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Competition between biomass and food production in the presence of energy policies: a partial equilibrium analysis

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Abstract

Bioenergy has several advantages over fossil fuels. For example, it delivers energy at low net CO_2 emission levels and contributes to sustaining future energy supplies. The concern, however, is that an increase in biomass plantations will reduce the land available for agricultural production. The aim of this study is to investigate the effect of taxing conventional electricity production or carbon use in combination with subsidizing biomass or bioelectricity production on the production of biomass and agricultural commodities and on the share of bioelectricity in total electricity production. We develop a partial equilibrium model to illustrate some of the potential impacts of these policies on greenhouse gas emissions, land reallocation and food and electricity prices. As a case study, we use data for Poland, which has a large potential for biomass production. Results show that combining a conventional electricity tax of 10% with a 25% subsidy on bioelectricity production increases the share of bioelectricity to 7.5%. Under this policy regime, biomass as well as agricultural production increase. A carbon tax that gives equal net tax yields, has better environmental results, however, at higher welfare costs and resulting in 1% to 4% reduction of agricultural production.

Keywords: Biomass; Bioenergy; Energy policy; Partial equilibrium model

1. Introduction

Toady, 40% of the European Union's energy supply depends on oil imported from OPEC countries (EC, 2000). Many studies predict an increased dependence on oil and gas imports, resulting in the share of imports in the European Union (EU) increasing to 70% by 2030 (EC, 2002; Salameh, 2003; Tahvonen and Salo, 2001). Moreover, fossil fuel combustion contributes to environmental and health damages via the emission of air pollutants and greenhouse gases (GHGs).

Biomass as a renewable energy source is considered one of the possible ways to reduce GHG emissions (Fearnside, 1999; Gielen et al., 1998a), and it has been claimed that it can contribute to sustainable development (van den Broek et al., 2002). It can play a role in maintaining biodiversity, once the biomass plantation can replace part of agricultural land (Borjesson, 1999a), and reduces fossil fuel dependency in Europe (EC, 2002). Biomass can also have a positive impact on land quality by adding humus to the soil and reducing erosion effects (Borjesson, 1999a, b; Hoogwijk et al., 2003). Moreover, it requires less energy and fertilizer per hectare than traditional food crops do.

Since World War II, agricultural policies in Europe have focused on providing sufficient food for the European population. These policies have been very successful, as is evidenced by today's overproduction of food (Tilman et al., 2002; Trewavas, 2002; WRR, 1992). A growing market for bioenergy, however, can affect present land use patterns. The implementation of climate policies may increase substantially the demand for bioenergy. As land for additional production is scarce in Europe, competition for land may lead to higher prices of agricultural commodities and/or a significant reduction in food production. Azar (2003)

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for instance, argues that due to stringent CO_2 policies, biomass production is expected to intensify, resulting in an expected increase of land prices and at least a doubling of grain prices.

Earlier studies tackle this problem from different perspectives. For example Azar and Berndes (2000), assess the biomass and food prices, under different carbon tax rates on the basis of unit costs of fuels, energy and land. Linear programming has been used commonly, e.g. in the determination of crop selection decisions by farmers, based on the goal of profit maximization. Optimization models with land use aspects include POLYSYS (de la Torre Ugarte and Ray, 2000), GOAL (WRR, 1992), BEAP (Gielen et al., 2001, 2002), and MARKAL MATTER (Gielen, 1995, Gielen et al., 1998b). The first two models focus mainly on land allocation between different crops and do not have specific energy systems included, whereas the latter two focus mainly on the energy systems. Johansson, and Azar (2003, 2004) developed a dynamic, non-linear optimization model dealing with competition between biomass and food crops, using a bottom up approach. They establish food and energy prices concerning stringent climate policies for the USA. Another approach consists of applying equilibrium models. These models mainly focus on the economic drivers of land use change and the equilibrium states dictate land use allocation (see for example the input–output model (IO) for China by Hubacek and Sun, 2001). The biggest drawback of IO models is that they do not react on relative prices by changing input shares in the production, given that they work with Leontief functions in which substitution is not possible. An example of an equilibrium model used for determining the allocation of food and biomass crops is the partial equilibrium model FASOM by McCarl et al. (2000). Different from our approach, he focused mainly on the agricultural sector.

The main aim of this paper is to investigate in a stylized model setting the effect of energy policies on GHG emissions (CO_2 and N_2O), land use, and the production and prices of biomass and agricultural commodities. We concentrate on two energy policies, namely (i) a tax on conventional electricity consumption and (ii) a carbon tax on fossil fuels. Furthermore, for both policies we analyze how a subsidy on bioelectricity generation or biomass production changes the tax effects. We set up a partial equilibrium model in which the main economic relationships between biomass production and bioelectricity are considered. For this we include the agricultural, biomass, conventional electricity and bioelectricity sectors. Although other sectors will also be affected by energy policies, we do not include them in our analysis. In the model, GHG emissions depend both on the land use patterns and fossil fuel use.

The innovative element of this model is that it integrates two distinct analyses, namely an analysis of substitution mechanisms between energy from biomass and from fossil fuels, and an analysis of the effects of changes in demand for biomass on land use and GHG emissions. Moreover, in the model, consumer income from renting out land and labor is endogenous. The partial equilibrium specification is adopted because it both provides a transparent and consistent framework and enables us to concentrate on only the relevant economic sectors (i.e., agriculture and electricity).

For illustrative purposes, the model is applied to Poland because of that country's high potential for biomass production, in combination with a relatively large share of agriculture in the economy (Hille, 2000; Ignaciuk, 2002). The modeling approach applied in this paper can be applied to many other countries that are characterized by a similar socio-geographical situation.

This paper is structured as follows. Section 2 describes the model structure. Section 3 provides an overview of the current energy policies in Poland and of Poland's environmental performance. Section 4 presents the data, model calibration, and the results of the scenarios. Section 5 provides some conclusions and recommendations.

2. The partial equilibrium model

We developed a partial equilibrium model to analyze the potential impacts of energy policies on the production of biomass and food crops. The stylized model comprises the main economic relations between electricity and agricultural sectors, with special attention to biomass production and the bioelectricity sector. A schematic representation of the model structure is given in Fig. 1. The model distinguishes six sectors: agriculture (potatoes (p) and cereals (c) sectors), biomass (hemp (h) and willow (w) sectors), conventional electricity (e) and bioelectricity (b). These define the set of sectors, $I = \{p, c, h, w, e, b\}$. Each of these sectors is assumed to

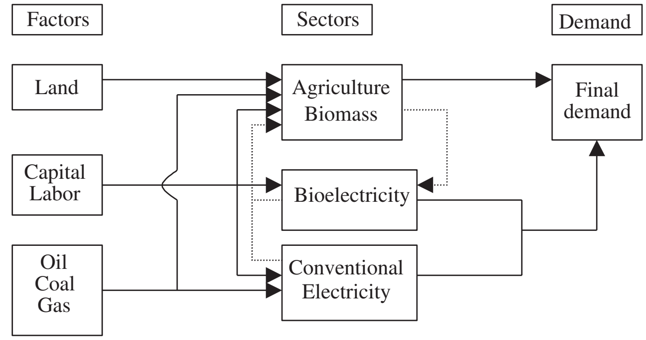

Fig. 1. Schematic representation of the model.

produce a homogenous good. For simplicity, multi-functionality of agricultural products is not considered. These goods are consumed by a representative consumer or are used as intermediate inputs in other sectors. To produce these goods, several primary factors and intermediate deliveries (dotted lines in Fig. 1) are needed. The model allows, to a limited extent, for international trade. For all produced commodities and most inputs, a closed economy setting is adopted in which relative prices are determined by the model. This assumption was made as Poland currently has a limited production of biomass and bioenergy. In order to concentrate on the potential impacts of national policies on the development of the biomass sector, international biomass trade is not considered. For the inputs of gas, oil and coal, however, an open economy setting is adopted, since Poland imports most of these fuels. The prices of gas, oil and coal are determined on the international market. In order to describe the structure of the partial equilibrium model, we discuss the elements of the model step by step.

2.1. Objective function

We adopted the usual objective of maximizing semi-welfare, or equivalently maximizing the sum of consumer and producer surplus. A representative consumer is considered who 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. Utility has a two level nest, where (limited) substitution is possible between consumption of potatoes, cereals, hemp, willow and electricity (see Fig. 2). A second level nest shows substitution possibilities between conventional and bioelectricity. Bioelectricity and conventional electricity, in physical terms are the same, but in reality consumers show different preferences toward traditional and green electricity. For example, consumer in the Netherlands or UK can choose between conventional or green electricity. Likewise, in Finland, Norway and Denmark different taxes are applied to fossil and non-fossil energy carriers (Vehmas, 2005; Svendsen et al., 2001) and in Finland bio-fuels are exempted from taxation (Ericsson et al., 2004). Due to these differences and as conventional and bioelectricity have a different environmental performance, in our analysis they are modeled as two different goods that are very good substitutes. The nested CES utility function is as follows:[1]

$$U = CES(C_p, C_c, C_h, C_w, EL^{UN}; \sigma^U) \quad (1)$$

in which U is utility, variable C_i is the consumption of commodities from sector i and $EL^{UN} = CES(C_e, C_b; \sigma^{UN})$. Parameters σ^U and σ^{UN} are substitution elasticities. In many partial equilibrium models, consumer income is fixed. However, a special feature in our model specification is that a large part of income is fixed and a small part depends on income from 'renting out' labor and capital endowments to the sectors considered in the model. In most partial equilibrium models, income from renting out endowments is not considered. Furthermore, all variables in the model are given in value terms, such that prices reflect relative prices.

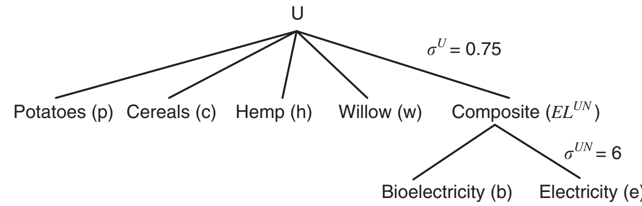

Fig. 2. Nesting structure of the utility function.

As a result of these assumptions on consumer income, it can easily be derived that producer plus consumer surplus is equivalent to consumer utility. Hence, the objective function of the model is equal to maximizing utility as specified in (1).

2.2. Production functions

Producers maximize profits subject to the available production technologies. Production technologies are represented by nested CES functions. Production functions of agricultural and biomass commodities have a three-level nesting structure (Fig. 3). Substitution is possible between labor, land, and a composite input (top-level nest). For land, different land types can be chosen (second-level nest). Moreover, the composite input reflects substitution possibilities between fossil fuels (gas, oil and coal), capital, and electricity (conventional electricity or bioelectricity; second-level nest). For the choice between electricity types, a third-level nest shows substitution possibilities between conventional electricity and bioelectricity. Each nesting level is characterized by a specific substitution elasticity, which describes to what extent the factors can be substituted for each other. The production functions for agricultural and biomass commodities are as follows:

$$Y_i = CES(L_i, Z_i^N, G_i^{N_1}; \sigma_i) \quad (2)$$

for $i \in \{p, c, h, w\}$, and with nested CES-functions $Z_i^N = CES(Z_{i,w1}, Z_{i,w2}, Z_{i,w3}; \sigma_i^z)$, $G_i^{N_1} = CES(K_i, EL_i^N, GAS_i, CO_i, OIL_i; \sigma_i^G)$ and $EL_i^N = CES(Y_e, Y_b; \sigma_i^E)$ in which Y_i is the production of sector i, L_i is labor input in sector i, $Z_{i,w}$ is land input in sector i of land class $w \in \{w_1, w_2, w_3\}$, and GAS_i, CO_i and OIL_i are gas, coal,

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

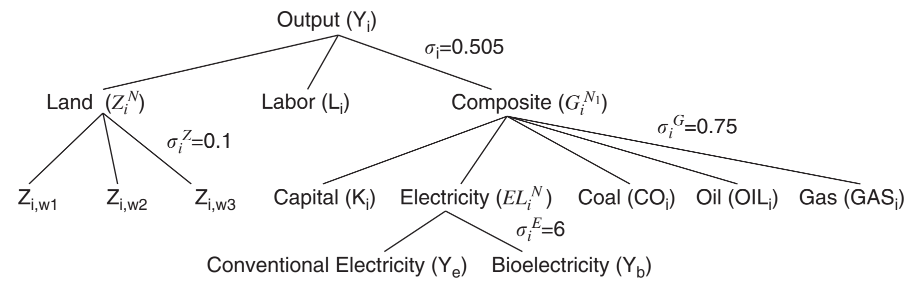

Fig. 3. Nesting structure of the production functions for potatoes, cereals, hemp, and willow.

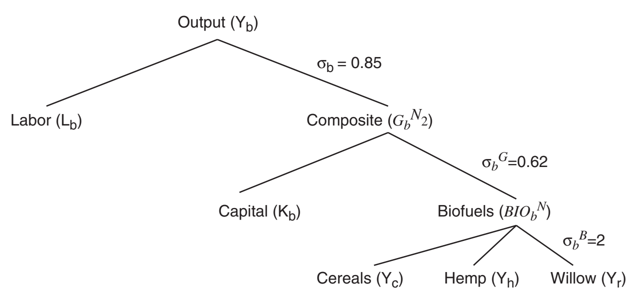

Fig. 4. Nesting structure of the production function for the bioelectricity sector.

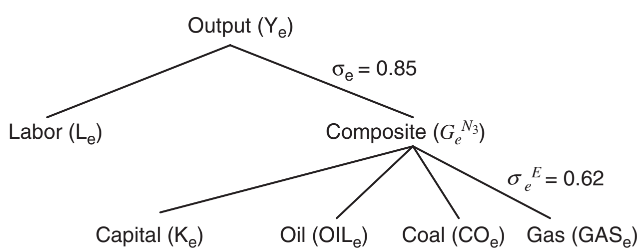

Fig. 5. Nesting structure of the production function for the conventional electricity sector.

and oil input in sector i, respectively. Parameters $\sigma_i, \sigma_i^Z, \sigma_i^G$ and σ_i^E are substitution elasticities.

The nested production function for the bioelectricity sector is described in Fig. 4. It is a three-level nested function, where the top-level nest shows substitution possibilities between labor and a composite input. The composite input reflects substitution possibilities between biomass crops and capital. The production function for bioelectricity is

$$Y_i = CES(L_i, G_i^{N_2}; \sigma_i) \tag{3}$$

for $i \in \{b\}$ with $G_i^{N_2} = CES(K_i, BIO_i^N; \sigma_i^G)$ and $BIO_i^N = CES(Y_c, Y_h, Y_w; \sigma_i^B)$ in which K_i is capital input in sector i, and σ_i^B is a substitution elasticity.

In our model, for conventional electricity production, substitution is possible between labor, capital, and fossil fuels. A combination of fossil fuels and capital can be substituted for each other in a top-level nest with labor (Fig. 5). The production function for electricity is

$$Y_i = CES(L_i, G_i^{N_3}; \sigma_i) \tag{4}$$

for $i \in \{e\}$ with $G_i^{N_3} = CES(K_i, GAS_i, CO_i, OIL_i; \sigma_i^E)$ where σ_i^E is a substitution elasticity.

2.3. Market clearance

In equilibrium models, demand cannot exceed supply for any commodity. The total supply of goods produced in sector i (Y_i) has to be greater than or equal to the demand by consumers (C_i) and intermediate demand from other sectors j (X_{ij}). For each commodity $i \in I$, the equilibrium constraint is defined as follows:

$$C_i + \sum_{j \in I} X_{ij} \leqslant Y_i. \tag{5}$$

Commodity prices are represented in the model by the shadow prices of the equilibrium constraints. Using the shadow prices, relative market prices can be determined. The wage rate is chosen as numéraire.

For the primary factors, total demand cannot exceed total supply. The total availability of labor and land is determined by the initial endowments of the representative consumer. Labor employed in the production sectors cannot exceed the total amount of labor available l^{tot}:

$$\sum_{i \in I} L_i \leqslant l^{tot}. \tag{6}$$

Land is divided into three land classes, which differ in terms of productivity. For each land class $w \in \{w_1, w_2, w_3\}$, land used for production cannot exceed land availability z_w^{tot}:

$$\sum_{i \in I} Z_{iw} \leqslant z_w^{tot}. \tag{7}$$

A simplifying, but necessary, assumption in the partial equilibrium model is that the supply of labor and land is immobile to other economic sectors.

Fossil fuels included in the model (gas, oil and coal) can be purchased at fixed prices from other sectors of the economy not implicitly modeled or can be imported.

2.4. Emissions

Emissions of CO_2 and N_2O are calculated as a function of production activities and fossil fuel use. CO_2 emissions are related to gas, coal and oil use

$$E_i^{CO_2} = GAS_i \varepsilon_{i,gas}^{CO_2} + CO_i \varepsilon_{i,co}^{CO_2} + OIL_i \varepsilon_{i,oil}^{CO_2}. \tag{8}$$

That is, the emissions of CO_2 resulting from gas, coal or oil combustion in sector i are calculated as the amount of gas, coal or oil needed (GAS_i, CO_i and OIL_i) for production purposes in the sector i multiplied by a fixed emission coefficient ($\varepsilon_{i,gas}^{CO_2}$ $\varepsilon_{i,co}^{CO_2}$ and $\varepsilon_{i,oil}^{CO_2}$).

Emissions of N_2O are mainly associated with crop production. Direct N_2O emissions occur mainly during the application of fertilizers and biological N_2 fixation (Mosier et al., 1998). In the model, N_2O emissions are attributed to the amount of land of a specific class used for agricultural production. Every crop has a specific coefficient reflecting the amount of fertilizers needed per unit of production

$$E_i^{N_2O} = \sum_{w \in W} Z_{iw} \varepsilon_{iw}^{N_2O} \tag{9}$$

for $i \in \{p, c, h, w\}$. N_2O emissions of sector i are calculated as the amount of land of land class w used in sector i multiplied by a sector-specific and land-class-specific fixed emission coefficient $\varepsilon_{iw}^{N_2O}$.

2.5. Taxes and subsidies

As prices are implicit in the model, taxes on consumption goods cannot be modeled directly. Following the approach of Ginsburgh and Keyzer (1997), taxes are included by differentiating between consumer prices (p_i^t) and producer prices (p_i). A unit tax t_i on produced goods is thus represented as a wedge between consumer and producer prices[2]

$$p_i^t = p_i + t_i. \tag{10}$$

As the model does not contain an income balance that takes the tax revenues into account, the welfare function has to be revised to include the tax (see Ginsburgh and Keyzer, 1997, for more details). Consequently, the objective function (1) is changed into:

$$\Omega = U - \sum_{i \in I} \gamma_i t_i TD_i, \tag{11}$$

in which the variable TD_i is total demand and γ_i is a scale parameter to account for benchmark values and Ω is the objective variable. The expression $\gamma_i t_i TD_i$ can be interpreted as a penalty on consumption that simulates a unit tax. In a partial equilibrium framework, the tax wedge can only be implemented if the balance equations are split into two parts. Therefore we introduce total demand as the sum of consumer and intermediate demand

$$TD_i = C_i + \sum_j X_{ij}. \tag{12}$$

The market clearance conditions (5) are rewritten as follows:

$$TD_i \leqslant Y_i. \tag{13}$$

The marginal value of Eq. (13) is the shadow producer price of good i, p_i. This price is equal to the marginal costs of production. The marginal value of Eq. (12) is the shadow consumer price, p_i^t and includes the tax. This can also be shown by taking the first-order conditions of model (11)–(13).

For primary production factors, a similar procedure is used by distinguishing between a demand price inclusive of taxes and a supply price. Subsidies can also be implemented in the model in this way, by specifying them as negative taxes.

3. Energy policies in Poland

The share of renewable energy in Poland is low compared to that of fossil fuel use. In 2001, around 0.8% of total energy consumption was considered to be from renewable sources (GUS, 2002b). Of this share, around 92% came from solid biomass (GUS, 2002b). It is expected that in the near future, bioelectricity from biomass will continue to play a dominant role within the renewable energy sources.

Recent policy changes in Poland have resulted in important changes in electricity laws and in the structure of the electricity sector. The policy scenarios analyzed in the following section refer to the possible instruments the Polish government can use to achieve their objectives on GHG emissions and renewable energy production. As a result of the policy changes, renewable energy production is likely to increase and the percentage of bioelectricity in total renewable energy production is subject to change.

Renewable energy production in Poland is expected to grow rapidly in the coming decades. This is for four reasons. First, a number of policies have recently been implemented in order to establish a competitive energy market. This included the introduction of the Energy Act in 1997 (DOE, 2000), the privatization of energy companies involved in the production and distribution of electricity by selling shares to investors in 1999 (Koschel et al., 2000), and the creation of the Energy Regulatory Authority (URE) (Art. 23 of the Energy Act; DOE, 2000).

Secondly, to promote renewable energy production, a decree was issued in 2000 (Maciejewska, 2003), obliging

[2] A convenient way to present the unit tax is to express it as a percentage of the benchmark producer price. As we calibrate the prices at unity (Harberger convention), this is comparable with the tax rate in an ad valorum tax. In the text, we therefore talk about percentage taxes.

electricity companies to purchase a certain share of their electricity from renewable sources. The contribution of renewable energy to total annual electricity sales is determined each year. The aim is to increase this contribution to 7.5% in 2010 and to 14% in 2020. To achieve this, the biomass sector must make a substantial contribution.

Thirdly, as a result of EU enlargement, the Polish Energy Law must be harmonized with EU laws. One of the first steps toward this was the opening of the Polish grid to EU countries (Article 4 of the Energy Act; DOE, 2000). This means that energy transmission and distribution companies are obliged to supply all end users (both domestic and foreign) on an equal basis, implying a free trade in conventional electricity/bioelectricity. Hence, Polish bioelectricity can be exported to other EU countries.

Fourthly, Poland ratified the Kyoto Protocol in 2002, thus committing itself to reducing GHG emissions by 6% compared to the 1990 emission level. Because of the structural changes in its economy, Poland currently fulfills this target. By 2002, Poland had reduced its 1990 CO_2 emission level by 17% (GUS, 2002b). Further emission reduction, however, will benefit Poland as it will allow the country to increase revenues from the sale of emission permits.

4. Analyses and results of the case study

To analyze the effects of energy policies on the production of biomass and agricultural commodities, we chose Poland as a case study. The country has a large potential for biomass production, in combination with a relatively large share of agriculture in the economy (Hille, 2000; Ignaciuk, 2002). The agricultural sector accounts for 7.2% of GDP. Arable farming accounts for around 3% of GDP, and 59% of the land is devoted to agriculture (GUS, 2002a). Moreover, its central location in Europe reduces the cost of transporting biomass to neighboring countries, such as Germany.

The results of two scenarios for stimulating the bioelectricity sector are presented in this section. For each scenario, different choices regarding the redistribution of the tax revenues involved are analyzed. The characteristics of the benchmark equilibrium and calibration of the model parameters are discussed in Section 4.1. This is followed in Section 4.2 by a discussion of the policy scenarios. The results of the model simulations are presented in Sections 4.3 and 4.4.

4.1. Data calibration

Two types of data are used in the model. First, a partial social accounting matrix (PSAM) for Poland is specified in order to determine the benchmark equilibrium. For this, a social accounting matrix for Poland for 1997 taken from GTAP (Dimaranan and McDougall, 2002) is used. In the PSAM, agricultural and biomass data are disaggregated based on the FEP-FARM model built by Mueller (1995), using FAO country land use data for Poland.

Secondly, substitution elasticities between the different production inputs in the production functions are specified. These data are based on literature surveys and experts' opinions. Estimates of substitution elasticities between energy, capital, and labor were estimated by Kemfert (1998) and are provided in Figs. 2, 3, and 4. The full data set used in the model can be obtained from the authors.

The three land use classes used in the model correspond to the six land classes used in the Polish land classification system. Land type $w1$ comprises very good and good land (classes I & II), $w2$ reasonably good and average (classes III & IV) and $w3$ poor and very low quality (classes V & VI). Data on current land use patterns is obtained from Polish statistics (GUS, 2002a).

4.2. Scenarios

In this section we present two policy scenarios aimed at increasing the share of bioelectricity in total electricity production and at reducing CO_2 emissions. An important policy goal of the Polish government is to reach an increase of this share up to 7.5%.

In Scenario 1 a unit tax on conventional electricity consumption and in Scenario 2 a net carbon tax on fossil fuels is introduced. For both scenarios, three subscenarios are considered, reflecting alternatives for stimulating the biomass and bioelectricity sectors. The scenarios are presented in Table 1. As the model does not allow for modeling a carbon market, the carbon content of gas, oil, and coal is determined, which is used to estimate different tax levels for the use of the three types of fossil fuels. Compared to the carbon content per ton of oil equivalent gas and coal have a 25% lower and 35% higher carbon content, respectively (IEA, 1998). For all six scenarios we analyze changes of GHG emissions, production, prices, and land use as compared to benchmark.

Table 1
Definition of scenarios

	Scenario 1	Scenario 2
a	Electricity tax without subsidies	Carbon tax without subsidies
b	Electricity tax plus a subsidy on bioelectricity production	Carbon tax plus a subsidy on bioelectricity production
c	Electricity tax plus a subsidy on biomass production	Carbon tax plus a subsidy on biomass production

In the model, we adopt a subsidy rate of 25% for bioelectricity production (Scenarios 1b and 2b) and a subsidy on bioelectricity production of 90% (Scenarios 1c and 2c). For biomass production, we adopt this high rate to analyze whether boosting production of biomass crops hemp and willow is an option. Two things have to be kept in mind here. First, for bioelectricity production, currently much more cereals than biomass crops are used. However, only a very small part of total cereal production (0.25%) is used for bioelectricity production. Hemp and willow account for around 15% of bio-fuels in bioelectricity production.

In order to compare the effects of the different policies, we adopt tax levels for which the tax yields net of subsidies are equal for all scenarios. In that way the revenues of the taxes in our model are the same for all scenarios. Of course, effects may differ for each of the individual sectors concerned in the model economy. This approach is analogous to an equal yield tax reform as used in many CGE models (see, e.g. Dellink, 2005). Moreover, tax levels have been determined in such a way that in Scenario 1b the share of bioelectricity in total electricity production is equal to the policy objective of 7.5%. This is attained at an electricity tax of 10.0%. For the other scenarios, the electricity tax levels for which the tax yields net of subsidies are the same as in Scenario 1b are 9.79% for Scenario 1a and 9.82% for Scenario 1c. The oil taxes for which the tax yields are equal are 26.0%, 26.6% and 26.1% for Scenarios 2a, 2b and 2c, respectively. Gas and coal taxes can be determined as described above.

4.3. Scenario 1: electricity tax

The impact of a tax on conventional electricity consumption is analyzed in this section. The results show that the effect of such a tax on conventional electricity consumption, and therefore on CO_2 emissions, is small. CO_2 emissions reduce linearly with electricity taxes. The results of Scenario 1a show that 9.79% electricity tax results in 1.2% decrease in CO_2 emissions. Scenarios 1a, 1b, and 1c show interesting differences with regard to bioelectricity production and agricultural and biomass production. We discuss the differences between these scenarios for the different sectors considered. Tax levels adopted, which result in equal tax yields net of subsidies in each scenario are 9.79%, 10.0% and 9.82% for Scenarios 1a, 1b and 1c, respectively. The results are presented in Table 2–4.

First, as a result of the increase in conventional electricity price, conventional electricity consumption and production decrease for all three scenarios (i.e., 1a, 1b, and 1c) within a range of 1.9 to 7.8% (see Table 2). As bioelectricity can easily be substituted for conventional electricity, the production and consumption of bioelectricity increase. The Polish policy objective of increasing the share of bioelectricity up to 7.5% is achieved in Scenario 1b only. This requires an increase of bioelectricity production by 815%. In Scenario 1a, the increase is 71.2%, which results in a share of bioelectricity production of 1.4%. In Scenario 1c, the production of bioelectricity increases by 280%, resulting in an increase of the bioelectricity share of 3.1%. These large increases of bioelectricity production can be explained by the large differences in the sizes of the sectors. Currently, the biomass and bioelectricity sectors are very small relative to the agricultural and electricity sectors. The biomass sector is only 0.03% of the total agricultural and biomass sector, and the bioelectricity sector is 0.8% of the total electricity sector.

Second, in Scenario 1a, the bioelectricity price hardly changed. Subsidies on biomass and bioelectricity result in a substantial reduction of bioelectricity prices despite the fact that increasing input prices (especially of land) give an upward pressure on those prices. The subsidy on bioelectricity in Scenario 1b results in a price decrease of

Table 2
Percentage changes in production, consumption and prices compared to benchmark in Scenarios 1a, 1b, and 1c

	Potatoes	Cereals	Hemp	Willow	Electricity	Bioelectricity
1a: *Electricity tax, no subsidy*						
Production	5.6	5.6	69.3	71.5	−1.9	71.2
Consumption	5.6	5.4	5.8	5.6	−1.9	71.2
Prices	0.2	0.4	−0.2	0.1	9.8	0.1
1b: *Electricity tax, bioelectricity subsidy*						
Production	3.7	5.5	786	828	−7.8	815
Consumption	3.7	3.5	4.3	4.5	−7.8	814
Prices[a]	0.1	0.4	−0.5	−0.8	10.0	−25.0
1c: *Electricity tax, biomass subsidy*						
Production	4.2	4.0	11111	10979	−4.5	280
Consumption	4.2	4.0	506	484	−4.5	270
Prices[a]	0.1	0.4	−90.6	−90.3	9.8	−12.4

[a]Prices after subsidy.

Table 3
Area of biomass and agricultural commodities in benchmark situation and in Scenarios 1a, 1b and 1c

	Thousands ha		
	Land class w1	Land class w2	Land class w3
Benchmark			
Potatoes	0.0	404.6	901.8
Cereals	416.2	8527.9	0.0
Hemp	0.0	0.0	0.07
Willow	0.0	0.1	0.4
1a: *Electricity tax, no subsidy*			
Potatoes	0.0	402.2	901.6
Cereals	416.2	8530.1	0.0
Hemp	0.0	0.0	0.1
Willow	0.0	0.3	0.5
1b: *Electricity tax, bioelectricity subsidy*			
Potatoes	0.0	393.0	897.8
Cereals	416.2	8539.0	0.0
Hemp	0.0	0.0	0.6
Willow	0.0	0.6	3.9
1c: *Electricity tax, biomass subsidy*			
Potatoes	0.0	468.4	841.3
Cereals	416.2	8460.6	0.0
Hemp	0.0	0.0	7.7
Willow	0.0	3.6	53.3

Note: the land classes mentioned above correspond to the land classes applied by the Polish government. Land class *w*1 corresponds to land classes I and II, *w*2 to III and IV, and *w*3 to V and VI.

Table 4
Percentage changes in total emissions and semi welfare level compared to benchmark in Scenarios 1a, 1b, and 1c

	CO_2	N_2O	SWF
1a: Electricity tax, no subsidy	−1.2	0.0	−4.5
1b: Electricity tax, bioelectricity subsidy	−6.7	0.0	−4.8
1c: Electricity tax, biomass subsidy	−3.7	−0.3	−4.4

bioelectricity of 25%, whereas the subsidy on biomass production in Scenario 1c results in a price decrease of bioelectricity of 12.4%. As biomass products are only one of the inputs in bioelectricity production, the bioelectricity price in Scenario 1c is higher than it is in Scenario 1b.

Third, the effects on the production of the biomass crops willow and hemp are clear. The increase is the smallest (around 70%) in Scenario 1a, substantial (786% for hemp and 828% for willow) in Scenario 1b, and large (around 11000% for hemp and willow) in Scenario 1c. In Scenarios 1b and 1c, the amount of land used for biomass production increases substantially. In Scenario 1b the amount of hectares for hemp and willow increases from 70 to 600 ha and from 500 to 4500 ha (Table 3), respectively. Scenario 1c resulted in an increase of plantation area of hemp and willow up to 7700 and 56,900 ha, respectively. The largest increase is on low quality land, land class *w*3. Note that the number of hectares cultivated with biomass crops is still a very small percentage of total acreage (see Table 3). As a result of the land use changes, land prices increase, leading to an increase in potato and cereal prices in all three scenarios and an increase in willow prices in Scenario 1a. However, this does not have a negative effect on potato and cereal production. In all three scenarios, the production of these commodities increases (ranging from 3.7% to 5.6%). If less labor, capital, and oil are used for electricity or bioelectricity production, these inputs will partly be used for intensifying agricultural and biomass production, resulting in higher yields. In Scenario 1c, cereal production increases less than it does in Scenario 1b, because a proportion of the cereals is used for bioelectricity generation. If only willow and hemp production is subsidized, less cereals will be used for bioelectricity generation.

Next, the emissions of CO_2 and N_2O are affected by the electricity tax. Table 4 shows that Scenario 1a has the lowest impact and Scenario 1b the highest impact on CO_2 emissions. In Scenario 1a, the effect is so small because the reduced demand for gas, oil and coal by the electricity sector is partly compensated for by an increased demand by the agricultural and biomass sectors. If the electricity tax is combined with a subsidy on biomass or bioelectricity production, gas, oil and coal demand decrease even more. Introducing a 25% subsidy on bioelectricity can provide a stronger incentive for the economy to reduce the use of fossil fuel than by introducing a 90% subsidy on biomass production. However, as the effect of the electricity tax on electricity generation is small, the effect on CO_2 emissions is small as well. The highest reduction is achieved in Scenario 1b (−6.7%). The effects on N_2O emissions are small as well. In Scenarios 1a and 1b they are negligible and in 1c Scenario the emission decrease with 0.3%. The biomass subsidy results in a change in land use supporting the biomass sector, which emits less N_2O per hectare of land than the agricultural sector does. Welfare is affected by the different taxes and subsidies analyzed. The welfare losses range within 4.4–4.8% of the benchmark situation.

An interesting, and for some people also a surprising, result of this analysis is that both the agricultural and the biomass sector can expand their output if the use of bioelectricity is promoted. This is the result of the reallocation of primary factors from electricity sector to other sectors in the economy. Under these circumstances there may be no conflict between agricultural and biomass production. Moreover, a small reduction in electricity production can lead to a substantial stimulus for the much smaller biomass sector. The effects on CO_2 emission reduction range between 1.2% and 6.7%. The impact on N_2O production, however, is small and ranges from 0% to 0.3%

4.4. Scenario 2: carbon tax

Alternatively, but equivalent to introducing a carbon tax, we introduce a tax on the use of fossil fuels in which differences in carbon content are taken into account. As discussed above, carbon content of gas is 25% lower and that of coal is 35% higher than carbon content of oil. Fossil fuel taxes adopted in the model are such that they are equivalent to a carbon tax per unit of carbon in the fuel used as input. For simplicity we report only oil taxes, whereas tax wedges for coal and gas can be calculated from the ratios presented above. The results are presented in Table 5–7.

Scenarios 2a, 2b, and 2c show interesting differences with regard to production, prices and land use in different sectors. First, as expected, results show that a carbon tax is a more efficient policy tool for reducing CO_2 emissions than an electricity tax. However, it fails to reach the policy goal of a 7.5% share of bioelectricity in total electricity production, given that the same amount of tax yield is collected as in Scenario 1. The share of bioelectricity in Scenarios 2a, 2b and 2c are 1.3%, 6.8% and 2.8%, respectively. This corresponds to an increase of bioelectricity production of 48%, 693% and 231% in Scenarios 2a, 2b and 2c respectively. If bioelectricity production or biomass production is subsidized with a 25% and 90% subsidy rate respectively, bioelectricity prices decrease. This effect is caused mainly due to substitutability of conventional electricity by bioelectricity. As expected, the largest effect on bioelectricity production and consumption occurs in Scenario 2b.

Second, as a result of tax on fossil fuels and the resulting price increase, all input prices increase. Because of the increased price of the inputs used for conventional electricity production, the price of conventional electricity increases in all three scenarios by 8.2% in Scenarios 2a and 2c and 8.4% in Scenario 2b (see Table 5). However, the effects on electricity production differ between Scenarios 2a, 2b, and 2c. In Scenario 2a, it decreases the least (6.7%), and in Scenario 2b it decreases the most (11.6%). These differences are caused by substitution between conventional electricity and bioelectricity, when bioelectricity becomes cheaper in Scenarios 2b and 2c.

Table 6
Sown area of biomass and agricultural commodities in benchmark situation and in Scenarios 2a, 2b and 2c

	Thousands ha		
	Land class w1	Land class w2	Land class w3
Benchmark			
Potatoes	0.0	404.6	901.8
Cereals	416.2	8527.9	0.0
Hemp	0.0	0.0	0.07
Willow	0.0	0.1	0.4
2a: *Carbon tax, no subsidy*			
Potatoes	0.0	399.6	901.5
Cerealsv	416.2	8532.9	0.0
Hemp	0.0	0.0	0.1
Willow	0.0	0.1	0.6
2b: *Carbon tax, bioelectricity subsidy*			
Potatoes	0.0	384.0	897.5
Cereals	416.2	8548.3	0.0
Hemp	0.0	0.0	1.1
Willow	0.0	0.3	3.7
2c: *Carbon tax, biomass subsidy*			
Potatoes	0.0	457.0	850.0
Cereals	416.2	8472.6	0.0
Hemp	0.0	0.0	4.4
Willow	0.0	3.1	47.8

Note: the land classes mentioned above correspond to the land classes applied by the Polish government. Land class *w*1 corresponds to land classes I and II, *w*2 to III and IV, and *w*3 to V and VI.

Table 5
Percentage changes in production, consumption and prices compared to benchmark in Scenarios 2a, 2b, and 2c

	Potatoes	Cereals	Hemp	Willow	Electricity	Bioelectricity
2a: *Carbon tax, no subsidy*						
Production	−2.2	−1.5	45.4	50.1	−6.7	48.1
Consumption	−2.2	−1.6	−1.7	−0.6	−6.7	48.0
Prices	2.2	1.4	1.5	0.2	8.2	0.2
2b: *Carbon tax, bioelectricity subsidy*						
Production	−3.7	−1.3	658	715	−11.6	693
Consumption	−3.7	−3.1	−2.5	−1.4	−11.6	692
Prices[a]	2.3	1.5	0.7	−0.8	8.4	−24.8
2c: *Carbon tax, biomass subsidy*						
Production	−3.3	−2.8	7510	9778	−8.8	231
Consumption	−3.3	−2.7	422	479	−8.8	222
Prices[a]	2.2	1.4	−89.2	−90.4	8.2	−12.3

[a]Prices after subsidies.

Table 7
Percentage changes in total emissions and semi welfare level compared to benchmark in Scenarios 2a, 2b, and 2c

	CO_2	N_2O	SWF
2a: Carbon tax, no subsidy	−17.7	0.0	−9.4
2b: Carbon tax, bioelectricity subsidy	−21.9	0.0	−9.4
2c: Carbon tax, biomass subsidy	−19.1	−0.3	−9.2

Third, in Scenario 2a, production of biomass crops increases considerably with 45% and 50% for hemp and willow, due to an increased demand for biomass crops by the bioelectricity sector. In Scenarios 2b and 2c, effects are much more prominent. Production of hemp and willow increase, respectively, with 658% and 715% in Scenario 2b and with 7510% and 9778% in Scenario 2c. Table 6 shows that the area of biomass crops increases, although total biomass acreage is still small compared to agricultural acreage. As a result of the changes in biomass production, less land can be allocated to the production of cereals and potatoes, and agricultural production decreases. Unlike in the electricity tax scenario (Scenarios 1a, 1b, and 1c) discussed above, agricultural intensification cannot compensate for the loss of agricultural land. In the previous scenario, less electricity was produced and part of the labor and capital released was used to intensify agricultural production. In the current scenario, less conventional electricity is produced as well. However, as a result of the carbon tax, the electricity sector substitutes fossil fuels for labor and capital. Thus, less labor and less capital become available to intensify agricultural production. Moreover, agricultural prices increase slightly (around 2.2% and 1.4% for potatoes and cereals respectively). This is caused by the decrease of agricultural production and the increase of fossil fuel prices, which are an input into agricultural production.

Fourthly, the reduced demand for oil and coal resulting from the introduction of a carbon tax implies that the reduction in CO_2 emissions is much larger than it is in the electricity tax scenario. The larger the reduction in conventional electricity production, the larger the reduction in CO_2 emissions. The reductions in CO_2 emissions are 17.7%, 21.9% and 19.1% for Scenarios 2a, 2b and 2c, respectively, which corresponds to oil tax levels of 26.0%, 26.6% and 26.1%, respectively. The reduction in emissions for Scenarios 2b and 2c is also explained by the reduction in the use of fossil fuel in the agricultural sector. Emissions of N_2O are significantly affected only in Scenario 2c, in which a part of the land use shifts from agriculture to biomass production. N_2O emission reductions are similar to those in the electricity tax scenario. As in Section 4.3, the reduction is most prominent in Scenario 2c in which the land use changes are largest. Finally, in Scenarios 2a, 2b, and 2c, the impact on semi-welfare is considerably higher than in previous scenario (−9.2 to −9.4%, see Table 7).

To conclude, having the same tax yield net of subsidies in both scenarios, a carbon tax results in larger environmental benefits but at higher welfare costs than an electricity tax. It can easily be seen, however, that average welfare costs per unit of emission reduction are lower for a carbon tax than for an electricity tax.

The carbon tax scenario illustrates that biomass and agricultural production are in competition. The intensification of agricultural production is not possible because the required labor and capital is used in the conventional electricity sector, where it is used to intensify production with lower inputs of more expensive fossil fuels.

5. Conclusions

This paper presents a partial equilibrium model for the environmental–economic analysis of biomass production. The model was developed to investigate the effects of different energy policies on biomass and food production, conventional and bioelectricity supply, prices, and GHG emissions. Before discussing the results, we would like to mention some of the limitations of the model. This is necessary because the results of the model depend crucially on the assumptions made in the model. Some of these should be addressed if the model is to be used for policy recommendations. First, a more detailed specification of production sectors, primary factors, and emissions would allow us to simulate more realistic scenarios. Second, a dynamic model would be able to show the transition path toward a "biomass economy." Third, a full open economy specification is necessary to properly specify all markets. Fourth, if we could include the positive impact of increased environmental quality on welfare, we would be able to calculate the efficient level of environmental policy and determine the optimal mix of agricultural and biomass production.

Despite these limitations, the current analysis shows the most important mechanisms that govern the interactions between agriculture and biomass in the presence of a tax on conventional electricity or on carbon use. First, from a sustainable energy point of view (i.e., increasing the production of bioelectricity), both policies serve their purpose: bioelectricity production increases, although it increases slightly more if an electricity tax rather than a carbon tax is levied. Only in Scenario 1b the bioelectricity share increase up to the Polish policy goals of 7.5% share in total electricity use. Moreover, the choice of the subsidy mechanism has a large impact on bioelectricity production. For both tax policies and given the subsidy rates adopted, the scenario in which bioelectricity production is subsidized performs the best for this purpose.

Second, looking at the effects of the taxes on food prices, an increase in both cereal and potato prices occurs in all scenarios. The electricity tax has a smaller effect on the food price. Despite the subsidies, changes in food prices are almost the same across both scenarios.

As for CO_2 emissions, an electricity tax is not as effective as a carbon tax, as expected. For N_2O emissions, the difference between both tax scenarios is negligible. The different subsidy schemes influence emissions significantly. A subsidy on bioelectricity production leads to the largest reduction in CO_2 emissions, whereas a subsidy on biomass production is the most effective for reducing N_2O emissions.

Both energy policies are welfare reducing (at least, if environmental benefits are neglected). An electricity tax reduces welfare less than a carbon tax does. For both energy policies, the welfare losses are the smallest if biomass production is subsidized.

To conclude, a fossil fuel tax combined with a subsidy on biomass can reduce substantially the emissions of CO_2 and N_2O, although at higher welfare costs and resulting in a smaller share of the bioelectricity sector in total electricity production than an electricity tax. Such a policy, however, leads to competition between food production and biomass production. This competition can be avoided by taxing conventional electricity consumption instead of fossil fuel use, however at the expense of higher CO_2 emissions.

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