Multi-Product Crops for Agricultural and Energy Production – an AGE Analysis for Poland

Adriana M. Ignaciuk and Rob B. Dellink

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Adriana M. Ignaciuk and Rob B. Dellink, *Environmental Economics and Natural Resources Group, Wageningen University*

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Summary

By-products from agriculture and forestry can contribute to production of clean and cheap (bio)electricity. To assess the role of such multi-product crops in the response to climate policies, we present an applied general equilibrium model with special attention to biomass and multi-product crops for Poland. The potential to boost production of bioelectricity through the use of multi-product crops turns out to be limited to only 2-3% of total electricity production. Further expansion of the bioelectricity sector will have to be based on biomass crops explicitly grown for energy purposes. The competition between agriculture and biomass for scarce land remains limited, given the availability of relatively poor land types and substitution possibilities. The importance of indirect effects illustrates that the AGE framework is appropriate.

Keywords: Applied general equilibrium (AGE), Biomass, Energy policy, Renewable energy

JEL Classification: D58, H23, Q28, Q42

Address for correspondence:

Adriana Ignaciuk
Environmental Economics and Natural Resources Group
Wageningen University
P.O. Box 8130
6700EW Wageningen
The Netherlands
E-mail: Adriana.Ignaciuk@wur.nl

1. Introduction

Growing demand for clean energy is one of the responses to (i) stringent environmental policies aimed at reducing greenhouse gas emissions and (ii) declining fossil fuel resource availability. One of the possible solutions is biomass, which can deliver large quantities of energy at low net CO_2 emission levels. However, an often-heard concern is that large-scale biomass plantations might increase pressure on the productive land and might cause a substantial increase of food prices (McCarl and Schneider, 2001; Azar, 2003). In contrast, many scientists claim that the food policies that were established after the 2nd World War resulted in today's overproduction of food, and hence the welfare impact of the increased pressure on land may be limited (Tilman et al., 2002; Trewavas, 2002; Wolf et al., 2003).

To increase biofuel supply and to reduce the demand pressure on land, multi-product crops can be utilized. Dornburg (2004) defines multi-product crops as "crops that can be split into two or more different parts that are used for different applications". A major product of the crop can for instance be food, while another part of the crop is used as energy, i.e. is used as solid fuel or converted to liquid fuel, and still another part of the crop is used for e.g. material applications. In this paper, we focus on multiproductivity of agriculture, forestry and biomass sectors, *i.e.* on multi-product crops that can be used for energy purposes. We refer to the residuals generated in these sectors as by-products.

There are several studies that quantify by-products on the global scale. According to Fisher and Schrattenholzer (2001), the energy potential of by-products of wheat, rice, grains, protein feed and other crops are between 18-25 ExaJoule per year (EJ/y), equivalent to 4-6% of world energy use. Hoogwijk et al. (2003), based on several studies, give even higher estimates of 10-32 EJ/y for using agricultural residuals in bioenergy production. For forestry residuals, their estimates are between 10 and 16 EJ/y. A study focusing on GHG emission in Europe is performed by Gielen et al. (2001). The results of the GLUE-11 simulation model (Yamamoto et al., 2001), where different scenarios concerning exogenous population growth and demand for energy are applied, suggest that biomass residuals can potentially satisfy 30 percent of world energy demand in 1990 i.e. 114EJ/y. There are also many studies that establish the biomass and biomass by-products potential for individual countries (Radetzki, 1997; van den Broek et al., 2001; Ignaciuk et al., 2005b). Most of these studies are based on linear techniques that have a fixed proportion of residuals per process. What all these models lack is insight in how these by-products can influence energy prices, agricultural prices, production of biomass and the supply of agricultural commodities.

Bottom-up models as the ones described above are characterized by a detailed description of the energy sector and specific technologies, but they do not take into account the interlinkages with the rest of the economy and often assume that energy demand is exogenous and independent of prices (Zhang and Folmer, 1998). The alternative is to specify economic behavior from a top-down perspective. Top-down models are aggregated models that are able to capture the secondary effects of energy policy on other economic sectors and on trade (Springer, 2003). There are many top-down models that involve detailed economic analysis of the energy sector, and that are able to provide the secondary effects of shifting energy production, e.g. Breuss and Steininger (1998), Kumbaroglu (2003), McFarland et al., (2004), Babiker (2005), and Ignaciuk et al., (2005a). However, none of these investigate the

interaction between multi-product crops and prices and quantities on related markets. Therefore we choose to incorporate essential bottom-up information on multiproductivity in a top-down CGE framework. More detailed discussions of top-down versus bottom-up models can be found in Böhringer (1998), Klinge Jacobsen (1998) and Dellink (2003).

In this paper, we assess the impact of climate policies on sectoral production levels and prices of land, food, electricity and other commodities, when multi-product crops are accounted for. We investigate to what extent the multi-product crops increase the economic potential of bioelectricity production. Moreover, we analyze the land use reallocations initiated by these policies by distinguishing various land types. For these purposes, we present a general equilibrium model for a small open economy where agricultural and biomass sectors are explicitly modeled. We choose this line of analysis because it allows us to comprise the bottom-up information about multi-productivity with the general description of the whole economy in an applied general equilibrium (AGE) setting. This allows us to analyze how responses to energy policies influence main economic sectors and indirectly the whole economy. The model is applied to Poland. Poland is a suitable case, as the land prices are relatively low and the modernization of the agricultural sector is still going on. Hence, we expect that the economic potential for biomass production in Poland is rather high.

This paper is structured as follows. Section 2 presents the background information about multi-product crops. In Section 3 the model characteristics are described and to the end of this section data and scenarios are briefly described. In Section 4 the results are gathered and discussed. The last section concludes.

2. Multi-product crops and bioelectricity production in Poland

2.1. MULTI-PRODUCT CROPS

From 1990 onwards, the Polish economy started its restructuralization towards market economy. One of the first observed changes was declining agricultural production. It was caused by (i) a decrease of relative wages and an increase of prices and (ii) an import of cheaper (subsidized by e.g. EU) food products (Okuniewski, 1996). In recent years wages increased, but this fact is not mirrored in an increase in the demand for food. Food is considered to be a basic good, and thus an increase in income results in a less than proportional increase in demand for this commodity. Empirical analysis of the Polish situation confirms this theory (Hunek, 1996).

Recent analyses show that the current level of agricultural production in Poland can be obtained from an area that is 14.9% smaller than the current acreage. It means that around 2.8 mln ha can be used for other production than agriculture (Wos, 1998; Gradziuk, 2001).

Such a situation provides scope to develop other activities. One of the options is to use this land for energy crops. Biomass in Poland comes from several sources, including (i) traditional agriculture, (ii) forestry, and (iii) biomass plantations (Kowalik, 1994; Gradziuk, 1999). Currently, however, it is marginally used for energy production. The potentials for using e.g. rape or cereals straw are large. Traditionally, straw is utilized for various purposes: (i) as fodder, or (ii) as lining for live stock, and (iii) as organic fertilizer and insulation material

(AEBIOM, 1999). Recently, the share of cereals production in total agricultural production increased, and the animal production decreased. This results in large straw surplus. According to EC Brec (2004), the amount of straw that technically can be used for energy production equals 11.3 mln t (170PJ). Gradziuk (2001) calculates that in the beginning of twenty first century overproduction of straw (from cereals and rape) sums to 11.6 mln ton. The European Biomass Association (AEBIOM) assumes that 22 mln ton of straw can be used for non-agricultural purposes in Poland (AEBIOM, 1999). Straw, that is produced as a by-product of hemp can be also used as an energy source. According to Dornburg (2004), 2.5 ton of straw per ha can be collected resulting in 1.25 thousand ton of hemp straw in Poland that can be used in e.g. bioelectricity sector. For the analysis in this paper we chose the conservative estimates of straw production. Our selection is presented in Table 1.

Table 1
Theoretical and technical energy potential of residuals use in Poland

Type of residuals	Potential use	
	Mln ton	PJ
Cereals straw	4.46	73.5
Wheat straw	4.44	73.5
Rape straw	1.4	23
Hemp straw	0.00125	0.02
Forestry residuals	3.27	53.9

Source: Based on: Gradziuk (2001), Dornburg (2004) , EC Brec (2004)

The Forestry sector also provides by-products that can be utilized for energy production. Gradziuk (2001) calculates that in Poland over 170 thousands m^3 of wood residuals can be used for e.g. bioelectricity. For our analyses we convert these residuals into straw equivalents by using the average caloric content of the residuals.

2.2. BIOELECTRICITY SECTOR

Coal is dominant in the production of electricity in Poland. Around 97% of all electricity generated in the country comes from coal-fired plants that are very inefficient. In 1997, 135.0 billion kWh of electricity was generated in Poland from which only from which 0.6 from renewable energy. In 2000, the situation was similar; 135.2 billion kWh was produced, from which 0.5 kWh from renewable energy. Poland is a net electricity producer. In 2001, Polish government set goals concerning an increase of bioelectricity share in total electricity production to 7.5% by 2010 and 14% by 2020. Hence, in the future the shares of 'green' electricity are expected to increase drastically.

In 1999 most of the 'green' electricity was produced from small hydro plants, but there is not much scope for expansion of this type of electricity in Poland. Other potential sources for electricity production are (i) solar panels, (ii) wind mills and (iii) biomass. Solar energy is relatively expensive compared to other renewable sources. To produce relatively cheap wind energy, the wind parks need to have good geographical conditions. Right now, only in the northern part of Poland there is some development in this field, but both atmospheric conditions and negative community attitude do not encourage further developments. Hence, in

the future, it is expected that the biomass is going to play a larger role in the production of green electricity.

Currently, in Poland, biomass is used mainly to generate heat. However, there are a few working plants combining production of heat and electricity, mostly using forestry products. Besides these, willow and hemp are considered to have a high potential for use in electricity production (EC Brec, 2004).

The costs of biomass-based plants generating electricity are currently 2 to 3 times higher than similar plants fueled by oil or gas (Zurawski, 2004). However, within the coming years, the electricity sector has to undertake serious modernization in order to fulfill both efficiency and environmental standards (Lynch, 2005). Most of the old plants need to be replaced, creating a large scope for development of new and clean biomass-based plants. In Poland, since many years, there is a tendency to develop small-scale plants that can be placed based on availability of crops in the region, thereby minimizing transport costs of biomass.

3. Model specification

To assess the impact of climate policies on land use allocation, sectoral production levels and prices of land, food, electricity and other commodities, we present an applied general equilibrium (AGE) model with special attention to biomass and multi-product crops. The section starts with the general description of the economic model, followed by a discussion of the specific elements related to biomass and environmental policy. Then, the data and scenarios are briefly presented.

3.1. GENERAL SPECIFICATION

The model describes the entire economy, with explicit detail in the representation of production of traditional agricultural and biomass crops. It is an extended version of the model described in Ignaciuk et al. (2005). Our model distinguishes 35 sectors, including 6 agricultural and biomass sectors. Moreover, the bioelectricity sector is explicitly described. As in all applied general equilibrium models (AGEs), all markets clear, which means that supply equals demand for all goods through adjusting relative prices (Ginsburgh and Keyzer, 1997). We include three types of primary production factors: labor, capital and land.

A *representative consumer* maximizes utility under the condition that expenditures on consumption goods do not exceed income. Utility is represented by a nested constant elasticity of substitution (CES) function[1]:

$$U = CES\left(C_i, EL^N; \sigma^U\right) \tag{1}$$

in which U is utility, C_i is the consumption of commodities from sector i (excluding electricity) and $EL^N = CES\left(C_e, C_{be}; \sigma^{EL}\right)$ denotes electricity consumption, where C_e and C_{be} are consumption of Electricity and Bioelectricity respectively. This specification allows for different substitution possibilities between different consumption goods, such as between

[1] The CES function $Y_i = \left(\alpha_1 X_1^{\rho} + \alpha_2 X_2^{\rho}\right)^{1/\rho}$ with $\rho = (\sigma\text{-}1)/\sigma$ is written as $Y_i = CES(X_1, X_2; \sigma)$.

conventional electricity and bioelectricity: parameters σ^{U} and σ^{EL} are the constant substitution elasticities and equal 0.5 and 0.75, respectively. Consumers own production factors and consume produced goods. Labor supply is fixed, while the wage rate is fully flexible. All taxes are collected by the government that uses them to finance public consumption and pay lump-sum transfers to private households.

Producers maximize profits subject to the available production technologies. Production technologies are represented by nested CES functions. Following Rutherford and Paltsev (2000), production functions of different commodities have a six-level nesting structure (cf. Figure 1).

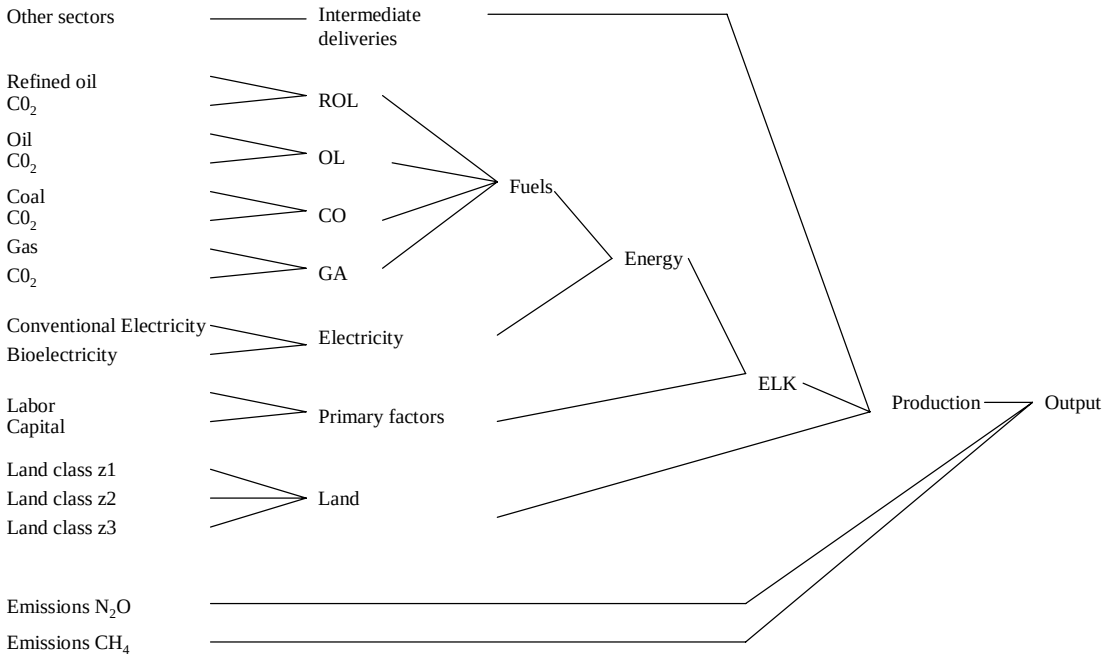

Figure 1
Nested CES function

In the model, we assume that Poland is a small open economy. It means that neither domestic prices nor traded quantities change the 'world market prices'. The international market is assumed to be large enough to absorb any quantities of goods produced in Poland and it can satisfy any Polish import demands. Trading partners are not modeled explicitly, however, they are addressed, following Keller (1980) as the 'Rest of the World' (RoW). The demand by the RoW represents Polish exports and its supply represents Polish imports. In this model, we choose the Armington specification for traded goods, assuming that domestic and foreign goods are imperfect substitutes (Armington, 1969). This allows for a difference in prices between domestically produced goods and their international substitutes. Hence, an increase in domestic prices leads to a shift in demand towards the competitive imports, but only to a limited extent. Similarly, a change in domestic prices will have a limited impact on exports.

The interactions between the various production sectors are relevant, as the agricultural and energy sectors have strong links with the rest of the economy. An economy-wide model, such as the AGE-framework provides, allows us to take these interlinkages fully into account.

Moreover, the indirect impacts of environmental policies are incorporated (cf. (Dellink, 2005)), ensuring a consistent assessment of the economic costs of environmental policy.

3.2. THE BIOMASS MODULE

Four land classes are identified to capture differences in productivity from different land types. Agricultural and biomass crops can grow on three different land use classes *z1*, *z2*, *z3*, which correspond to the six land classes used in the Polish land classification system (GUS, 2002c). Land type *z1* comprises very good and good land (class I & II), *z2* reasonably good and average (class III & IV) and *z3* poor and very low quality (class V & VI). Forestry grows on the *z4* type of land.

In the formation of utility and in the production function, emissions (emission permits) are incorporated as a necessary input. Environmental policy is implemented by reducing the number of emission permits the government auctions. This way of modeling environmental policy ensures that a cost-effective allocation is achieved (Dellink, 2005).

The emissions of the major greenhouse gases, CO_2, N_2O and CH_4, are included, all expressed in CO_2 equivalents. Data on emissions is obtained from Sadowski (2001). CH_4 and N_2O data are directly linked to output. As CO_2 emissions come mostly from fossil fuel combustion they enter the production function assuming a fixed relation with fossil fuel use (cf. Figure 1).

In our model, we deal with multiproductivity characteristics of cereals, rape, hemp and forestry products by including straw or residuals as a by-product, as explained in Section 2. The by-products are produced in fixed proportions to the production of the main product, and can be used only by the bioelectricity sector. Besides using labor and capital, the bioelectricity sector has the choice between using willow, hemp, wood, and straw and residuals as inputs, with high elasticity of substitution. In the benchmark, straw is not available as input, which allows us to analyze the impact of using by-products in the scenarios.

3.3. THE EU SUBSIDY ON LAND USE

In May 2004, Poland joined the EU. This historical moment initiated some changes in the agricultural and forestry sectors. Since the entry date Polish farmers are subjects to extensive European subsidies. These subsidies cover traditional agricultural crops, energy crops and aforestation practices. The Polish government chooses a relatively simple subsidy scheme. Each farmer that owns a land of acreage of more than 1 ha receives on yearly basis 61 Euro per ha[2]. Moreover, farmers get 72 Euro subsidy per ha if they grow traditional agricultural crops on his land. For a detailed list of crop subsidies see UKIE (2004). Grass landowners receive 69 Euro subsidy per ha. The energy crops are subsidized in the amount of 45 Euro per ha (EU, 2003).

The EU proposed a long-term program for Poland, regarding afforestation of agricultural land (UKIE, 2004). In present value terms, using a discount factor of 4%, landowners receive 175 Euro per ha for afforested land.

[2] One zloty (zl) equals around 0.25 Euro (exchange rate 27.06.2003 http://www.xe.com).

The EU subsidies are paid from external sources, namely EU. The traditional agriculture and biomass sectors are directly subsidized, but the Forestry sector only gets subsidy on land that is converted into forestry.

The foreign financing of the EU subsidies is simulated in the model by endowing the RoW with assets that can exactly cover the payments involved in the subsidies. To ensure *ex post* balance between the assets and payments involved, this endowment is rationed endogenously in the model.

3.4. DATA

A Social Accounting Matrix (SAM) for Poland is specified in order to determine the benchmark equilibrium. GTAP5 data for 1997 (Dimaranan and McDougall, 2002), are adopted in our model. In the SAM, agricultural and biomass data are disaggregated based on the FEPFARM model built by Mueller (1995), using FAO (2005) land use data for Poland. The FEBFARM model provides the shares of production costs.

Substitution elasticities between the different inputs in the production and utility functions are specified based on Kemfert (1998), Rutherford and Paltsev (2000), Kiuila (2000), and Dellink (2005).

Data on land use pattern and emissions are obtained from Polish statistics (GUS, 2002b; 2002a). Data on agricultural and biomass residuals are taken from Gradziuk (2001) Dornburg (2004) and EC Brec (2004). The full data set used in the model can be obtained from authors.

3.5. SCENARIOS

We present two policy scenarios aimed at increasing the share of bioelectricity in total demand for electricity and at reducing CO_2 emissions. For each scenario, we adopt some restriction on the number of emission permits and applied bioelectricity subsidy rate. This allows us to investigate at which level of climate policy the national targets for bioelectricity use are achieved. Polish policy makers set goals concerning an increase of bioelectricity share in total electricity production to 7.5% by 2010 and 14% by 2020.

The following scenarios are adopted

- Scenario S, the single-product setting, considers the introduction of emission permits in steps of 5% and adoption of a bioelectricity subsidy of 25%.
- Scenario M, the multi-product setting, adopts the same rate of emission permits reduction and subsidy on bioelectricity but incorporates the multiproductivity of agricultural and biomass sectors.

4. Results and discussion

This section comprises the results of the policy analysis for both scenarios.

General results

Figure 2 presents the welfare impacts for scenarios S and M, at different levels of emission permit reduction.

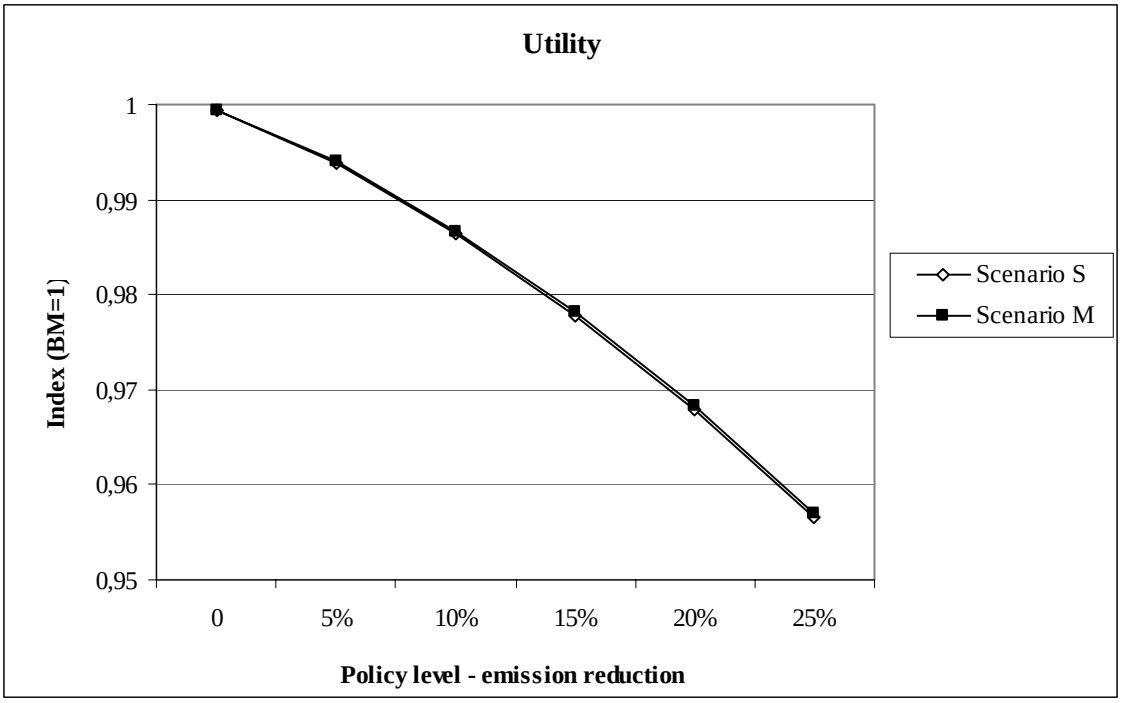

Figure 2
Utility change for single-product (S) and multi-product (M) scenarios for different levels of emission reduction in unilateral setting (for Poland)

Clearly, the environmental policy leads to welfare costs. It should be stressed that the environmental benefits of these policies are not taken into account in this measure of welfare, and hence it cannot be concluded whether these policies are justified. The welfare costs of these policies tend to be decreasing more than proportionately with increasing stringency of environmental policy, and the impacts are virtually the same for the single- and multi-product settings.

Production

Table 2 comprises the results of production changes in a unilateral setting for different emission reduction levels. The economy adapts to the reductions in allowed emissions by switching towards (i) 'clean' energy; (ii) 'clean' production; and (iii) 'clean' consumption. Since the Bioelectricity sector is very small compared to conventional Electricity, it has to grow considerably to achieve the policy target: more than 1000 percent in both scenarios. Labor and capital, released primarily from the declining Electricity sector, are used to intensify the production of Bioelectricity sector. In the multi-product setting scenario, these changes are stronger than in the single-product setting. Since the by-products are cheap, the Bioelectricity sector demands them in large quantities, and the availability of multi-product crops can keep production costs in the Bioelectricity sector relatively low. This allows for an

additional increase in production of bioelectricity of roughly one third (1342% vs. 1023%, at 10% emission reduction level).

Table 2
Changes in the production in selected sectors, for Poland, for all scenarios for an emission reduction of 10% and 25% (% change compared to benchmark)

	10% emission Reduction		25% emission reduction	
	Scenario S	Scenario M	Scenario S	Scenario M
Other Agriculture	-1	-1	-5	-5
Rape	29	35	56	64
Willow	1086	1457	2060	2656
Hemp	92	108	168	195
Wheat	-2	-2	-5	-5
Other Cereals	3	4	3	4
Forestry	4	5	6	7
Coal	-9	-9	-23	-23
Oil	-17	-16	-40	-40
Gas	-14	-14	-34	-34
Electricity	-10	-12	-22	-24
Bioelectricity	1023	1342	1840	2333
Industry	-2	-2	-5	-5
Services	-1	-1	-4	-4

The biomass sectors such as the sectors producing rape, willow or hemp increase their production substantially in both scenarios to meet the demand for biofuels in the Bioelectricity sector. This indicates that the availability of by-products can only partially reduce the competition between agricultural and biomass crops. Essentially, all by-products that are available will be used in the Bioelectricity sector, but any further expansion in this sector will have to be based on biomass crops that are explicitly grown for energy purposes. There are two countering mechanisms. On the one hand, climate policy increases the price of these by-products substantially, and thereby increases revenues in the agricultural sectors. On the other hand, the higher costs for emission permits imply that the agricultural sectors face increased production costs.

The other agricultural sectors decrease their production only to a minor extent; one percent with 10% emission reduction and five percent with 25% emission reduction. This result is not as surprising as it may seem at first sight. First, the arable agricultural sector in Poland is relatively clean in terms of GHGs emission (the use of fertilizers is relatively low in Poland), and hence requires few emission permits and there is relatively small need for reducing demand for these goods. Secondly, absolute levels of employment in the agricultural sector will remain roughly equal, and capital use will decline less than output. Thus, agricultural production intensifies. This illustrates the importance of the CGE approach: there are several mitigating mechanisms that limit the impact of environmental policy on agricultural production, that are not captured in a partial equilibrium model.

Both in scenarios S and M the dirty sectors decrease their production substantially (see Table 2). In the multi-product setting, these losses are slightly smaller, as the availability of the by-products reduces the need to use scarce production factors to produce biomass.

Sectoral impacts increase in a non-linear manner with more stringent climate policy: small changes in the production structure, needed to reduce emissions by 10%, can be achieved at relatively low costs, but more stringent environmental policies will affect production substantially stronger. This holds not only for the "losers", but also for the "winners": stringent environmental policy is in the best interest of the clean production sectors.

Bioelectricity shares

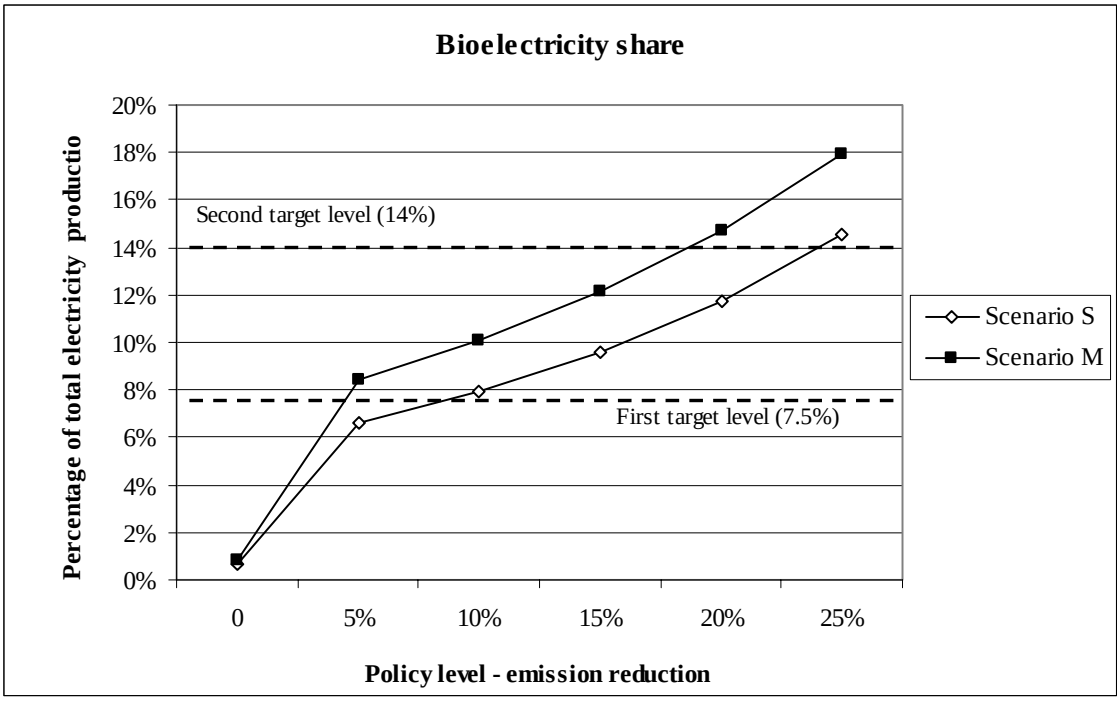

Figure 3
Bioelectricity share, for Poland, for single-product (S) and multi-product (M) scenarios for different levels of emission reduction in unilateral setting

Figure 3 presents the influence of the implementation of the scenarios on the share of bioelectricity in electricity production. The results show clear differences between the bioelectricity shares for single-product and multi-product settings. Notably, for every level of emission reduction, in multi-product setting there are higher shares of bioelectricity than in single-product setting. This does not come as a surprise, considering the fact that in the multi-product setting bioelectricity producers can benefit from the availability of cheap biofuels in the form of straw. The picture clearly confirms the main impact of the availability of multi-product crops as discussed above: the existing by-products are used in the Bioelectricity sector even at low rates of emission reductions, but beyond that, these by-products can only provide a marginal contribution to the expansion of the Bioelectricity sector.

The first policy goal of 7.5% bioelectricity share is reached with around 10% and 5% emission reduction, for scenarios S and M respectively. The more stringent goal of 14% requires a much more ambitious climate policy: 25% emission reduction in single-product setting. When by-products are available, i.e. in the multi-product setting, such a reduction in the number of permits induces the share of bioelectricity to rise to around 18%.

Both lines observe a kink at a 10% emission reduction level, which can be attributed to the introduction of the biomass subsidy in the scenarios that does not exist in benchmark. This leads to an instant increase in the bioelectricity share and is an essential part of the strategy to achieve the national policy targets for the share of bioelectricity (this issue is investigated in more detail in Ignaciuk et al., 2005).

Prices

Table 3
Prices of selected commodities, for Poland, for both scenarios in unilateral setting

		10% emission reduction		25% emission reduction	
	BM	Scenario S	Scenario M	Scenario S	Scenario M
Prices of selected commodities (in % change compared to benchmark)					
Other Agriculture		2%	2%	5%	5%
Rape		0%	0%	-1%	-1%
Willow		0%	0%	0%	0%
Hemp		0%	0%	1%	0%
Wheat		0%	0%	1%	1%
Other Cereals		1%	1%	2%	2%
Forestry		0%	0%	0%	0%
Electricity		3%	3%	9%	9%
Bioelectricity		-20%	-22%	-21%	-23%
Price of emission permits (in Euro per ton of carbon)					
Emission permit		4.8	4.7	15.0	14.8
Prices of land (in Euro per ha, referred to benchmark prices from 1997)					
Very good land (z_1)	91.4	82.7	81.8	71.7	70.8
Good land (z_2)	66.4	68.6	69.3	67.3	67.3
Poor land (z_3)	37.1	48.5	51.8	54.4	59.8
Forestry land (z_4)	37.1	47.4	50.5	53.1	58.4

Note: Price levels are expressed in relation to the numéraire, the Consumer Price Index.

The policies adopted in the model also induce price changes. The impact of the emission reduction policies on the relative price level for a selection of goods is presented in Table 3. Generally, the prices of dirty goods go up compared to the prices of cleaner goods, as the production costs for the dirty sectors increase substantially due to the expensive emission permits; the emission permit prices for two policy levels are reported in Table 3. The price of bioelectricity decreases relatively to other prices, because it benefits from a subsidy and cheap by-products.

We can observe an increase of agricultural commodity prices. However, this increase is low, at most 5%, even though the emission permit price rises to around 15 Euro per ton of carbon. Such small increase in prices, despite the competition for land, shows that the competition between agriculture and biomass is less strong in our CGE setting than commonly encountered in a partial equilibrium framework. Table 3 also presents the price levels of different land types; we observe an increase in prices for good (type z_2), poor (type z_3), and forestry (type z_4) land types. This increase is caused by several factors. First, there is increased competition for land, as more biomass crops are demanded to fuel the clean Bioelectricity sector. Second, in the multi-product setting (Scenario M), the productivity of land increases due to the availability of by-products. Perhaps more surprisingly, the price of

very good land (type z_1) decreases, though it remains the most expensive land type. The large demand for biomass crops primarily increases the pressure on z_2 and z_3 and the additional production of the Forestry sector puts an upward pressure on z_4. With increasing stringency of climate policy, all the land prices tend to wards the same price. This effect is governed by the possibilities to used different land types for producing different crops: biomass crops will start out on poor land, but can also use better land types, and agricultural land can be converted to forestry land. These substitution possibilities tend to even out the differences in land prices between the different types.

The permit price increases nonlinear with the stringency of the policy; with 10% emission reduction a permit for a ton of carbon costs 5 Euro and with 50% emission reduction it costs 15 Euro. This is more or less in line with the results obtained in integrated assessment models as reported in Weyant (2004).

Land use

Table 4 presents the land allocation for scenarios S and M at 10% and 25% emission reduction levels. In the single-product scenario, there is less reallocation of land than in the multi-product scenario, in line with the changes in economic activity of the related sectors.

Table 4
Land use (in 1000 ha), in Poland, with 10% and 25% emission reduction for scenario S and M

			10% emission reduction		25% emission reduction	
		BM	Scenario S	Scenario M	Scenario S	Scenario M
Other Agriculture	Z1*	102,4	100,6	100,5	98,6	98,3
	Z2**	1839,5	1784,1	1778,8	1726,2	1717,7
	Z3***	1051,6	997,1	988,7	952,0	939,6
Rape	Z1	0,0	0,0	0,0	0,0	0,0
	Z2	349,4	443,5	458,9	534,8	557,6
	Z3	87,3	108,3	111,5	128,9	133,3
Willow	Z1	0,0	0,0	0,0	0,0	0,0
	Z2	0,0	0,0	0,0	0,0	0,0
	Z3	0,5	6,2	8,1	11,2	14,2
Hemp	Z1	0,0	0,0	0,0	0,1	0,3
	Z2	0,0	0,0	0,0	0,0	0,0
	Z3	0,1	0,3	0,3	0,2	0,0
Wheat	Z1	87,4	85,2	84,7	83,5	82,7
	Z2	1570,1	1510,6	1499,1	1461,8	1444,5
	Z3	897,7	844,2	833,3	806,2	790,2
Other Cereals	Z1	218,6	222,6	223,1	226,2	227,0
	Z2	3894,5	3915,2	3916,6	3930,7	3933,8
	Z3	2301,1	2261,3	2249,8	2240,3	2223,9
Forestry	Z4^	8769,0	8890,0	8915,7	8968,7	9006,2

* Very good land (z_1)
** Good land (z_2)
*** Poor land (z_3)
^ Forestry land (z_4)

We consider forestry and willow production to carry out functions that attribute to nature conservation, since they contribute to sustaining biodiversity, improve the quality of land and

create a suitable environment for many species (Borjesson, 1999; Londo et al., 2005). Moreover, forest plantations and other biomass plantations have the potential to sequester carbon in the soil (Tolbert et al., 2002). In the multi-product setting, a climate policy of 25% emission reduction induces a conversion of agricultural land in Forestry area of 237 thousands hectares. Adding the acreage gained by willow plantation, the acreage of natural areas increases with 250 thousands hectares. This large increase is caused by (i) the EU subsidy, (ii) the fact that Forestry sector produces fuel for bioelectricity and, (iii) related to that, by increased demand for clean electricity. Hence, the policies implemented contribute not only to lower CO_2 emissions and a higher share of bioelectricity, but also to an increase in semi-natural areas. In the single-product scenario, the gains for nature are lower, showing the role of by-products in the changes in the Forestry sector.

5. Sensitivity analysis

The reactions of producers and consumers depend on the calibrated elasticities as used in the CES functions. We conduct a sensitivity analysis on the values of these elasticities by de- and increasing the values of one elasticity at a time with 50%, using a policy level of 25% in scenario M as reference. The main results of these additional simulations are reported in Table 5 and briefly discussed here.

Table 5
Main results of the sensitivity analysis on 25% emission reduction in scenario M

	Utility	Share of bioelectricity	Price of emission permit	Price of Other Agriculture	Land use Forestry
Reference (sc. M)	-4.3%	18.0%	59.3	4.8%	2.7%
Low σ_{ELK}	-6.5%	26.4%	85.4	7.1%	5.7%
High σ_{ELK}	-3.1%	14.3%	45.0	3.6%	2.0%
Low σ_{Elec}	-4.5%	3.4%	62.9	5.0%	0.0%
High σ_{Elec}	-3.8%	46.3%	51.4	4.3%	14.2%
Low σ_{Ener}	-4.5%	18.3%	61.9	5.0%	2.6%
High σ_{Ener}	-4.1%	17.7%	56.9	4.6%	2.8%
Low σ_{PR}	-4.3%	17.9%	59.9	4.9%	3.5%
High σ_{PR}	-4.3%	17.9%	58.8	4.7%	2.2%
Low σ_{Z}	-4.3%	17.9%	59.3	4.8%	2.0%
High σ_{Z}	-4.3%	18.0%	59.3	4.8%	3.3%
Low σ_{Trade}	-4.4%	18.4%	62.3	5.0%	2.7%
High σ_{Trade}	-4.2%	17.7%	56.6	4.6%	2.7%

When the substitution elasticity between energy and primary production factors in the production function is reduced (e.g. for Other Agriculture from 0.5 to 0.25), welfare costs as measured by the change in utility increase substantially to 6.5%. This shows that in the reference scenario producers can limit the costs of the environmental policy by substituting

away from energy towards labor and capital. This is a clear example of the importance of the feedback effects that occur in the CGE setting. Essentially, the lower elasticity implies that there are fewer possibilities to avoid an impact of the policy on behavior of all producers and consumers. Thus, there is more demand for bioelectricity (the share increases to 26.4%), a higher emission permit price, more competition for the agricultural sector (as indicated by the stronger increase in the price of Other Agricultural goods) and more conversion of land to forestry.

Increasing the value of this elasticity by 50% (for Other Agriculture to 0.75) has the opposite effect, as expected. It is however worth noting that the sensitivity is not symmetric: an increase in the elasticity has a smaller impact on the results than a decrease.

The results are also influenced by a increase in the substitution elasticity between electricity and bioelectricity. These two goods are close substitutes, reflected in the reference case by an elasticity of 12. Increasing this elasticity implies that the two goods are even closer substitutes, and it is no surprise that this lowers the welfare costs of the policy, reduces the emission permit price and diminishes the competition with agriculture. Almost half of all electricity is produced from biomass (46.3%), to a large extent through the increased production of wood in forestry.

A lower substitution elasticity between electricity and bioelectricity has much less pronounced effects: only the share of bioelectricity and the conversion of land towards forestry change substantially, but the welfare costs and emission permit prices are hardly affected.

Changes in the other major substitution elasticities have a much smaller or even negligible effect on the results, indicating that the results are fairly robust against most parameter values chosen. For instance, the substitution elasticity between different land types, which is difficult to calibrate empirically, plays only a minor role; it has some effects on forestry land, but virtually none on utility.

6. Conclusions

In this paper we present a general equilibrium model to investigate the effects of climate policies on biomass and bioelectricity and their influence on the economy and resulting land reallocation.

Before discussing the results; we would like to mention some of the major caveats of our model. First, we address the issue in a comparative-static manner. A dynamic model would be able to describe the transition path toward cleaner economy. Secondly, environmental benefits are not taken into account in the measure of welfare, and hence it cannot be concluded whether the proposed policies are justified. Moreover, only when the benefits are accounted for we can calculate the efficient levels of policies and determine optimal production quantities. Thirdly, one should keep in mind that the model is a stylized representation of the economy, and though it is calibrated using the best available data, numerical results from the simulations should be interpreted with sufficient care. Despite these limitations, we would like to highlight some interesting results.

Given our assumptions, utilizing multi-product crops can contribute to the policy target of increasing the share of bioelectricity in total electricity consumption; however, the potential to boost production of bioelectricity through the use of multi-product crops turns out to be limited. Only 2-3% of total electricity production can be produced using by-products. Existing by-products from agricultural crops, such as straw, will be utilized as a cheap input for bioelectricity production, but further expansion of the bioelectricity sector will have to be based on biomass crops explicitly grown for energy purposes. Utilization of multi-product crops has virtually no effects on the welfare costs of environmental policy.

Despite the increased demand for biofuels, the adverse effects on the agricultural sector are limited. This result can be explained by several mechanisms. First, the GHGs emission levels in this sector are relatively low. Secondly, the biomass sectors are very small compared to the agricultural sector, and hence a relatively small reduction in land use by the agricultural sector is consistent with a huge boost in biomass production. Thirdly, the biomass sectors have large potentials to grow on the poorer land types, which are much cheaper. Fourth, the agricultural sector can to some extent substitute away from land to labor and capital, which is released from the industrial sectors, and so intensify its production per hectare. Fifth, due to the EU subsidies, production of land intensive sectors becomes more profitable. Finally, the CGE framework incorporates essential feedback effects that are absent in partial equilibrium studies. The importance of these feedbacks is illustrated by the sensitivity of the price of agricultural products for the elasticity of substitution between energy and primary factors.

The policies presented in this paper not only have a positive impact on emission reduction and the share of bioelectricity, but also on nature conservation. Both scenarios induce a strong increase in the acreage of forestry and biomass plantations, thereby leading to reestablishment of semi natural areas. Thus, substantial environmental gains can be reached in several domains.

One of the most noticeable effects of climate policies on the economy is a switch in production and consumption towards ‘clean’ commodities. By comparing results for different reduction levels, it can be seen that the sectoral impacts increase in a non-linear manner: small changes in the production structure to reduce emissions by 10% can be achieved at relatively low costs, but more stringent environmental policies will affect production and costs substantially stronger. This holds not only for the “losers”, but also for the “winners”, in our case mainly the biomass producers. Stringent environmental policy is in the best interest of these clean production sectors.

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(lxxvii) This paper was presented at the Workshop on Infectious Diseases: Ecological and Economic Approaches held in Trieste on 13-15 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics.

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