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Do Climate Policies Contribute to Nature Conservation? On Biomass and Land Use in an AGE Approach

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Do Climate Policies Contribute to Nature Conservation? On Biomass and Land Use in an AGE Approach

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Abstract. This paper deals with the economic interactions between biomass production, climate policies, nature conservation, and land use allocation. To investigate the possible transition from conventional electricity to biomass based electricity and its effects on land use and re-establishing natural areas a computable general equilibrium model is introduced. The model and its application to Poland illustrate the trade-off between production of biomass and 'traditional' agricultural goods. Three scenarios are presented and compared in context of (a) unilateral policy, and (b) multilateral policy. The results show that the first Polish policy target of achieving a 7.5 percent bioelectricity share in total electricity production can be achieved in all three scenarios. Moreover, for a small reduction of greenhouse gases 10 percent, the emission permit price is around 5 Euro per ton of carbon. This price increases to around 50 Euro per ton of carbon if the emission reduction is increased to 50 percent. Concerning land use allocation, Poland can substantially increase its semi-natural areas. As expected, prices of agricultural commodities increase due to competition for primary resources such as land. If the price of permits is around 30 Euro per ton of carbon, prices of agricultural commodities may rise by about 10 percent.

Key words: Applied General Equilibrium (AGE), Biomass, Energy Policy, Nature Conservation, Renewable Energy

JEL classification: Q2, Q4, D5

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1.   Introduction

In many European countries agriculture dominates in current land use. Natural areas are diminished to little oases scattered across countries. Currently, much attention is paid to biomass crops that can potentially be used as a source of carbon free fuel and that can change current land use and land cover patterns. Moreover, increasing biomass production can result in more semi-natural areas. Such a change might take place if stringent environmental policies for climate change reduction are implemented

Due to the Kyoto protocol and subsequent climate policies, there is an increasing demand for carbon free energy (Azar & Rodhe, 1997). Much attention is paid to biomass crops that can provide clean energy, increase the share of semi-natural areas and improve biodiversity (Makeschin, 1994; Borjesson, 1999; Cook & Beyea, 2000; Dhondt et al., 2004). Forest plantations and other biomass plantations have the potential to sequester carbon in the soil (Tolbert et al., 2002). Moreover, they improve the quality of land and create a suitable environment for many species (Lewandowski et al., 2000; Londo, 2002). Due to these characteristics, biomass plantations are considered to be semi-natural areas.

There are, however, many concerns about the land availability for biomass production. On the one hand, some scientists are worried that due to changing life style patterns, more land is needed to satisfy human food requirements (Bouma et al., 1998; Gerbens-Leenes & Nonhebel, 2002). On the other hand, others argue that today's overproduction of food allows for using agricultural land for other practices (WRR, 1992; Tilman et al., 2002; Trewavas, 2002). Wolf (2003) indicates that current food requirements can be sustained with only 55% of the total productive area, leaving 45% for e.g. biomass plantations.

Different types of models exist to study the possible land shift between agriculture and biomass or forestry and its impact on the economy and environment. Linear programming has been used often as a tool for analysing land allocation and energy production. Examples of such models include POLYSYS (Torre Ugarte de la & Ray, 2000), GOAL (WRR, 1992), BEAP (Gielen et al., 2001b), and MARKAL MATTER (Gielen et al., 2001a). 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 energy production. Walsh et al. (2003) modified the agricultural model POLYSIS to include specific biomass crops (switch grasses, poplar and willow) and to provide estimates for changes in annual land use. BEAP and MARKAL MATTER focus on detailed descriptions of the energy system, and their biomass modules boil down to agricultural and forestry residuals and waste.

Johansson, and Azar (2004) set up a dynamic, non-linear optimisation model, LUCEA. This model deals with competition between biomass and food crops, using a bottom up approach. They determine food and energy prices in case of stringent climate policies in the USA with exogenous CO_2 emission permit prices. They focussed on different energy carrier possibilities, and they did not focus on modeling the interactions within the entire economy and the secondary effects of policy implementations.

An example of an equilibrium model used for determining the allocation of food and biomass crops is the partial equilibrium model ASM by McCarl (1993). This is a model where the detailed agricultural sector in USA is described. The dynamic FASOM model is the ASM model, enlarged with a forestry sector (van Ierland & Lansink, 2003). Another successor of the ASM model is the ASMGHG model, which includes emissions of greenhouse gases and

mitigation possibilities (Schneider and McCarl (2000; 2003)). Different from our approach, these models focus mainly on the agricultural and forestry sectors. In our paper, the interactions between agricultural sectors and other sectors in the economy are included. Moreover, we include explicitly the electricity market and endogenous CO_2 permit prices.

The aim of this paper is to investigate the impact of emission permit policies to reduce greenhouse gas emissions by means of promoting biomass and bioenergy. We analyse the impact of these policies on land use and land cover change, and possible impacts on nature, mainly on reestablishment of natural areas. In this context, we analyse how these policies might affect production of agricultural commodities and trade patterns of biomass and bioelectricity.

For this purpose, we develop an applied general equilibrium model (AGE) with special attention to biomass and agricultural crops for a small open economy, with an Armington specification for international trade. The model describes the entire economy, but explicitly focuses on production of agricultural and biomass crops. The model distinguishes 35 sectors, including six agricultural and biomass sectors. Moreover, the bioelectricity sector is explicitly described. We include three primary production factors: labour, capital and land. Three land classes are identified to capture differences in productivity from different land types. The emissions of the major greenhouse gases CO_2, N_2O and CH_4 are calculated. We focus on possible land switches between agriculture and biomass. Such a reallocation can bring additional benefits in terms of an increased size of semi-nature areas. This integrated analysis is performed using data for Poland. We analyse both a unilateral and multilateral environmental policy setting and their impact on trade patterns and the environment.

The paper is structured as follows. Section 2 describes the model structure. In Section 3 and 4, the data and the background situation in Poland are presented. Section 5 introduces the scenarios. In Section 6, the results are discussed. Finally, conclusions are drawn in Section 7.

2. Model description

The model is a comparative-static general equilibrium model, where a benchmark equilibrium situation is compared to an equilibrium that emerges from a policy impulse. This model is useful to illustrate the medium-term equilibrium state and analyses the steady state properties of the equilibrium. For an overview of environmental-economic applied general equilibrium models see e.g. Conrad (1999) for static and Dellink (2005) for dynamic models.

2.1. Model structure

This model consists of a set of 'economic agents', operating on perfectly competitive markets, who demand and supply commodities or services named 'goods'. The equilibrium that emerges, concerning the allocation of resources, is based on simultaneous decision making of all agents.

There are three categories of agents: (i) consumers, (ii) producers, and (iii) government. A *representative consumer* maximises 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 and $EL^N = CES\left(C_e, C_{be}; \sigma^{EL}\right)$ where C_e and C_{be} are consumption of Electricity and Bioelectricity respectively. Parameters σ^U and σ^{EL} are substitution elasticities. Consumers own production factors; land, labour and capital and consume produced goods.

All markets clear, which means that supply equals demand for all goods through adjusting relative prices (Ginsburgh & Keyzer, 1997; Dellink, 2005). Call I the set of sectors. Total supply of goods produced in sector $i \in I$ (Y_i) has to be greater than or equal to demand by consumers (C_i) and intermediate demand from other sectors j (ID_{ij}). For each commodity $i \in I$, the equilibrium constraint is defined as follows:

$$C_i + \sum_{j \in I} ID_{ij} \leq Y_i \tag{2}$$

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 consumer price index is chosen as numéraire.

Producers maximise 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 seven-level nesting structure (Figure 1).

$$Y_i = CES\left(PR_i^N, E_{e,i}; \sigma_i^Y\right) \tag{3}$$

for $i \in$ {*all sectors excluding fuel sectors*}, and with nested CES-functions $PR_i^N = CES\left(ID_i^N, ELK_i^N, Z_i^N; \sigma_i^{PR}\right)$ where: $ID_i^N = CES\left(ID_{1i}...ID_{Ii}; \sigma_i^{ID}\right)$,

$ELK_i^N = CES\left(ENER_i^N, KL_i^N; \sigma_i^{ELK}\right)$, and $Z_i^N = CES\left(Z_{i,w1}, Z_{i,w2}, Z_{i,w3}; \sigma_i^Z\right)$. In which PR_i is the production of sector i, $E_{e,i}$ are emissions of e pollutant by the i sector, ID_i is the intermediate input, $Z_{i,w}$ is land input in sector i of land class $w \in \{w_1, w_2, w_3\}$.

The capital-labour nest is described as follows: $KL_i^N = CES\left(K_i, L_i; \sigma_i^{KL}\right)$ where L_i is labor input in sector i and K_i is capital in sector i. The energy nest is described as $ENER_i^N = CES\left(ELEC_i^N, FU_i^N; \sigma_i^{ENER}\right)$ where $ELEC_i^N = CES\left(ID_e, ID_{be}; \sigma_i^{ELEC}\right)$ and

$FU_i^N = CES\left(CO_{coal}^N, OL_{oil}^N, ROL_{roil}^N, GA_{gas}^N; \sigma_i^{FU}\right)$ where $CO_{coal}^N = CES\left(ID_{coal}, E_{CO_2,coal}; \sigma_{coal}^{CO}\right)$,

$OL_{oil}^N = CES\left(ID_{oil}, E_{CO_2,oil}; \sigma_{oil}^{OL}\right)$, $ROL_{roil}^N = CES\left(ID_{roil}, E_{CO_2,roil}; \sigma_{roil}^{ROL}\right)$, $GA_{gas}^N = CES\left(ID_{gas}, E_{CO_2,gas}; \sigma_{gas}^{GA}\right)$.

ID_e and ID_{be} is an intermediate delivery from Electricity and Bioelectricity sectors and ID_{coal}, ID_{oil}, ID_{roil}, ID_{gas} are the intermediate delivery of natural resources (Coal, Oil, Refined Oil and Gas). Parameters $\sigma_i^Y, \sigma_i^{PR}, \sigma_i^{ID}, \sigma_i^Z, \sigma_i^{ELK}, \sigma_i^{KL}, \sigma_i^{ENER}, \sigma_i^{ELEC}, \sigma_i^{FU}, \sigma_i^{ROL}, \sigma_i^{CO}, \sigma_i^{OL}$ and σ_i^{GA} are the respective substitution elasticities.

Other agriculture
Rape
Willow
Hemp
Wheat
Cereals grains
Animal products
Forestry
Vegetable oils and fats
Food products
Textiles
Wood products
Paper products
Chemicals
Metal and mineral products
Transport and vehicles equipment
Electronic equipment
Manufactures
Gas manufacture and distribution
Water
Construction
Trade
Transport
Water transport
Air transport
Communication
Services
Public spending

Intermediate deliveries

Coal
Emissions CO_2

CO

Oil
Emissions CO_2

OI

Gas
Emissions CO_2

GA

Refinery
Emissions CO_2

RoI

Fuels

Conventional electricity
Bioelectricity

Electrictricity

Energy

ELK

Labor
Capital

Primary Factors

Production

Very good land
Good land
Poor land

Land

Output

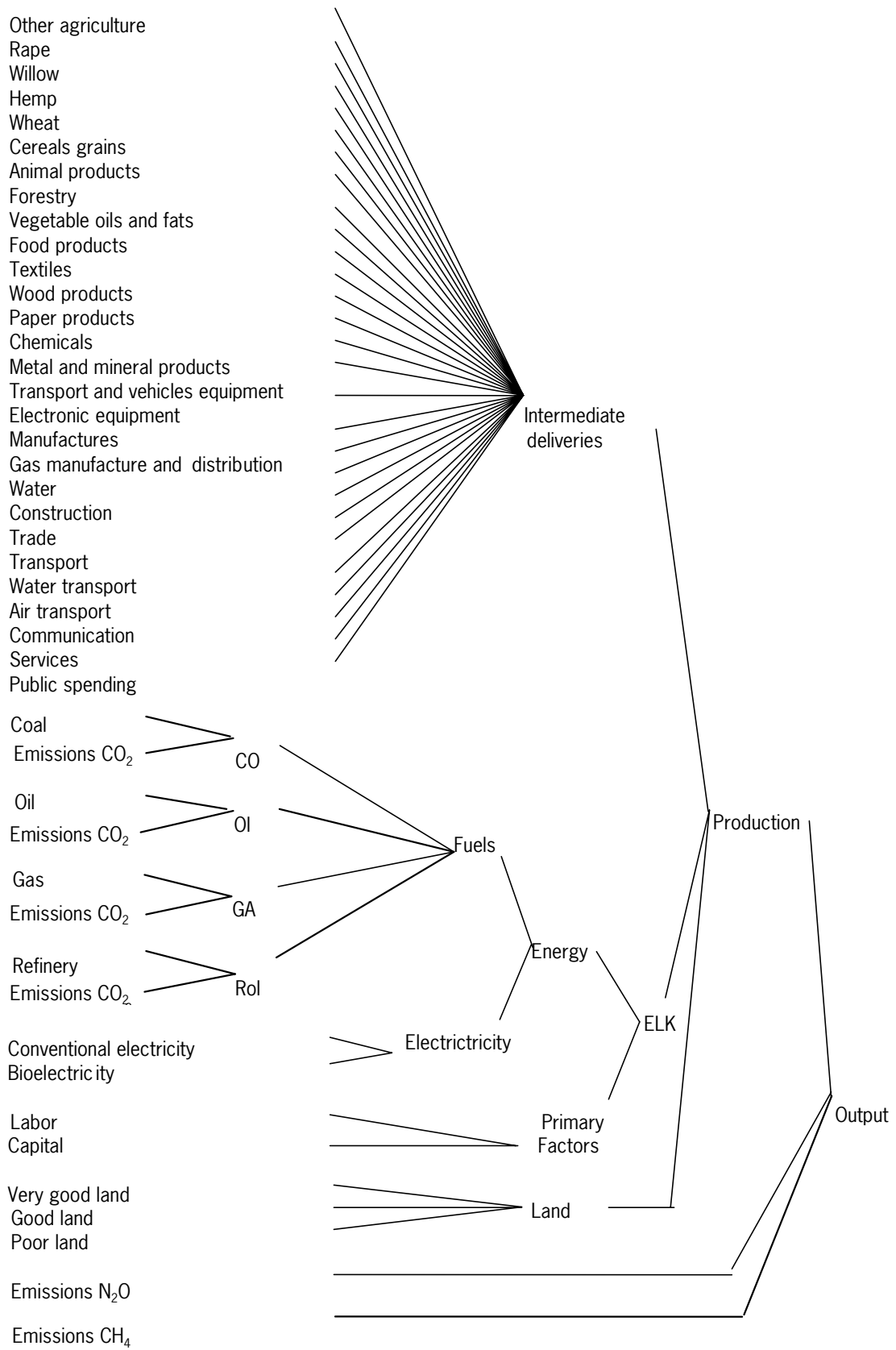Emissions N_2O

Emissions CH_4

Figure 1   Nested structure of the production function (CES)

Government collects taxes on goods and factors and uses them to finance public consumption and pay lump-sum transfers to private households. For government behaviour the assumption is made that government surplus or deficit is unaffected by the model simulations. The assumption is obtained by adjusting the tax rates to compensate changes in income/expenditures of the government. Hence, its surplus/deficit remains the same (Dellink, 2005).

Labour supply is fixed. The wage rate is fully flexible. The total availability of labour is determined by the initial endowments of the representative consumer.

2.2. Land use

Land is divided into three land classes, which differ in terms of productivity. The total amount of hectares of specific land type is multiplied by the average price of hectare of specific conditions. The price of land reflects its productivity. For each land class $z \in \{z_1, z_2, z_3\}$, land used for production cannot exceed land availability z_w^{tot}.

$$\sum_{i \in I} Z_{iw} \leq z_w^{tot} \tag{4}$$

In the model the total land use for agriculture, biomass and forestry is accounted. Crops can be cultivated on all land types, however substitution possibilities are low (see Appendix 1). Generally, certain types of crops are grown on specific soils.

Most biomass crops and forestry products are grown on the least profitable soils. In the benchmark situation, agriculture uses about 60 percent of the land. The transformation from intensive agriculture to forestry reduces pressure on the environment and supports biodiversity. That is why these transformations are considered as reclaiming semi-natural areas.

2.3. Trade specification

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 Polish import demands. Trading partners are not modelled explicitly, however, they are addressed as the 'Rest of the World' (RoW) (Keller, 1980). The demand by the RoW represents Polish exports and its supply represents Polish imports.

International trade is often represented with the underlying assumptions of either the Heckscher-Ohlin or the Armington model. Hecksher-Ohlin models assume homogeneity of traded goods and technologies are identical in trading countries. Armington specifications, however, assume that goods are heterogeneous depending on the country of origin.

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. There will be a demand for export goods even if the domestic price is above the world market price (Dellink, 2005). Exports are modelled by creating an export good that accounts for

additional costs created by transport and storage of this product. Imports are modelled by adding imports and domestic production of goods into an 'Armington aggregate'. This implies that imports are disaggregated by imported good. Depending on consumer preferences for imported or domestic goods, different substitution elasticities are used in the aggregate.

The total trade deficit, i.e. the value of imports minus the value of exports, is compensated by a budget benefit of domestic consumers, as otherwise the monetary flows in the model would not close. The trade deficit is kept constant with all policy simulations, and the adjusting factor is an exchange rate, that can not be seen as monetary variable but rather as a variable rationing the trade deficit (Dellink, 2005).

2.4. Environment

The emissions module includes the emissions of CO_2 coming from fossil fuels use and the CH_4 and N_2O emissions related to the production per specific sector. Both CH_4 and N_2O emissions are expressed in CO_2 equivalents. Data on emissions is obtained from Sadowski (2001) (see Appendix 1). CH_4 and N_2O data are directly applied to the model and enter the highest nest in the production function (Figure1).

CO_2 emissions, however, are disaggregated[2] according to the type and amount of fuels used by sector,

$$\overline{Em_{f,i}} = cf_f \varepsilon_f \frac{ID_{f,i}}{\overline{p}_f} \qquad (5)$$

where $\overline{Em_{f,i}}$ are the emissions coming from combusting fuel f from sector i, calculated on the basis of Social Accounting Matrix (SAM) data (see section 3) and cf_f, ε_f are the conversion coefficient and emission coefficient respectively. The prices used are the 1997 world market prices.

As CO_2 emissions come mostly from fossil fuel combustion they enter the production function in a different place as NH_4 and N_2O emissions (Figure 1). Depending on the source of CO_2 emissions; emissions related to coal, oil, refined oil, or gas combustion, enter specific nests (Figure 1).

3.   Data

Two types of data are used in the model. First, a Social Accounting Matrix (SAM) 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 & McDougall, 2002) is used. In the SAM, agricultural and biomass data are disaggregated based on the FEPFARM model built by Mueller (1995), using FAO (2005)country land use data for Poland. FEBFARM model provides the shares of production costs. Emission data are taken from Polish statistics (GUS, 2002c).

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 capital, labour and energy, are estimated by

(Kemfert, 1998), Rutherford and Paltsev (2000), Kiuila (2000), and Dellink (2005), see Appendix 2.

The three land use classes used in the model correspond to the six land classes used in the Polish land classification system (GUS, 2002b). 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), further in the paper we refer to $z1$ as a very good, $z2$ as good and $z3$ as poor land. Data on land use patterns is obtained from Polish statistics (GUS, 2002a). The full data set used in the model can be obtained from the author.

4.   Biomass in Poland

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

The policy scenarios analysed in the following section refer to some of the possible instruments the Polish government can use to achieve its objectives on GHG emissions and renewable energy production. Moreover, Poland recently joined the EU and it is expected to join the European tradable permits market. As a result of policy changes, renewable energy production is likely to increase, and the percentage of bioelectricity in total renewable energy production is subject to change. 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.

According to the Polish Academy of Science (PAN, 1999), a large potential for bioenergy is coming from agricultural and forestry by-products. Currently, few applications of straw for energy purposes exist (7 in the 1999 (IBMER, 2004)). However, some small scale burning facilities for forestry residuals exist (45 in the 1999 (IBMER, 2004)). In the future, the number of conversion facilities for both straw and forestry residuals is expected to grow.

5.   Scenarios

We present three policy scenarios aimed at increasing the share of bioelectricity in total electricity production and at reducing CO_2 emissions. The first scenario, Scenario 1, considers the introduction of emission permits as a tool to achieve the policy goals of increasing bioelectricity share of 7.5% and 14% by 2010 and 2020 respectively. We analyse different levels of emission reduction in order to determine under which conditions those Polish policy goals can be achieved. In Scenario 2, emissions permits are applied as well, however, additionally we adopt a subsidy rate of 25% for biomass production. The third scenario, Scenario 3, differs from Scenario 2 by the fact that we adopt a subsidy rate of 25% for bioelectricity instead of biomass production. We analyse the three scenarios in (A) a unilateral and (B) a multilateral setting. An overview of the scenarios is given in Table 1.

Table 1   Definition of scenarios

	Unilateral Setting - A	*Multilateral Setting - B*
Scenario 1	Emission permit reduction	Emission permit reduction
Scenario 2	Emission permit reduction + subsidy on biomass (25%)	Emission permit reduction + subsidy on biomass (25%)
Scenario 3	Emission permit reduction + subsidy on Bioelectricity (25%)	Emission permit reduction + subsidy on Bioelectricity (25%)

In the unilateral specification, only Poland undertakes the proposed policies. In the multilateral specification, the RoW adopts the same policy level as Poland, leading to price increases on the world market that are the same as the price increases in Poland. To mimic such behaviour in multilateral specification, the Armington elasticities are set to zero. In other words, there is no possibility of substitution between domestic and imported goods. Both goods are demanded in fixed proportions (i.e. a Leontief specification). Such specification implies that there is no difference between domestic and world market prices. The same holds for domestic goods and export; domestic and world market prices are the same (Dellink, 2005).

6.   **Results and discussion**

This section comprises the results of the policy analysis for three scenarios, both in unilateral and multilateral setting. In section 6.1, we present and discuss in detail the results of the unilateral specification. In subsection 6.1.1 we discuss the general results, including the impact of the scenarios on bioelectricity share, utility and prices of emission permits. Subsections 6.1.2 and 6.1.3 focus on policies impact on production and land allocation respectively. Next subsection, Subsection 6.1.4 analyses the changes in prices of different commodities, once the scenarios are implemented and the last subsection focuses on trade patterns. In section 6.2, we compare some of the core results of the unilateral with the multilateral setting.

6.1. Unilateral setting

General results

As presented in Figures II and III, the results show clear differences between the bioelectricity shares for the different scenarios. Welfare costs of all policies, however, tend to be similar. Figure 2 presents the influence of the implementation of an emission permit reduction for CO_2 on the share of bioelectricity in electricity production. Figure 3 presents the associated welfare costs. The utility losses in Scenario 3A are slightly smaller than the utility losses in Scenario 2A, and in Scenario 1A.

If a system of emission permits is used to reach the first policy goal of a bioelectricity share of 7.5%, strict emission reductions are needed. In Scenario 1A, the policy goal is reached at an emission reduction level of 49%. A 25% subsidy on biomass production combined with a 49% reduction of emission permits results in a higher bioelectricity share than in Scenario 1A. In Scenario 2A, the first policy goal of 7.5% is achieved with an emission reduction of 40%.
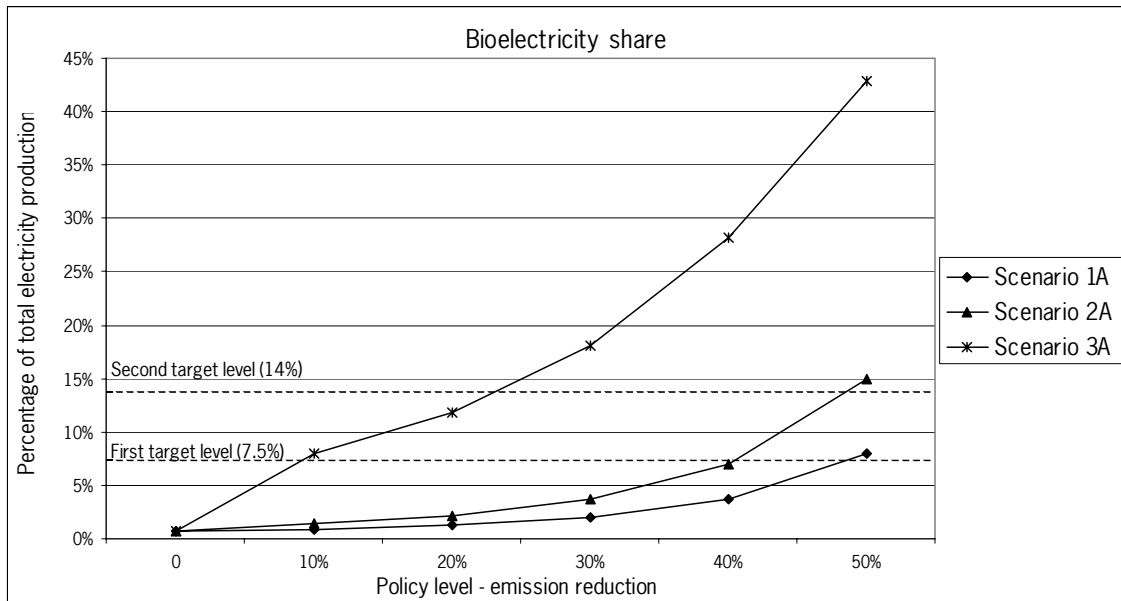
Figure 2   Bioelectricity share in all scenarios for different levels of emission reduction

Due to the biomass subsidy, the second policy goal of a bioelectricity share of 14% can also be achieved with an emission reduction level of less than 50%. As expected, the highest share of bioelectricity production is achieved in Scenario 3A. As a result of a 25% subsidy on bioelectricity production, in Scenario 3A, the first policy goal is reached with a reduction of emission permits of less than 10%. The second policy goal of a 14% bioelectricity share is reached with an emission reduction of around 25%. In Scenario 3A, the share of bioelectricity almost reaches 45% if the emission reduction would be 50%. The kink in Figure 2 at a 10% emission reduction level is explained by the introduction of the biomass subsidy, which leads to an instant increase in the bioelectricity share compared to the benchmark that does not have such a subsidy.
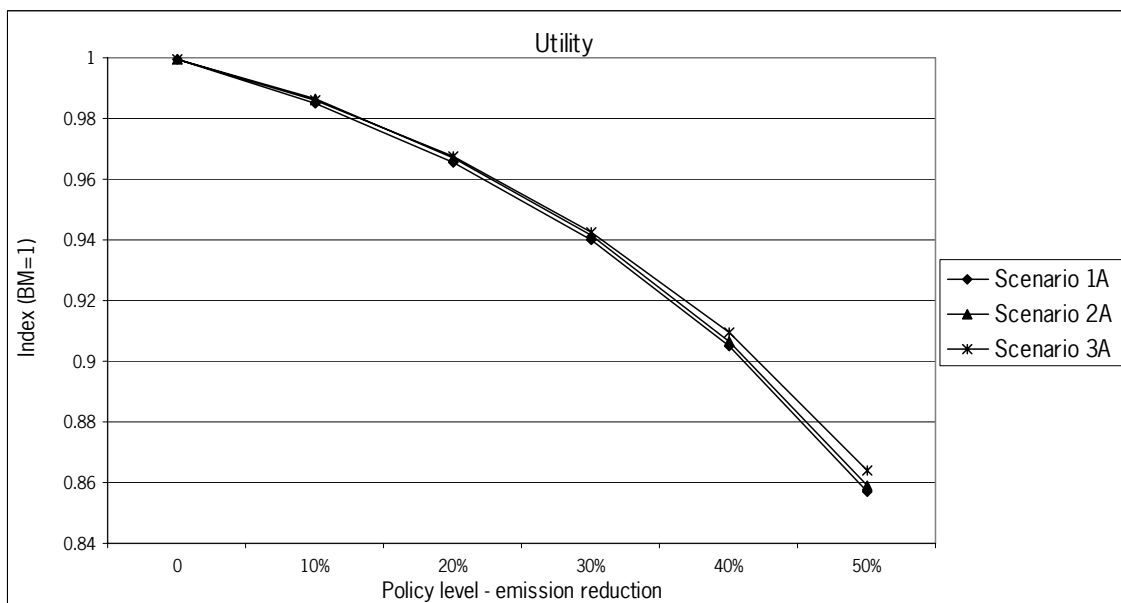

Figure 3   Utility change in all scenarios for different levels of emission reduction

As expected, the larger the emission reduction, the higher the welfare costs for society. The largest decrease of utility for a given level of emission reduction is observable in Scenario 1A. In this Scenario the economy restructure the most. The smallest changes, at a given reduction level, are in Scenario 3A. In a second best world with taxes and subsidies, an additional subsidy can partly resolve the market distortions caused by the changes in the emission permit market. One should notice that the utility function in this model does not include all the positive impacts of an increased environmental quality as e.g. an increased air quality, nor the impacts of more semi-natural areas.

Figure 4 presents the influence of the implementation of an emission permit reduction on the price of emission permits. As expected, the price of emission permits rises with the reduction level: the larger the changes in emission reduction, the higher the price of the permit. Due to the fact that in Scenario 3A bioelectricity is subsidised, demand for conventional electricity decreases, resulting in a decreased demand for permits. For a small emission reduction of 10%, emission permit prices are around 5 Euro per ton. This increases, to around 50 Euro per ton of carbon for a 50% reduction. This is in line with the integrated assessment models as reported in Weyant (1999).

Comparing Figure II-IV shows that the share of the Bioelectricity sector, utility and price levels change in a non-linear manner. Small changes in emission reduction triggers small changes in bioelectricity shares, utility level and price of emission permits. But more stringent environmental policies will affect bioelectricity shares, utility level and price of emission permits substantially more.
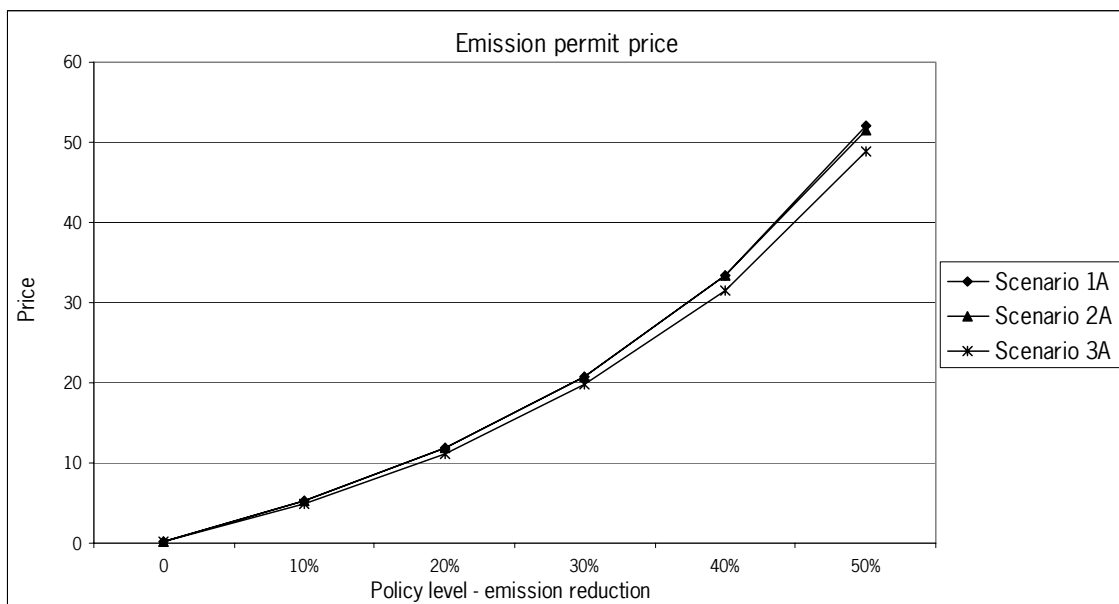

Figure 4   Emission permits price (in Euro/t of carbon) for different levels of emission reduction

Production

The impact of different policy scenarios on sectoral production is presented in Table 2. It comprises the results of production changes for all three scenarios in a unilateral setting for two different emission reduction levels: a reduction of 10% and of 40%. The economy adapts to these reductions in two ways. First, there is clear switch to cleaner energy carriers; in Scenario 1A, the Bioelectricity sector increases its production by 25% and 317% for a 10% and 40% emission reduction respectively; in Scenario 2A, this increase is 98% and 696%, for a 10% and 40% emission reduction respectively. In Scenario 3A the increases in production of the Bioelectricity sector are larger: 1021% and 3400% for a 10% and 40% reduction level, for carbon dioxide, respectively.

Table 2   Changes in the production in selected sectors for a unilateral setting for all scenarios for an emission reduction of 10% and 40% (% change compared to benchmark)

	Benchmark	*10% emission reduction*			*40% emission reduction*		
	mln Euro	1A	2A	3A	1A	2A	3A
Other Agriculture	6297.1	-3	-3	-1	-16	-15	-12
Rape	99.0	-1	-1	29	2	2	112
Willow	1.1	32	360	1138	456	2055	4869
Hemp	0.1	25	324	1010	315	1486	3519
Wheat	1557.1	-2	-2	-2	-10	-10	-10
Other Cereals	1481.4	-2	-2	3	-9	-9	4
Food & animals	34424.6	-2	-1	-1	-9	-9	-9
Forestry	1141.2	-1	19	4	-7	20	12
Coal	5417.2	-9	-9	-9	-36	-36	-36
Oil	1435.3	-17	-17	-17	-63	-63	-62
Gas	384.3	-14	-14	-14	-54	-54	-54
Petrochemicals	4245.9	-15	-15	-15	-59	-58	-57
Electricity	6623.9	-5	-6	-10	-27	-28	-40
Bioelectricity	45.9	25	98	1021	317	696	3400
Industry	87682.9	-1	-1	-1	-8	-7	-8
Services	133109.2	-2	-1	-1	-9	-9	-9

The second effect is a restructuring of the economy towards cleaner production. The sectors that increase their production are those that emit relatively little CO_2 per unit of production, i.e. Bioelectricity, Willow and Hemp. In Scenarios 2A and 3A, also forestry production increases. In Scenario 3A, Rape and production of 'Other Cereals' increase as well. In Scenarios 2 and 3, at a reduction level of 10%, the production of rape decreases. However, at a reduction level of 40%, when demand for cleaner and cheaper electricity increases, production of rape does increase. This switch is due to the fact that part of rape production is also used in the bioelectricity sector. However, bioelectricity production based on rape requires some fossil fuels due to which the price of rape increases. Hence it is a relatively more expensive input for bioelectricity production.

In all scenarios, production levels of all other sectors decrease. The larger losses occur in the energy sectors: Coal, Oil, Petrochemical, and Gas at all emission reduction levels. In case of a 10% emission reduction, the food producing, industry and services sectors experience a 1% to

2% production loss. The largest losses in production are in Scenario 1A. As expected, higher emission reductions imply larger changes in production.

An increase in the biomass and forestry sectors triggers a decrease of agricultural production. The changes are, however, not very large in the case of a 10% emission reduction. However, with a 40% emission reduction, the production of wheat decreases with 10% and the production of other agricultural crops decreases with 12% to 16%. In the third scenario, despite the largest increase in production of biomass crops, the sector 'Other Agriculture' decreases its production the least. Also other sectors show a decrease in production. The decrease in agricultural production is, however, smaller than the decrease in the other, 'dirty' sectors. Due to these production decreases, labour and capital from these sectors are transferred to the bioelectricity, biomass and agricultural sectors. One should notice that a small percentage change in the industry and services sectors triggers large movements of labour and capital towards the much smaller biomass and agricultural sectors. Agricultural, biomass and forestry sectors can intensify their production by substituting land for other production factors that become available due to the production losses in the industrial, energy and services sectors.

The subsidy on bioelectricity in Scenario 3A triggers a larger increase in biomass production than the direct subsidy on biomass production in Scenario 2A. This can be explained by the fact that the Bioelectricity sector is larger than biomass sector, hence more subsidies are directed towards bioelectricity production. An increased demand for (cheaper) bioelectricity in Scenario 3A triggers a much higher demand for biomass than when these small biomass sectors are directly subsidised.

By comparing both reduction levels, it can easily 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 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.

Land allocation

An increase of biomass production has an important effect on land use. Table 3 shows the results of land use allocation for all three scenarios. It presents land use allocation when emissions are decreased by 10% and 40%. Most biomass sectors increase their production. Such an increase in production triggers an increase in the amount of land used. Hemp increases its acreage in all scenarios, but the largest increase is observed in Scenario 3A, where its acreage increases by 1,250 ha. Willow plantations increase in Scenario 2A by 1,900 ha, and in Scenario 3A by around 6,000 ha. Forestry acreage decreases in Scenario 1A, but increases considerably in Scenarios 2A and 3A (see Table 3). The input of the Forestry sector into bioelectricity production is small relative to the amount of land needed. Trees need a growing period that is usually around 30 years. In our model, standard growing time for Polish conditions is applied in this analysis.

One of the major objectives of this paper is to analyse the change in the size of semi-natural areas: forestry, willow and hemp. Each of these crops is considered to create a good environment for many species and to improve the quality of land. Moreover, compared to traditional annual agricultural crops, biomass plantations can have a large potential to sequester carbon. As follows from Table 3, the size of the semi-natural areas decreases in scenario 1A.

Table 3   Land use (in 1000 ha) with 10% and 40% emission reduction for all scenarios in unilateral setting

		Benchmark	10% emission reduction			40% emission reduction		
			1A	2A	3A	1A	2A	3A
Other Agriculture	Z1	102.4	101.9	97.8	100.6	99.3	92.9	91.7
	Z2	1839.4	1829.3	1701.4	1782.7	1774.8	1618.0	1596.3
	Z3	1051.7	1051.6	918.3	997.4	1051.1	873.8	861.6
Rape	Z1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	349.4	352.4	332.6	443.1	388.0	363.0	713.9
	Z3	87.3	87.4	78.4	108.3	100.4	85.7	168.4
Willow	Z1	0.0	0.0	1.1	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	1.3	0.0	0.0	11.1	25.3
	Z3	0.5	0.5	0.0	6.5	3.2	0.0	0.0
Hemp	Z1	0.0	0.0	0.4	0.0	0.0	1.7	3.8
	Z2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z3	0.1	0.1	0.0	1.5	0.6	0.0	0.0
Wheat	Z1	87.4	87.5	83.9	85.2	87.3	81.6	77.9
	Z2	1570.0	1570.8	1461.1	1511.1	1560.1	1421.8	1356.2
	Z3	897.7	898.1	788.6	845.4	924.0	767.8	732.0
Other Cereals	Z1	218.6	219.0	209.8	222.6	221.8	207.0	226.1
	Z2	3894.3	3901.1	3621.8	3915.2	3931.8	3576.4	3903.5
	Z3	2301.2	2302.1	2020.2	2263.7	2406.6	1996.1	2177.4
Forestry	Z1	0.0	0.0	15.4	0.0	0.0	25.1	8.9
	Z2	31.6	31.3	566.7	32.7	30.0	694.5	89.6
	Z3	8757.6	8756.4	9290.7	8873.4	8610.3	9372.8	9156.8
Total	Z1	408.4	408.4	408.4	408.4	408.4	408.4	408.4
	Z2	7684.8	7684.8	7684.8	7684.8	7684.8	7684.8	7684.8
	Z3	13096.2	13096.2	13096.2	13096.2	13096.2	13096.2	13096.2

With a 10% emission reduction, the reduction in semi-natural acreage in Scenario 1A is 1,700 ha. With an emission reduction of 40%, it increases up to 146,000 ha. The size of forestry acreage does not increase that much as it requires relatively much land but and less capital and labour. Sectors like Hemp and Willow, however, increase their land use, but they are too small to account for the losses in natural area caused by the reduction in forestry. The released labour force and capital from shrinking industrial sectors can be used for intensifying the biomass sectors. In contrast, in Scenarios 2 and 3, there is a large increase in semi-natural areas. In these scenarios, nature can benefit from either a direct subsidy on biomass or an indirect subsidy by subsidising the bioelectricity sector, the main purchaser of biomass. The largest increase in the acreage of forestry and hence in semi-natural areas can be observed in Scenario 2A. With a 10% emission reduction, the area increases by 1,086,000 ha to 9,876,000 ha and with 40% emission reduction by 1,315,000 ha to 10,105,000 ha. Since forestry uses much land, even small changes in production can trigger large changes in land use. It means that even a low policy target can generate large changes in the size of natural areas. Scenario 3A shows a smaller increase in the amount of semi-natural areas compared to Scenarios 2A. With a 10% emission reduction the acreage increase by 124,000 ha to 8,914,000 ha and with a 40% emission reduction by around 500,000 ha to 8,284,000 ha. This result may seem counterintuitive, realising that Scenario 2A

showed a smaller increase of biomass production than Scenario 3A. It can, however, be explained by the fact that in Scenario 2A higher demand for biomass is translated in requiring more production factors, including land, without much emphasis on intensification. In Scenario 3A there is a much stronger reallocation of capital and labour from the electricity sector that can be used to intensify production of biomass using relatively less land inputs.

Generally, for all three scenarios, the land use allocation for a 40% emission reduction shows the same trends as for a 10% emission reduction. Though the absolute numbers are much larger, the same mechanisms underlay the changes in land use compared to the lower reduction level (Table 3).

Prices

The policies adopted in the model induce price changes; the AGE framework allows an analysis of relative prices, but the absolute price level is undetermined (this is solved by choosing the Consumer Price Index as numéraire). Generally, the prices of dirty goods, for which the production costs increase substantially due to the expensive emission permits, go up compared to prices of clean goods. The impact of the emission reduction policies on price level for a selection of goods is presented in Table 4. We can observe an increase of agricultural commodity prices. However, this increase is much lower than in other studies, at most 10%, if the emission permit price rises to around 40 Euro per ton of carbon. For instance Azar and Berndes (2000) conclude that with stringent environmental policies the prices of wheat can double, and McCarl and Schneider (2001) expect more than a doubling of prices for all agricultural goods if the price of emission permits would rise to 500 $ per metric tonnes of carbon equivalent.

Table 4   Changes in prices of selected commodities in unilateral setting for all scenarios

	10% emission reduction			*40% emission reduction*		
	1A	2A	3A	1A	2A	3A
Other Agriculture	2%	2%	2%	10%	9%	9%
Rape	0%	0%	0%	-1%	-1%	-1%
Willow	0%	-20%	-1%	-3%	-22%	-3%
Hemp	0%	-20%	0%	2%	-19%	1%
Wheat	0%	0%	0%	2%	2%	2%
Other Cereals	1%	1%	1%	3%	3%	3%
Forestry	0%	-20%	0%	-2%	-21%	0%
Coal	-1%	-1%	-1%	-7%	-7%	-7%
Oil	0%	0%	0%	-2%	-2%	-2%
Gas	1%	1%	1%	5%	5%	5%
Petrochemicals	4%	4%	4%	24%	24%	22%
Electricity	3%	4%	3%	18%	18%	17%
Bioelectricity	0%	-5%	-20%	-2%	-8%	-21%

The price of conventional electricity increases by 3-4% for 10% emission reduction and 17-18% for 40% emission reduction, which can be explained by the increase in emission permit price. Due to high substitution elasticity between conventional electricity and bioelectricity, the demand for electricity shifts towards bioelectricity. The largest increase of electricity prices is in Scenario 2A (Table 4).

Trade

In Table 5, the trade results are presented for the unilateral specification. In all scenarios, Poland exports much more bioelectricity compared to the benchmark, in which it is almost negligible. For most biomass crops exports rise as well. Due to high emission prices, the price of domestic petrol production increases and therefore the import level for this product remains close to its benchmark level and the export level decreases. The reductions of imports are the largest in the dirtiest sectors such as coal, oil, and gas.

Changes in exports and imports are larger in Scenarios 2A and 3A than in Scenario 1A. Due to the fact that prices of willow, hemp and forestry products go down (caused by the subsidy), the price of bioelectricity goes down as well. This triggers higher demand for those goods both domestically and in the Rest of the World (RoW). Exports of these goods increase substantially (see Table 5). The Forestry sector reduces its production in Scenario 1A, while exports increase by 1.2%. However, in Scenario 2A the subsidy stimulates the growth of this sector, and as the price of the good decreases compared to the world market price, much of the forestry goods are exported. In Scenario 3A, the export of bioelectricity increases substantially, mainly due to lower prices induced by the subsidy. Export of biomass increases as well.

Table 5　　　　Changes in imports and exports for a selection of traded goods when 10% and 40% emission reduction is reached for all Scenarios (represented as % change compared to benchmark)

| | Imports | | | | | | Exports | | | | | |
| | 10% emission reduction | | | 40% emission reduction | | | 10% emission reduction | | | 40% emission reduction | | |
	1A	2A	3A	1A	2A	3A	1A	2A	3A	1A	2A	3A
Other Agriculture	4	4	5	21	21	25	-9	-8	-7	-38	-38	-35
Rape	-2	-1	27	-3	-2	102	0	-1	32	8	7	122
Willow	30	85	1083	401	694	4276	35	1044	1196	516	5749	5541
Hemp	27	76	1008	343	595	3715	24	922	1012	288	3520	3332
Wheat	-1	0	0	-4	-4	-3	-3	-3	-3	-16	-16	-15
Other Cereals	0	1	5	1	3	18	-4	-4	0	-18	-19	-7
Forestry	-3	-50	5	-13	-52	12	0	173	3	0	189	11
Coal	-14	-13	-14	-52	-52	-52	-5	-5	-5	-16	-17	-18
Oil	-18	-18	-18	-65	-65	-65	-16	-16	-16	-60	-60	-59
Gas	-10	-10	-11	-44	-44	-45	-17	-17	-17	-61	-61	-61
Petrochemicals	0	0	-1	-3	-3	-5	-16	-16	-16	-57	-57	-56
Food & Animals	-1	-1	-1	-8	-8	-8	-2	-1	-2	-10	-9	-9
Electricity	8	9	2	43	40	15	-17	-18	-21	-61	-62	-67
Bioelectricity	23	59	355	282	474	1239	27	146	2644	355	1002	8977
Industry	-2	-2	-2	-13	-13	-13	-1	0	-1	-4	-3	-4
Services	-2	-2	-2	-14	-13	-13	-2	-2	-2	-10	-10	-10

Comparing the results of unilateral specification results it can be concluded that Scenario 3A offers the most efficient solutions in reducing the emissions with the smaller utility losses. The Polish policy goals are reached faster than in Scenarios 1A and 2A. The size of the nature area increase considerably in this scenario, larger increase is observable only in Scenario 2A. The price level changes of food crops were similar in all scenarios.

6.2. Multilateral setting

A comparison between the unilateral and multilateral specification for a 40% emission reduction level is presented in Table 6.

Table 6   Bioelectricity share (in % change), utility change (in % change) and price of emission permits (in Euro /t of carbon) in all scenarios for unilateral and multilateral specification at 40% emission reduction level

	1A	2A	3A	1B	2B	3B
Share of bioelectricity	4%	7%	28%	5%	8%	31%
Utility change	-10%	-9%	-9%	-10%	-10%	-9%
Price of permits	33	33	31	37	37	35

In the multilateral specification, the policy goal for the share of bioelectricity is reached at a lower level of emission reduction. This is due to the model assumption that in the multilateral setting the RoW adopts the same policy level as Poland, leading to price increases on the world market that are the same as the price increases in Poland. Hence, Poland cannot import large quantities of cheap electricity and this result in an increased demand for bioelectricity and biomass, both domestically and abroad. In Scenario 3B, the share of bioelectricity in total domestic production of electricity reaches almost 45% at an emission reduction level of 50%. The multilateral setting has virtually no influence on the level of utility for all scenarios and all levels of emission reductions. However, these reductions are very comparable. Emission permit prices turn out to be higher in the multilateral case, as Poland can no longer import cheap dirty goods but has to produce them. This induces higher prices for emission permits.

Table 7   Changes in imports and exports for a selection of traded goods when 40% emission reduction is reached for all scenarios in multilateral setting (represented as % change compared to benchmark)

	Imports			Export		
	1B	2B	3B	1B	2B	3B
Other Agriculture	-13	0	4	-13	0	4
Rape	5	0	114	5	0	114
Willow	590	285	112	590	285	112
Hemp	400	281	110	400	281	110
Wheat	-11	0	0	-11	0	0
Other Cereals	-9	0	16	-9	0	16
Forestry	-7	9	13	-7	9	13
Coal	-41	-41	-41	-41	-41	-41
Oil	-47	-47	-47	-47	-47	-47
Gas	-37	-37	-38	-37	-37	-38
Petrochemicals	-36	-36	-36	-36	-36	-36
Electricity	-27	-29	-42	-27	-29	-42
Bioelectricity	400	840	3723	400	840	3723
Food	-9	-9	-9	-9	-9	-9
Industry	-10	-10	-10	-10	-10	-10
Services	-12	-12	-12	-12	-12	-12

Table 7 presents the changes in imports and exports for all scenarios in the multilateral specification. In the unilateral setting, Poland exports more bioelectricity than in the multilateral one. This is due to the fact that in the unilateral specification only Poland specialises in clean production, whereas in the multilateral specification the rest of the world is following the same policies, and hence goes through a similar process of economic restructuring.

7. Conclusions

This paper presents a general equilibrium model for an environmental-economic analysis of biomass production. The model is developed to investigate the effects of energy policies on production and trade patterns of biomass and bioenergy and the resulting land reallocation.

Reality is, of course, more complex than a model. Since we present comparative static model it is useful to point out that the Polish economy is of course dynamic. Currently, Poland faces many changes, both in environmental and economic areas. 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 dynamic model would be able to show the transition path toward cleaner economy. Second, for a better specification of trade issues a model with several regions would be preferable. Third, if we could include the positive impact of an increased environmental quality on welfare, in terms of increased nature areas and a reduction of emissions, we would be able to calculate the efficient level of environmental policies and determine the optimal mix of agricultural and biomass production.

Based on our analysis, we would like to highlight some interesting results:

1. The first policy target of achieving a 7.5% bioelectricity share can be achieved within an emission reduction of carbon dioxide of 50%, in all three scenarios. To achieve the second policy target of a 14% share of bioelectricity in total electricity production, the emission permit system should be supported by subsidies on biomass or bioelectricity production. This target can be reached e.g. by using a 10% emission reduction combined with a 25% bioelectricity subsidy.

2. For a small emission reduction of carbon dioxide of 10%, the emission permit price is low (around 5 Euro per ton of carbon). This price increases to around 50 Euro per ton of carbon if the emission reduction is increased to 50%. This is in line with the results from the integrated assessment model of Weyant (1999).

3. In a second best world, additional policies can reduce the negative impact of existing taxes. In the first scenario, without subsidies, utility losses are slightly higher than in the other two scenarios that include subsidies. Hence, the subsidies on biomass or bioelectricity have positive effects on utility.

4. The emission permit system induces a large restructuring of the economy. It will result in a clear transition towards production of clean goods. Moreover transitions will take place towards clean energy and energy carriers.

5. Energy policies influence land use allocation. Poland, targeting an improvement in its clean energy performance, can increase substantially its semi-natural areas. A subsidy of 25% for

biomass can increase the size of the semi-natural areas substantially. Semi-natural areas increase as well in case of an indirect subsidy of 25% on bioelectricity production.

6. AGE models enable the analysis of land reallocation between agriculture and biomass. From the case studies we observed that under some circumstances climate policy does not cause an increase of semi-natural areas.

7. Due to a positive impact of emission reduction policies on biomass production, and higher prices for fossil fuels, the prices of agricultural goods increase. Our results show, however, much smaller price increases than some other studies. For instance Azar and Berndes (2000) conclude that with stringent environmental policies the prices of wheat can double, and McCarl and Schneider (2001) expect more than a doubling of prices for all agricultural goods, if the price of emission permits would rise to 500 $ per metric tonnes of carbon equivalent. As a reallocation of labour and capital allows for an intensification of agricultural production, such high price increases are not to be expected.

8. The reduction in fossil fuel imports reduces the export necessity of other goods and this in itself can reduce emissions (given the current trade balance). Poland, implementing the proposed energy policies, has a chance to specialise in clean production such as bioelectricity and biomass and becoming an exporting country of those goods.

9. In the multilateral specification the target shares of bioelectricity are reached faster. However, the permit prices are higher, due to the fact that Poland cannot import cheaper dirty goods from the Rest of the World.

This paper examines land use relocations induced environmental policies, but cannot answer where new nature areas will be created. Therefore, a spatially explicit extension of the model, using a regional disaggregation, could provide interesting new insights that cannot be derived form the current paper.

Appendix

Appendix 1   Emission data based on Sadowski (2001)

	CO_2	CH_4	N_2O
Agriculture	0	598	31
Forestry	-19322	0	0
Fossil fuels combustion	254276	994	6
Transport	26662	9	1
Industrial processes	95554	16	16
Other sources	4456	677.46	0.288

Appendix 2   Substitution elasticities

	ELK	ENER	KL	PR	ID	ELEC	FU	Z	Y	CO	OL	GA	PET
Other Agriculture	0.5	0.7	0.79	0.4	0.1	10	0.5	0.3	0	0	0	0	0
Rape	0.5	0.7	0.79	0.4	0.1	10	0.5	0.3	0	0	0	0	0
Willow	0.5	0.7	0.79	0.1	0.1	10	0.5	0.3	0	0	0	0	0
Hemp	0.5	0.7	0.79	0.1	0.1	10	0.5	0.3	0	0	0	0	0
Wheat	0.5	0.7	0.79	0.4	0.1	10	0.5	0.3	0	0	0	0	0
Other Cereals	0.5	0.7	0.79	0.4	0.1	10	0.5	0.3	0	0	0	0	0
Animal Products	0.5	0.7	0.79	0.4	0.1	10	0.5	0.1	0	0	0	0	0
Forestry	0.5	0.7	0.79	0.1	0.1	10	0.5	0.3	0	0	0	0	0
Coal	0.7	0.4	0.79	0.9	0.5	10	0.5	0.1	0	0	0	0	0
Oil	0.7	0.4	0.79	0.9	0.5	10	0.5	0.1	0	0	0	0	0
Gas	0.7	0.4	0.79	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Vegetable oils and fats	0.7	0.7	0.79	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Food products	0.64	0.7	0.58	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Textiles	0.7	0.5	0.79	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Wood products	0.7	0.7	0.79	0.5	0.2	10	0.5	0.1	0	0	0	0	0
Paper products	0.96	0.7	0.52	0.5	0.2	10	0.5	0.1	0	0	0	0	0
Petroleum and coal products	0.7	0.4	0.79	0.9	0.5	10	0.5	0.1	0	0	0	0	0
Chemicals	0.96	0.4	0.55	0.3	0.2	10	0.5	0.1	0	0	0	0	0
Metal and mineral products	0.98	0.4	0.55	0.7	0.2	10	0.5	0.1	0	0	0	0	0
Transport and vehicles equipment	0.7	0.55	0.79	0.3	0	10	0.5	0.1	0	0	0	0	0
Electronic equipment	0.7	0.55	0.79	0.6	0.6	10	0.5	0.1	0	0	0	0	0
Manufactures	0.7	0.55	0.79	0.6	0.6	10	0.5	0.1	0	0	0	0	0
Electricity	0.7	0.4	0.79	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Bioelectricity	0.7	0.4	0.79	0.4	6	10	0.5	0.1	0	0	0	0	0
Gas manufacture and distribution	0.7	0.5	0.79	0.4	0.2	10	0.5	0.1	0	0	0	0	0
Water	0.7	0.5	0.79	0.1	0.1	10	0.5	0.1	0	0	0	0	0
Construction	0.7	0.7	0.79	1	0.3	10	0.5	0.1	0	0	0	0	0
Trade	0.7	0.5	0.79	1.8	0.7	10	0.5	0.1	0	0	0	0	0
Transport	0.88	0.5	0.17	0.7	0.3	10	0.5	0.1	0	0	0	0	0
Water transport	0.7	0.5	0.79	0.7	0.3	10	0.5	0.1	0	0	0	0	0
Air transport	0.7	0.5	0.79	0.7	0.3	10	0.5	0.1	0	0	0	0	0
Communication	0.7	0.5	0.79	1.5	0.7	10	0.5	0.1	0	0	0	0	0
Services	0.5	0.5	0.79	0	0	10	0.5	0.1	0	0	0	0	0
Public spending	0.5	0.52	0.52	0	0	10	0.5	0.1	0	0	0	0	0

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Notes

[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 $Y_i = CES(X_1, X_2; \sigma)$.

[2] There are some inaccuracies in the calculated total emissions with respect to the total emissions from Polish statistics, concerning the aggregation of top down and bottom up data. To account for this, the following calculation method was used:

$Em_{f,i} = (\overline{Em_{f,i}} / \sum_i \sum_f \overline{Em_{f,i}})TEm$, where the *TEm* are the emissions given by Polish statistics.