the percentages of arable land in the 1km² pixel, which is the area of interest for the analysis.

3.2 The economic data

The economic data contains calculation of gross margins (= revenues minus variable costs) for standard crop rotations and livestock units in Austria. The reference situation is based on standard gross margin calculation assuming that output and input prices are the same across Austria (BMLFUW, 2008b).

The variable crop production costs consist of fertilizer, plant protection, machinery operation, harvesting, seed, and insurance costs. For each municipality, an aggregated gross margin of animal production has been calculated using observed livestock numbers from the IACS database as well as standard gross margin calculations (BMLFUW, 2008a, 2008b), which are part of the opportunity costs of biomass production in the municipality.

The revenues per hectare from crop production have two components namely market revenues (tonnes of crop per hectare multiplied with market prices per tonne) and agri-environmental payments if applicable. In the agri-environmental program, farmers receive payments if production is extensified and particular management measures are implemented. Therefore, we have classified three input farming systems with corresponding average agri-environmental payments including (i) standard production (no subsidy); (ii) reduced input farming (50 € ha^{-1}); and (iii) low input farming (115 € ha^{-1}).

Producer prices and input costs for 2008 are based on survey data from Statistik Austria (2009b). The price and costs forecasts for 2020 and 2030 are based on forecasts from OECD and FAO (2008) and extrapolations. We use price projections of EU prices, world market prices of oil and the US-EUR exchange rate to derive Austrian producer prices and costs. We make the assumption that deviations from EU prices observed in the past will prevail in the future. The trend for producer prices is derived from OECD and FAO forecasts and extrapolated linearly to 2030.The producer prices and the variable costs for the years 2008, 2020 and 2030 are shown in Table 1.

Table 1: Producer prices [€ (t FM)$^{-1}$] and variable production costs [€ ha^{-1}] for major crops in Austria in 2008, 2020 and 2030

Crop	DM content	2008 price	2008 costs	2020 price	2020 costs	2030 price	2030 costs
Winter wheat	0.85	134.7	373.1	152.3	414.1	154.4	421.6
Winter rye	0.85	132.6	333.2	159.1	369.9	154.4	376.5
Sommer barley	0.85	125.5	346.7	127.9	384.8	124.4	391.8
Winter barley	0.85	125.5	353.0	127.0	391.8	124.4	398.9
Durum wheat	0.85	211.0	360.8	222.6	393.3	225.4	400.5
Triticale	0.85	112.4	350.4	142.8	388.9	137.6	396.0
Oats	0.85	109.0	330.7	141.4	367.1	138.6	373.7
Corn	0.85	89.7	529.1	148.8	571.4	148.8	582.0
Sunflowers	0.85	214.5	426.2	351.2	451.8	359.8	460.3
Rapeseeds	0.85	345.0	320.0	353.0	367.9	359.6	374.6
Horsebeans	0.85	171.8	317.6	232.0	339.8	237.8	346.2
Peas	0.85	173.5	319.9	137.5	342.3	141.8	348.7
Soybeans	0.85	327.7	353.4	294.4	378.1	303.6	381.7
Cornsilage	0.35	24.0	395.3	24.0	423.0	24.0	430.9
Sugar beets	0.20	27.8	1,025.7	26.4	1,097.5	26.4	1,118.0
Potatoes	0.20	95.7	1,594.8	50.0	1,658.6	50.0	1,674.5
Vegetables	0.20	120.0	1,875.9	168.0	1,875.9	168.0	1,875.9
Fallow	0.85	0.0	120.9	0.0	130.6	0.0	133.0
Grass-clover	0.85	124.6	466.4	132.0	513.0	132.0	522.4
Alfa alfa	0.85	129.0	373.9	138.0	422.5	138.0	430.0
Grass	0.85	129.0	466.4	138.0	513.0	138.0	522.4
Clover	0.85	124.6	433.1	132.0	480.7	132.0	489.4
Poplar (10 year harvest)	1.00	75.0	34.2	90.0	34.2	90.0	34.2
Poplar (3 year harvest)	1.00	75.0	19.6	90.0	19.6	90.0	19.6
Energy grass-clover	0.85	120.0	470.0	120.0	517.0	120.0	526.4
Energy grass	0.85	120.0	470.0	120.0	517.0	120.0	526.4
Energy wheat	0.85	134.9	360.0	134.9	399.6	134.9	410.4
Energy rye	0.85	124.8	335.0	124.8	371.9	124.8	378.6
Energy triticale	0.85	137.8	352.0	137.8	390.7	137.8	397.8
Energy corn	0.85	138.0	530.0	138.0	572.4	138.0	583.0
Energy sugarbeets	0.20	17.6	1,023.0	17.6	1,094.6	17.6	1,115.1
Energy sunflowers	0.85	345.1	428.0	345.1	453.7	345.1	462.2
Energy rapeseeds	0.85	349.8	339.0	349.8	369.5	349.8	376.3

Source: Statistik Austria (2009b); own estimates; prices and costs in 2020 and 2030 based on OECD and FAO (2008) forecasts. Except for poplar, prices refer to the wet product

3.3 The modeling framework

The data described in the previous sections are used in a sequence of model applications that are organized to produce two major outputs for food and non-food crops at HRU and municipality level:

- bio-physical impacts i.e. crop yields, nitrogen emissions and soil organic carbon changes, and
- producer surpluses as well as economic biomass production potentials.

The crop rotation model CropRota (SCHÖNHART et al., 2011), the biophysical process simulation model EPIC (Environmental Policy Integrated Climate; WILLIAMS, 1995), and the economic biomass optimization model BiomAT (ASAMER et al., 2011) are sequentially applied to produce spatially explicit results on the economic potentials of food, feed, and bioenergy crops (Figure 2). Most of the model outputs are designed to be fed into another model, however, the results of each step are of interest as well.

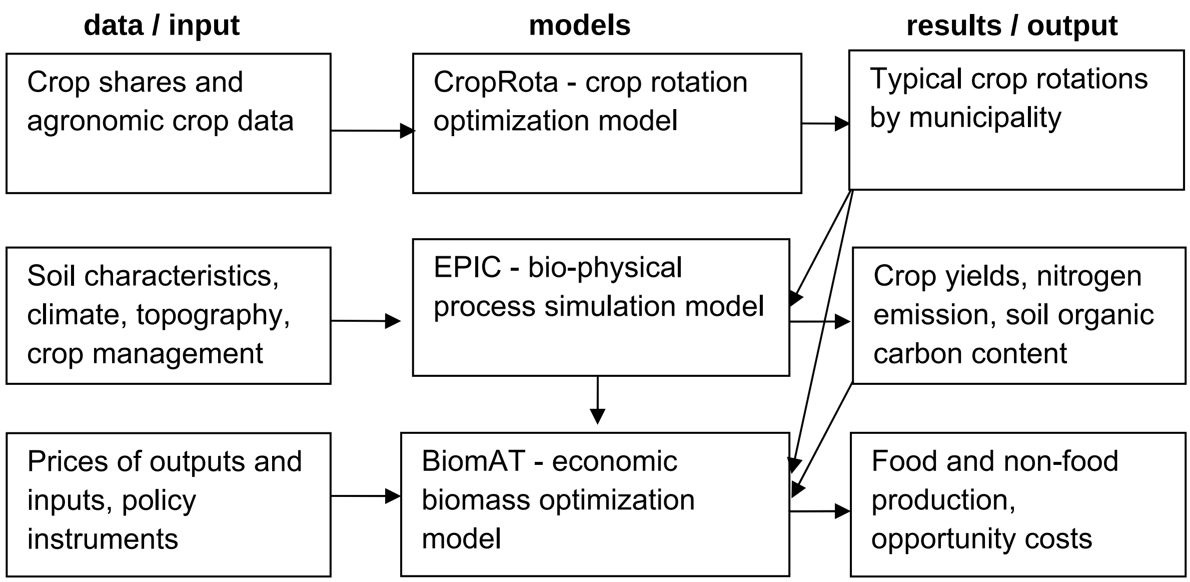

Figure 2: The modeling framework – data – models – outputs

The crop share and other agronomic data (i.e. crop sequence value matrix) are used in the crop rotation model CropRota to derive typical crop rotations at municipality level. The CropRota model has been validated in a farm case study analysis in Austria (SCHÖNHART et al., 2011). Currently, we use 22 crops (see table 1), which represent about 89% of total arable land in Austria. We assume that the crops can be utilized either by food, feed, or bioenergy purposes. CropRota has produced up to 25 different crop rotations per municipality with one to five crop sequences. These crop rotations are used in EPIC for bio-physical impact simulations as well as in BiomAT for economic biomass potential assessments. The bio-physical impacts are simulated with EPIC (Environmental Policy Integrated Climate; WILLIAMS, 1995) using the HRU data as well as weather and crop management data. EPIC is an agro-ecosystem model, which has been developed over more than three decades to simulate major processes in agricultural land management such as evapotranspiration, erosion, mineralization, nitrification and respiration (IZAURRALDE et al., 2006). The bio-physical impacts of 22 crops i.e. crop rotations and poplar coppice plantations are simulated for a 30-year simulation period with respect to different climates, soil and management regimes across Austria. The nationally average crop yields by farming system are listed in Table 2. The impacts on nitrogen emissions and soil organic carbon changes are not reported, but can be provided upon request.

Table 2: Average and standard deviation of simulated crop dry matter yields for three levels of production intensity in t ha^{-1}

Crop	standard input farming		reduced input farming		low input farming	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Alfa alfa	5.84	1.84	6.88	1.53	7.42	1.99
Barley	4.92	0.56	4.40	0.62	2.01	0.72
Clover	7.10	1.77	9.33	1.94	8.72	1.92
Corn	8.38	1.43	7.81	1.45	6.02	1.38
Vegetables	4.08	1.83	3.97	1.74	3.81	1.70
Cornsilage	14.28	2.98	13.86	2.87	11.66	2.64
Durum wheat	3.64	0.31	3.47	0.31	2.30	0.55
Horsebeans	3.75	0.24	3.72	0.22	3.69	0.23
Fallow	-	-	-	-	-	-
Peas	3.57	0.42	3.51	0.40	3.46	0.40
Grass-clover	7.30	3.49	10.06	3.35	9.79	3.25
Oats	4.88	1.30	4.20	1.41	2.93	1.35
Potatoes	4.59	1.91	4.59	2.06	3.62	1.82
Spring barley	4.42	0.90	4.00	0.96	2.97	1.02
Sugar beets	11.55	1.61	10.30	1.54	7.97	1.67
Soybeans	2.69	0.32	2.64	0.33	2.58	0.32
Sunflowers	2.63	0.43	2.24	0.50	1.74	0.55
Grass	8.92	1.74	8.18	1.91	6.91	1.54
Triticale	5.14	0.67	4.67	0.69	2.70	1.00
Rapeseeds	2.73	0.34	2.62	0.28	1.30	0.44
Winter rye	5.12	0.79	4.71	0.84	2.80	1.03
Winter wheat	5.29	1.10	4.57	1.22	2.32	0.96
Poplar	5.85	1.01	-	-	5.16	1.08

Source: own results based on EPIC simulations.

The model outputs of EPIC and CropRota serve as inputs in BiomAT, which is an economic biomass optimization model for Austria. BiomAT maximizes total gross margins (TGM) from food and non-food crop production options (i), which can produced on arable lands available in the HRU and municipality (h). The average gross margins (c) per hectare include revenues and costs from food and non-food production options as well as average agri-environmental payments and livestock gross margins at municipality level.

The linear program of BiomAT is given by

$$\max TGM = \sum_{h,i} (c_{h,i} x_{h,i})$$

$$s.t. \quad \sum_{i} \left(A_{h,i} x_{h,i}\right) \leq b_h \quad \textit{for all } h$$

$$x_{h,i} \geq 0$$

where the variable $x_{h,i}$ denotes the level of production of food and non-food crops as well as intensity level in the HRU and municipality (*h*). The parameter $c_{h,i}$ denotes the average gross margin from food and non-food crop production. Production activities are described in form of a Leontief production functions in the coefficient matrix ($A_{h,i}$) and arable land available in the HRU and municipality (h) are denoted by parameter b_h .

4 The policy simulation experiment

The economic potential analysis focuses on feedstock supply responses for first and second generation biofuel production by implementing premiums for biomass production. The situation observed in Austria in 2008 refers as the reference situation. We are interested in the costs of a further expansion of bioenergy crops given that

- arable land is limited to the acreage observed in 2008, and
- bioenergy crops displace crops planted for other purposes i.e. food, feed.

This scenario is not tailored to a policy in place or under review but attempts to show the implications of bioenergy policies in a stylized setting. The notion of such a scenario is that we assume an equilibrium state of food, feed, and bioenergy production in the reference situation (which was observed in 2008). In the policy experiment, a further expansion of bioenergy crops is only possible if other production activities are reduced in a likewise manner. Such a reduction may imply a loss of farm profits unless the production of bioenergy is at least as economical as the abandoned production activity. In the policy experiment, this is facilitated via an increasing subsidy for bioenergy crops per tonne of dry matter (DM). In regions with low opportunity costs, a low subsidy will be sufficient to switch from food or feed production to bioenergy production. In regions with high opportunity costs, higher subsidies have to be granted in order to boost bioenergy crop production.

A mechanism that would implement such an experiment is accommodated in a public auction asking for the minimum subsidy for one tonne of DM of domestically produced biomass crops. Incoming bids would be ordered according to the height of the requested subsidy. The rising subsidies would represent the supply curve at the currently given market conditions. We expect that such a supply curve is much more inelastic than the supply of biomass crops from the world market.

In the quantitative analysis, we explore the consequences of three scenarios:

- 1G_2020: subsidy for cereals and oil crops for 1G biofuel production in 2020.
- 1G_2030: same assumptions as 1G_2020 for the year 2030.
- 2G_2030: subsidy for grass and short rotation poplar grown on arable land for 2G biofuels production in 2030.

We calculate the supply responses of bioenergy crops to subsidies ranging from 0 to 200 € (t DM)$^{-1}$.

5 Results

5.1 Effects of subsidies for bioenergy crops on land use

A subsidy for bioenergy crops is granted ranging from 0 to 200 € (t DM)$^{-1}$ in the policy scenario for the years 2020 and 2030. The supply response of this policy experiment is shown in Figure 3. Assuming that the acreage of land is fixed and that bioenergy crops cannot be imported, a subsidy of 40 € (t DM)$^{-1}$ is sufficient to induce the production of 1G bioenergy crops on 350,000 hectares (equivalent to more than a quarter of the total of 1,3 million hectares of arable land) in Austria. Such an acreage will be used for 2G bioenergy crops (poplar and grass) only if subsidies are considerably higher (approximately 70 € per t DM).

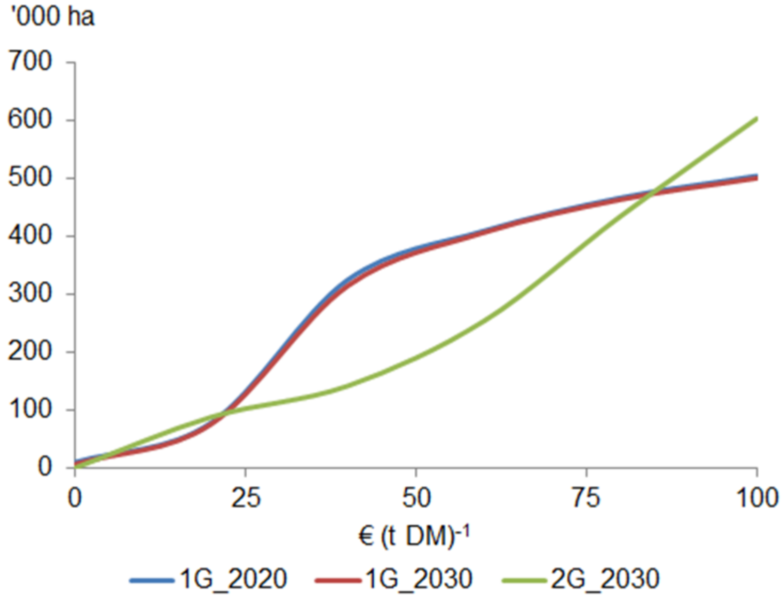

Figure 3: Changes in the total area of 1G and 2G energy crops by biomass premiums

Figure 3 shows an interesting detail: From an economic perspective, 1G crops are less competitive during the phase of a light expansion of bioenergy crops (up to a subsidy of 20 € (t DM)$^{-1}$ which induces production on 100,000 hectares). But above this threshold, 2G crops become less competitive until another threshold at subsidies of approximately of 80 € (t DM)$^{-1}$. The reason for these results relies in the total revenues of crop rotations over a longer time period. While wheat for food or feed production is easily changeable with wheat for energy production, poplar is planted for 30 years and has to be economically competitive with all other possible crop rotation combinations within that period.

The expansion of bioenergy crop production does not take place in a uniform pattern. Crop yield differences, regional crop rotations and a given level of animal production in the municipalities lead to different spatial patterns of energy crop production in 1G and 2G scenarios. Figure 4 shows the regional distribution of bioenergy crop production for two levels of biomass subsidies in Austria. The 1G scenarios for 2020 and 2030 are very similar (see first and second row of Figure 4). In the 2G scenario, relatively more biomass is produced in the South of Austria. A shift of production can be seen from the North-East to the South of Austria due to higher crop yield potentials of 2G compared to 1G bioenergy crops.

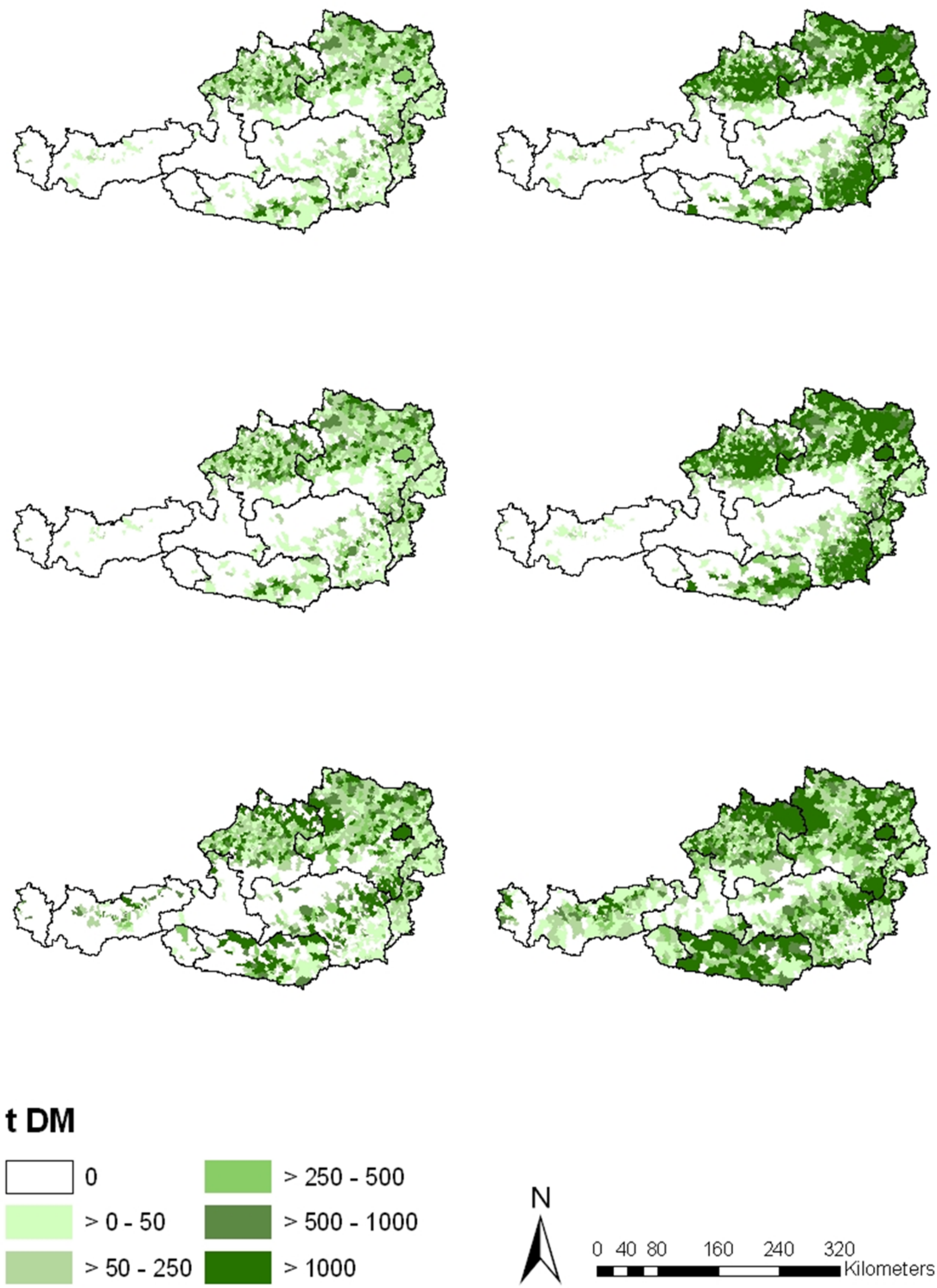

Figure 4: Regional biomass production in t of DM of six scenarios (1st row: 1G_2020, 2nd row: 1G_2030, 3rd row: 2G_2030) and premium level [left: 20 € (t DM)$^{-1}$; right: 60 € (t DM)$^{-1}$].

Given the assumption that the arable land is constrained, increasing an expansion of bioenergy crops implies that the acreage for food and feed crop production is decreasing. Wheat and corn are the crops which are most easily switched from food and feed to energy production. At low additional incentives the substitution between food and non-food crops are marginal, however, increase with the level of premium. The promotion of 1G feedstock does not change the relation of field crop categories, i.e. the type of crop planted. This is not the case in the 2G scenario: short rotation poplar plantations cause a decrease in the area of all the other crops. Land which is well suited for wheat production usually is also well suited for 2G bioenergy crop production. Therefore 2G bioenergy crops replace mainly wheat and other crops. The utilization of grass-clover and grass is deviated from feed to energy production.

5.2 Effects of subsidies for bioenergy crops on production intensity

In the BiomAT model, it is possible to simulate the effects of different prices and subsidies on farm management choices. The model differentiates between standard input farming systems, reduced input farming systems (less fertilizer and pesticides), and low input farming systems (no commercial fertilizers). Bioenergy crops are produced using standard input farming systems. An expansion of these crops therefore induces a displacement of crops produced by lower input farming systems, particularly if subsidies to bioenergy crops are high (e.g. 200 € per t DM). This result is due to the assumption that the Austrian agri-environmental program will stay in place. In this program, farmers receive subsidies for reduced and low input farming systems. The Austrian agri-environmental program and the nitrogen price for plant nutrition pose economic barriers to intensification. Consequently, the trade-offs between crop production intensity increases with raising premium for biomass production. Hence, the acreage of reduced input farming systems is rapidly decreasing (Figure 5).

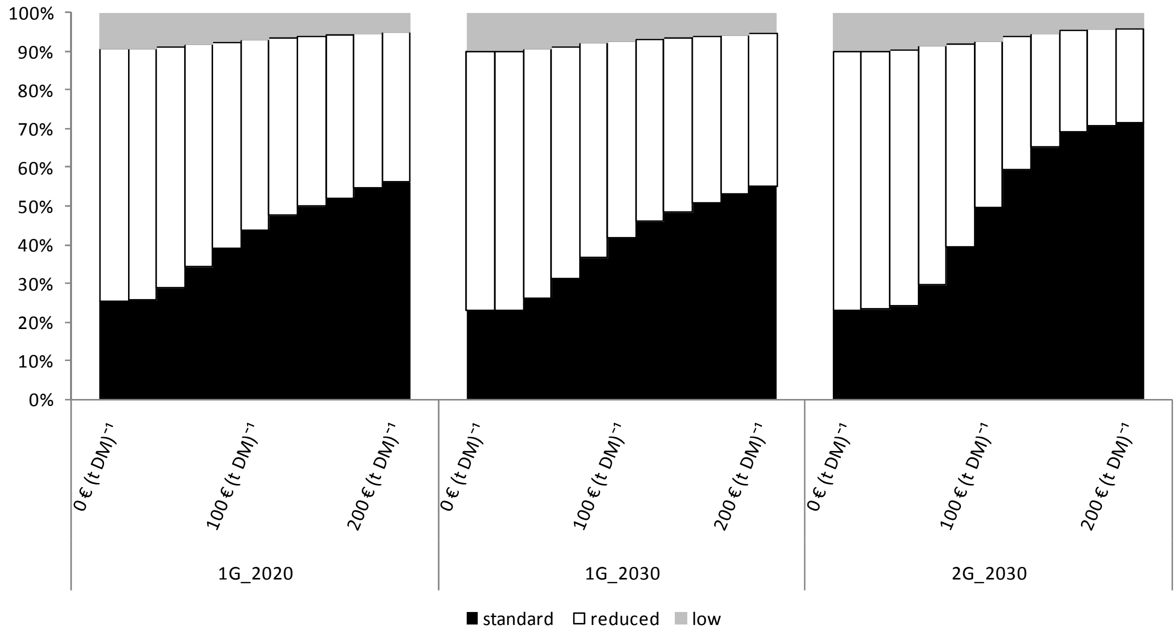

Figure 5: Shares of input farming systems with respect to biomass premium levels in % of total arable land in Austria

Higher subsidies for bioenergy crops are triggering more intensive production methods. It is becoming more and more attractive for farmers to switch from low intensity food and feed production to more intensive bioenergy crop production. Food and feed production becomes less intensive due to the counteracting incentives of the agri-environmental program. For instance, the average yield per hectare of energy rye rises from 4.90 t DM ha^{-1} to 5.25 t DM ha^{-1}, whereas the average yield of rye for food and feed declines by 5.5%. The yields of corn for food and feed decline by 3.8%, while the yield for energy corn increases by 5.6%.

Not in all scenarios, average yields of bioenergy crops are increasing with rising subsidies. In the scenario 2G_2030, the model results show decreasing average yields of poplar. This is due to the fact that less suitable land is available for a further expansion of poplar plantations.

5.3 Output response

In the policy scenarios 1G_2020, rising subsidies have been simulated in order to identify economic production potentials of bioenergy crops (see Figure 6). In Austria, the maximum output of bioenergy crops on arable land is approximately $3.5x10^6$ t DM. Even extremely high subsidies for such crops [250 € $(t\ DM)^{-1}$ and more] do not cause a significant further output response. Energy sugar beet seems to be the most economical choice in Austria for low production levels and prices. Up to 160 € $(t\ DM)^{-1}$, only sugar beet is chosen as energy crop.

If subsidies are higher than the level of acreage for energy wheat, energy triticale and corn are going to increase (Figure 6). At the range of subsidies chosen for this policy simulation experiment, energy corn reaches a maximum production level at about $1.5x10^6$ t DM. A maximum of energy oil crops is approximately 80.000 t DM each, but both crops are not competitive compared to sugar and starch crops.

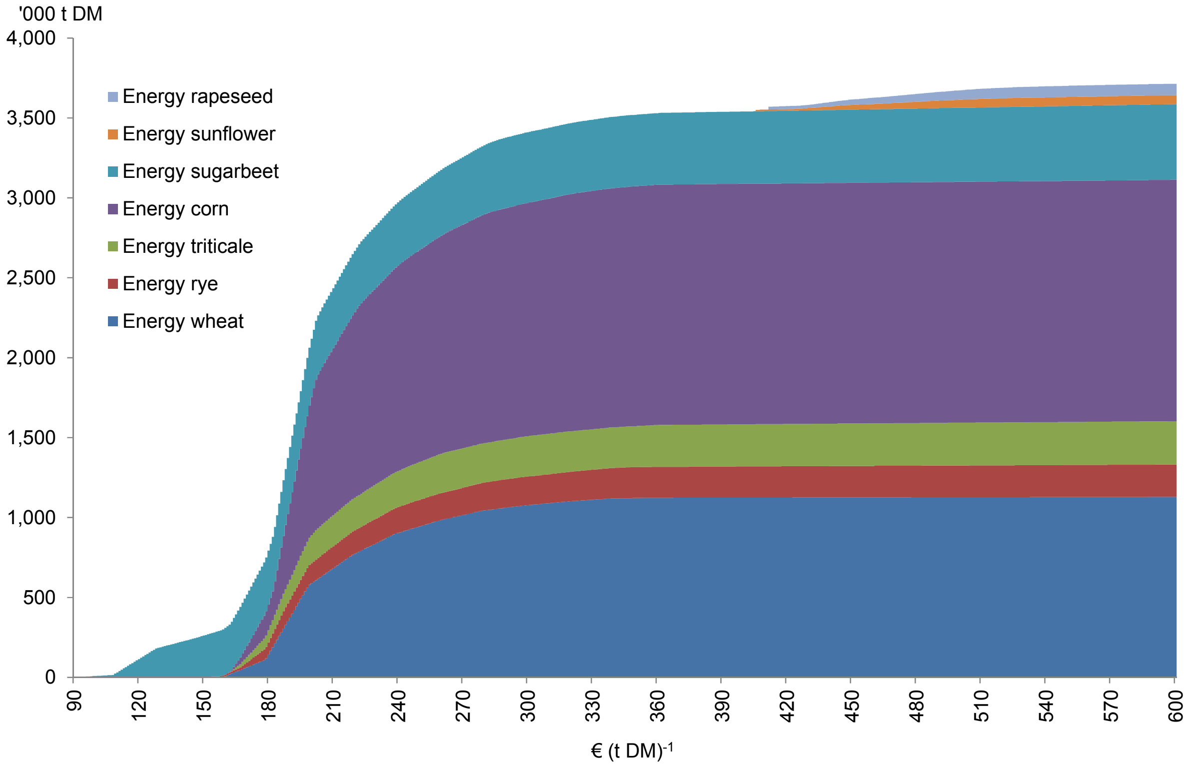

Figure 6: Supply responses for scenario 1G_2020

A uniform subsidy is simulated for all biomass crops in the policy scenarios. A total price (producer price plus premium) of 200 € $(t\ DM)^{-1}$ induces the production of about $2.2x10^6$ t DM of biomass for 1G biofuels. However, a price of 410 € $(t\ DM)^{-1}$ is necessary to make oil crops for bioenergy production economically viable.

For scenario 1G_2030, the results are rather similar to 1G_2020 as indicated in section 5.1. By supporting feedstock for 2G biofuels production, the total supply potential can be raised by the factor 1.7 in comparison to feedstocks for 1G biofuels (c.p. Figure 7). For instance, poplar plantations deliver about 3,500 t DM at a price of 200 € $(t\ DM)^{-1}$, while energy corn yields about 850 t DM at this price. At a price of 220 € $(t\ DM)^{-1}$ for energy grass-clover and 240 € $(t\ DM)^{-1}$ for energy grass respectively, a maximum potential for hay is reached. Rising feedstock subsidies increase the direct competition for land between poplar, energy grass-clover, and energy grass. The biomass potential of grass for 2G biofuel production decreases with further price increases therefore.

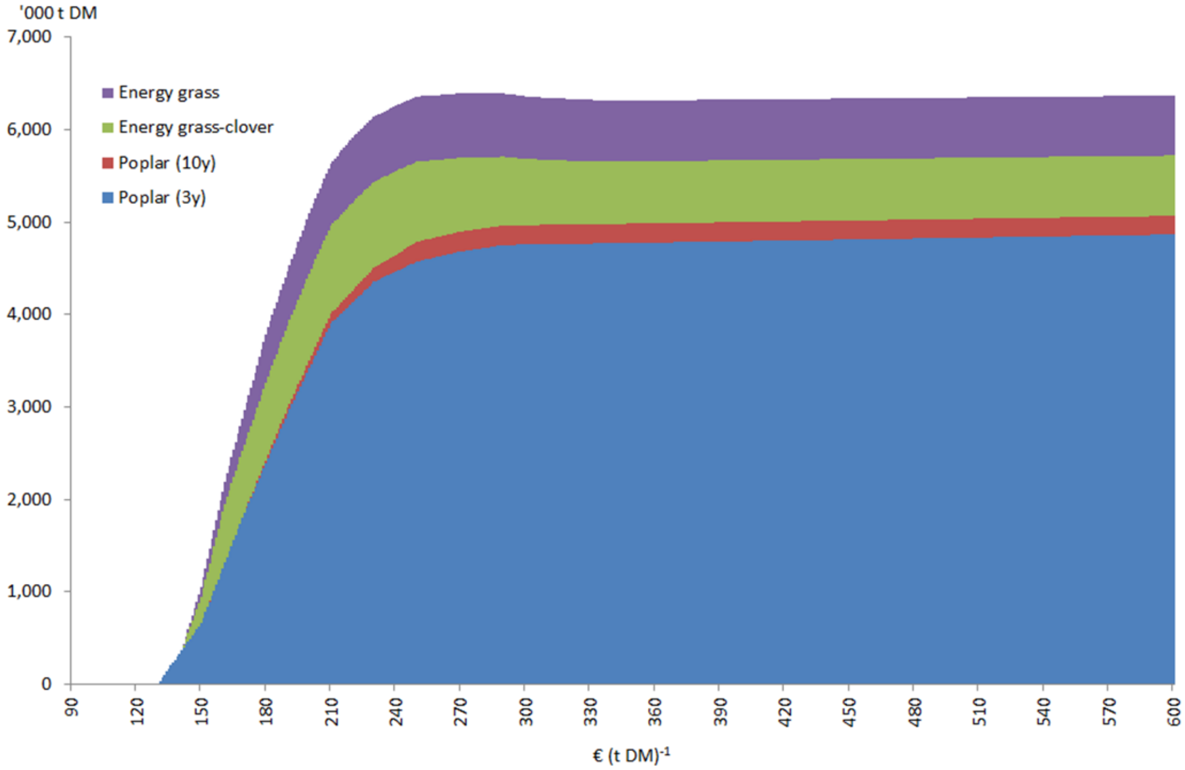

Figure 7: Supply responses for the scenario 2G_2030

6 Discussion and Conclusion

While many economic analyses apply constant opportunity costs (e.g. DE WIT and FAAIJ, 2010; VAN DAM et al., 2007), we use bio-physical and economic data to account for differences in opportunity costs to analyze economic biomass production potentials.

We have developed and applied three models sequentially: CropRota (SCHÖNHART et al., 2011) provides typical crop rotations at municipality levels in Austria; EPIC (WILLIAMS, 1995) simulates crop yields and environmental impacts with respect to site conditions (i.e. soil type, topography, weather) and management alternatives (crop rotation, fertilization); and BiomAT (ASAMER et al., 2011), a spatially explicit biomass optimization model, optimizes agricultural production and land use using data from the former two models to provide economic biomass production potentials in a land constrained economy. The consideration of crop rotations instead of single crops accounts for agronomical constraints in crop production. The spatially explicit simulation of crop yields accounts for the natural and agronomic heterogeneity in Austrian crop production. The land constrained optimization among alternative crop production choices accounts for the opportunity costs in food and non-food production.

A spatial explicit representation of biomass production potentials, land use changes and environmental impacts provides valuable insights for regional planners and stakeholders as well as the possibility to compute regional levels of biomass supply. The results can be used to balance biomass supply with sustainability aspects (e.g. competition with food and feed or environmental impacts; cp. STREUBING et al., 2010).

The economic potentials of domestic energy crop production rely mainly on three criteria. Firstly, the relative differences in the gross margins between food and non-food crops. While no additional incentive for biomass production leads to low area shares for energy crops (only sunflowers and rapeseeds are produced in small amount), biomass subsidies would increase domestic energy crop production. Secondly, domestic biomass production competes directly with alternative land uses to produce food and feed in a land constrained economy. Thirdly, promoting energy crop production intensifies production which competes with extensification measures promoted by agri-environmental programs. All these influence the opportunity costs of biomass production, which are assessed spatially explicitly in our integrated modeling system.

Consequently, the feedstock costs and economic production potentials are quite different to the results of DE WIT and FAAIJ (2010). DE WIT and FAAIJ (2010) are calculating 10.5 € GJ^{-1} for oil crops, 9.0 €GJ^{-1} for starchy crops, 5.5 € GJ^{-1} for sugar crops and 3.5 € GJ^{-1} for wood crops. Our calculations show higher costs ranging from about plus 60% to 120% for oil crops, 30% to 130% for starchy crops, 40% to 220% for sugar crops, and 100% to 350% for woody crops, depending on biomass production level.

Our analysis allows evaluating the influence of rising biomass production on feed and food production. However, feedbacks on market prices for food and feed crops are not accounted for in our analysis. International trade may reduce such feedback effects but may increase leakage effects i.e. indirect land use changes and GHG emissions. In addition, reducing the degree of self-sufficiency can locally lead to rising food and feed prices as well as factor prices (e.g. land renting).

The analysis focuses on production of energy crops and does not consider subsequent transformation to biofuels. Conversion efficiencies as well as production costs differ between 1G and 2G biofuels as well as between ethanol and biodiesel. Costs and amounts of crop yields can therefore not be directly compared with respect to final demand for fuels.

Acknowledgment

This research has been funded by the Jubiläumsfonds of the Oesterreichische Nationalbank (ÖNB) as well as by the FP7 project “crops2industry” of the European Commission (http://www.crops2industry.eu/).

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Bestelladresse:
Universität für Bodenkultur Wien
Department für Wirtschafts- und Sozialwissenschaften
Institut für nachhaltige Wirtschaftsentwicklung
Feistmantelstrasse 4, 1180 Wien
Tel: +43/1/47 654 – 3660
Fax: +43/1/47 654 – 3692
e-mail: Iris.Richter@boku.ac.at
Download unter: http://www.wiso.boku.ac.at/h731_publikationen.html