Economics of multifunctional biomass systems

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Dla Roba i Mamy

PREFACE

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CHAPTER 1

Introduction

1.1 Biomass as one of the future energy sources

Human activities give rise to emissions of a variety of air pollutants, which contribute to environmental problems like global warming (IPCC, 2001b,c; Ignaciuk et al., 2002). In response to these environmental problems, national and international policies have been debated and implemented. Due to these policies, such as the Kyoto protocol and subsequent climate policies, there is an increasing demand for carbon neutral energy (Azar and Rodhe, 1997). Many international organizations call for an increase in the share of renewable energy in total energy production, including the European Union (EU) (2000), IEA (2005), and World Bank (2005).

In 2002, the global primary[1] energy production (either extracted or captured directly from natural resources) adds up to 432 EJ/year (IEA, 2005). In the European Union, the primary energy production amounts to 32 EJ/year. The shares of renewable energy production on the global and European Union scales are 13.4% and 8.4%, respectively. A detailed composition of primary energy production is gathered in Table 1.1.

Table 1.1 World and European Union primary energy production in 2002 (EJ/year)

	Coal	*Crude oil*	*Gas*	*Nuclear*	*Hydro*	*Geothermal & Solar*	*Biomass & Waste*	*Total*
World	101	153	91	29	9	2	47	432
EU	4.1	6.5	7.8	9.7	1.0	0.3	2.3	31.7

Source: based on IEA (2005).

[1] Electricity and transportation fuels are secondary resources.

Both in the world (10.9% of total world energy production) and Europe (7.2% of total European energy production), biomass is the largest source of renewable energy. The end-use of biomass-based energy differs between the different world regions: on a global scale biomass is used mainly for heating and cooking purposes, and on a European scale there is slightly more emphasis on the production of electricity and liquid fuels. In 2002, the share of biomass in the total electricity production reached 2.2% globally and 4.8% for Europe (IEA, 2005).

What are, however, the potentials for using biomass for energy purposes? Are we able to substantially increase the share of energy produced from biomass (bioenergy), in total energy production? Many scientists claim that, potentially, biomass can replace much of the use of fossil fuels. Fischer and Schrattenholzer's (2001) estimates vary between 370 and 450 EJ/year, and Hoogwijk et al. (2003) estimate the long term world biomass potentials between 80 to 1,250 EJ/year. Smeets et al. (2004) provide even higher ranges for bioenergy production by 2050, 273-1471 EJ/year. The highest estimate is based on the expectation of a significant increase of the crop yields and large improvement in animal production systems. According to the IMAGE model, the global potentials for bioenergy range between 311 and 706 EJ/year (Hoogwijk et al., 2003). More modest estimates of biomass potentials, provided by Berndes et al. (2003), give a range between 50-200 EJ/year, which still implies that almost 50 percent of energy production can be based on biomass resources (cf. Table 1.1). Those figures indicate the possible range of potentials that depend on many factors, such as (i) population growth, (ii) dietary patterns, (iii) development of food production systems, (iv) yield of energy crops on different types of land (agricultural and degraded), and (v) developments of material substitutions systems (Hoogwijk et al., 2003). For instance, the degree of effectiveness of new production systems determines how much good quality land can be available for energy crops production, since that is considered to be one of the limiting factors for biomass production (Lewandowski et al., 2006).

There are several advantages that biomass can provide: (1) it adds to a sustainable future energy supply and (2) it contributes to greenhouse gas (GHG) emission reduction via (a) direct substitution of fossil fuels and (b) replacing fossil fuels based materials, like plastics and different chemicals (IPCC, 2001a). Next to providing inputs to 'green' energy, biomass plantations can also have positive effects on biodiversity and environment; though this depends strongly on the type of biomass plantations and on the land use on which biomass plantations are established. A major positive aspect of biomass plantations is that they can positively affect the quality of land, especially of previously intensively used agricultural land. Furthermore, they can contribute to the quality of groundwater and improve biodiversity (Makeschin, 1994; Borjesson, 1999a,b; Tolbert et al., 2002). Those advantages are mainly accurate for perennial crops and for short rotation forestry (willow, poplar and others) or grasses (miscanthus, switchgrass, reed canary grass). For annual crops (like rape seed, or sugar beet), the studies are not always conclusive (Lewandowski et al., 2006). The impact on biodiversity can even be negative, for instance when virgin forest is turned into biomass plantations. Pimentel (2003) claims that corn grown for ethanol production causes diverse environmental problems in the USA. Without making a distinction between corn grown for food or for energy production, he states that US corn production causes more total soil erosion than any other US crop (Pimentel et al., 1995; Pimentel, 2003).

Biomass plantations, in general, use less fertilizer, and some of them have the potential to clean up polluted soils. Under proper management, forest and other biomass plantations have the potential to sequester CO_2 in the soil (De Jong et al., 2000; Creedy and Wurzbacher, 2001; Tolbert et al., 2002; Lal, 2005). Moreover, they can create a suitable environment for many species and serve as corridors between separated nature areas (Lewandowski et al., 2000; Londo et al., 2005).

There are, however, some downsides of bioenergy. One of the drawbacks is that production costs are high as compared to fossil fuel energy (Lewandowski et al., 2004). The production costs of woody biomass range between 0.5 to 16.4 US$/GJ world wide, and 2.5 to 16.4 US$/GJ for Europe (Hoogwijk et al., 2004). For comparison, in 2003 prices of coal ranged between 1-2 US$/GJ (Gielen and Unander, 2005). Another drawback might be that a relatively high energy input is required in biomass production. Pimentel (2003) claims that to produce a gallon of ethanol from corn in the US, 20-30% more energy is needed, than the energy that actually is provided by the gallon of ethanol. Grabowski and McClelland (2003) come up with different energy balance estimates. They claim that the energy balance of a gallon of ethanol produced from US corn is positive by about 30%, i.e. 30% more energy is produced than that is necessary in the production process. The assumptions chosen by Grabowski and McClelland differ from those chosen by Pimentel; generally they did not include the energy associated with labor and production of machineries. Moreover, they use energy input data for the US and not average values for the world, including also higher corn yields than chosen by Pimentel. Another aspect that is often reflected upon in the literature is the conversion loss that appears with the transformation from biomass into a higher energy form, liquid fuels, heat, or electricity. Following Pimentel et al. (1981), the conversion losses of biomass transformation into liquid fuels are the highest, often involving net energy losses. Conversion of biomass for heating purposes can result in around 12% energy gain, and into electricity the energy gain can increase to around 25%. The conversion to electrical power has several advantages: i) it is a high quality energy source, ii) the power plant can be located close to a biomass source, iii) electricity can be transported easier than raw biomass, and iv) crop and forestry residuals burn cleaner than coal (Pimentel et al., 1981).

Another limitation that may be important is the land availability for biomass production. On the one hand, many scientists are concerned that due to changing life style patterns, more land is needed to satisfy human food requirements (Bouma et al., 1998; Gerbens-Leenes and Nonhebel, 2002; Gerbens-Leenes et al., 2003). Some claim that due to ethical and moral issues such as existence of malnourished people, and expectations of further growth of world population, productive land should be used for food production (Pimentel et al., 1999; Pimentel, 2003). On the other hand, other authors argue that today's overproduction of food allows for using agricultural land for other practices (WRR, 1992; Tilman et al., 2002; Trewavas, 2002). Wolf et al. (2003) indicate that current global food requirements can be sustained with only 55% of the total productive area, which implies that an additional 45%

can be dedicated to non-food production like biomass plantations. Smeets et al. (2004) provide different estimates of potential surplus of agricultural land that can be dedicated to energy crops production, based on several factors: (i) population growth, (ii) efficiency in agricultural production, (iii) new technologies, (iv) animal production developments, and (v) land requirements for other non-food sectors. They assess that by 2050 the acreage for dedicated energy crops, can amount to 12-61 Mha in Western Europe, 4-40 Mha in Eastern Europe and 729-3,586 Mha on a world scale, respectively. This means that in the least optimistic scenario 14% of the agricultural land might be available for energy production, and in the most optimistic case, it increases to even 70%.

With increasing concerns about global warming, more stringent energy policies are expected to be implemented in the future. The EU has set ambitious targets to increase the use of biomass for energy: (i) a contribution of 5,700 PJ from biomass in 2010 and (ii) an increase in consumption of biofuels (mainly diesel and gasoline) to 5.75% in 2010. These targets are outlined by the so called ‘White’ and ‘Green’ papers (CEC, 1997, 2000) and the biofuel directive (CEC, 2003b) adopted by the EU in 1996, 1997 and 2003, respectively. They cannot be met by the use of agricultural and forestry residues alone. That means that large areas of agricultural land in the EU will have to be dedicated to the production of energy crops (Faaij, 2006). This might result in increased competition for land that can lead to an increase of agricultural commodity prices. Azar and Berndes (2000), for instance, conclude that with stringent energy policies the prices of wheat can double; similar results are obtained by McCarl and Schneider (2001).

In this thesis, the potential of biomass as a source of energy and materials is explored in an economic setting, with explicit attention to the limited availability of land. Moreover, the impact of increasing demand for land for biomass plantations on traditional agriculture is studied. Before elaborating on the problem definition and specific objectives of this study, first some information is provided about the biomass systems that can be applied to enhance biomass and bioenergy production and limit their possible negative effects on land use and the environment. The systems that are dealt with in this thesis are: (i) multi-product crops, (ii) multifunctional biomass plantations, (iii) material substitution, and (iv) cascading of biomass resources. They are described in more detail in Section 1.2. Section 1.3 presents the scope and objectives of this thesis. Different types of models that have been used to analyze some of the issues concerning biomass and energy, and/or biomass and agriculture are discussed in Section 1.4. Section 1.5 provides the background information about the case study country – Poland. Section 1.6 presents the outline of this thesis.

1.2 Multifunctional biomass systems

Multifunctional biomass systems potentially can contribute to more efficient biomass resources, and hence they can reduce the pressure on productive land. Therefore, in this thesis we analyze four types of multifunctional biomass systems; (i) multi-product crops, (ii) multifunctional biomass plantations, (iii) material substitution, and (iv) cascading.

The first system analyzed is a possible use of multi-product crops. Such crops are characterized by providing to society the major commodity such as food or materials and, additionally, also cheap residues for energy production. The second system that is analyzed, multifunctional biomass plantations, concerns the potential exploration of different land use functions that can be combined with biomass plantations. Exploring such functions may result in a reduction of production costs of biomass or more efficient allocation of plantations and in more efficient land use, because several services are generated from the same piece of land. The third system, material substitution, focuses on using biomass substitutes for currently fossil fuel-based products. The fourth system is cascading. Cascading is a descending use of a biomass resource, ending up as a cheap fuel for bioenergy. The following subsections provide a more detailed description of all systems and the recent development in those fields.

1.2.1 Multi-product crops

Generally, the concept of '*multi-product crops'* is applied mainly to describe the multiple outputs of traditional agricultural crops. One of the definitions is given by Bindraban (1999): "*beyond the primary food production, agriculture goods are often used for energy and materials production*". Nowadays, it is used also to define different applications of biomass crops: *"Multi-product crops can be defined as crops that can be split into two or more different parts that are used for different applications. One part of the crop is used directly as energy, i.e. it is used as solid fuel or converted to liquid fuel and the other for material applications"* (Dornburg, 2004).

Utilizing multi-product crops systems of both agricultural and biomass crops can substantially reduce (i) the pressure on land and (ii) the price of biomass, since they can be used for different applications without conflicting interests. For instance, the production of cereals can result in a supply of grains for food purposes and at the same time the crop residues (straw) can be used for energy production. Another example is maize, where starch is used for polymers production and by-products from starch production as a fodder. Moreover, the residues such as stalks and leaves can be used as fuels for energy production (Dornburg, 2004).

Currently, much of the residues are used. For instance straw is used in many countries as e.g. (i) fodder, (ii) organic fertilizer, and (iii) insulation material (AEBIOM, 1999). Forest residues are often used in the construction sector as base materials for MDF production or as additional input in the paper industry. A reduction in the current use of by-products might lead to e.g. a reduction of soil fertility (Pimentel et al., 1981). For example, if an insufficient amount of straw is left on the field, soil erosion may increase and humus levels might decrease. This argument is also valid for forestry. Therefore only a limited amount of by-products can be transformed into bioenergy.

There are several studies that quantify residues on a global scale. A selection of these studies is provided in Table 1.2. According to Fisher and Schrattenholzer (2001), the energetic potential of by-products of wheat, rice, grains, protein feed and other crops are between 18-25 EJ per year, equivalent to 4-6% of world energy use. Hoogwijk et al. (2003), based on several studies, give even higher estimates of 10-32 EJ/year for using agricultural residues in bioenergy production. For forestry residues, their estimates are between 10 and 16 EJ/year. The results of the GLUE-11 simulation model (Yamamoto et al., 2001), where different scenarios concerning exogenous population growth and demand for energy are applied, suggest that biomass residues can potentially reach 114EJ/year equivalent to 30% of the world energy demand in 1990. There are also many studies that establish the biomass and biomass by-products potential for individual countries (Radetzki, 1997; Van den Broek et al., 2001).

The figures in Table 1.2 indicate the possible range of by-product potentials that depend on several factors e.g. (i) population growth, (ii) dietary patterns, (iii) development of food production systems, (iv) yield of energy crops on different types of land (agricultural and degraded), and (v) developments of material substitutions systems (Hoogwijk et al., 2003). It is very difficult to compare those figures since some of them are based on different policy assumptions, e.g. an exogenous price of carbon or fixed energy prices, and are based on materials or energy balances.

This kind of methodology, generally, allows for estimating the energy potentials of by-products under different types of scenarios and assumptions. What lacks is an integrated economic analysis of how alternative use of these by-products can influence energy and agricultural prices, and production quantities of both agricultural and biomass commodities.

Table 1.2 Potentials of using by-products - a selection of studies

Type of residues	*Area*	*Potential (EJ/year)*	*Source*
Agricultural and forestry residues	World	114	Yamamoto et al. (2001)
Agricultural and forestry residues	World	58-75	Smeets et al. (2004)
Agricultural residues	World	18-25	Fisher and Schrattenholzer (2001)
Agricultural residues	World	10-32	Hoogwijk et al. (2003)
Agricultural and forestry residues	World	5-2	Lazarus (1993)
Agricultural and forestry residues	Western Europe	3-5	Smeets et al. (2004)
Agricultural and forestry residues	Western Europe	0.9-1.6	Ericsson and Nilsson (2006)
Agricultural and forestry residues	Eastern Europe	0-1	Smeets et al. (2004)
Agricultural and forestry residues	Eastern Europe	0.3-0.6	Ericsson and Nilsson (2006)
Agricultural and forestry residues	Europe (OECD)	0.3	Radetzki (1997)
Agricultural and forestry residues	Poland	0.4	ECBREC (2004a)
Agricultural and forestry residues	USA	0.0003*	Pimentel et al. (1981)
Forestry residues	Ireland	0.01	Van den Broek et al. (2001)

* Potential net electrical energy.

1.2.2 Multifunctionality of biomass plantations

The second type of biomass system dealt with in this thesis, is multifunctionality of biomass plantations, which is seen as one of the most promising solutions to reduce the pressure on productive land (Janssen and Suedmeier, 2000; LNV et al., 2000). Multifunctional biomass plantations carry out several different functions simultaneously. The main function is to deliver inputs for energy purposes. At the same time, the biomass plantations can provide other function/services such as waste water purification, soil decontamination or carbon sequestration. Table 1.3 presents an overview of a selection of possible function of biomass plantations and their environmental and economic benefits.

As can be read from Table 1.3, most of the studies focus on recognition and quantification of different functions of biomass plantation. The valuation of these services often proved to be difficult for several reasons, e.g. the market for a specific function does not exist, or the function is a public good. Moreover, many of these studies concentrate on small 'case-study' areas and the results are difficult to upscale to a potential at national or international scales.

A few examples from the literature that actually assess some environmental benefits are Borjesson (1999b; 2000), Berndes et al. (2004), Londo et al. (2004) and Lewandowski et al. (2006).

Borjesson (1999b) qualifies and quantifies several functions of *Salix* plantations for Sweden. He estimates, based on a literature review, the additional values (per ha) of the following functions; i) reduction of GHG, and nutrient leaching, ii) reduction of heavy metals in soils, iii) improvement of soil fertility and prevention of erosion, iv) cleaning of municipal waste water, and v) improvement of biodiversity. A selection of his findings is provided in Table 1.3. His main conclusion is that the price of biomass crops can drop substantially (reduction of up to 50%) if the environmental benefits are considered. However, due to non-existence of markets for most of environmental benefits, and what is probably more important, due to the common agricultural policy in EU, farmers are bound to use their land mainly for annual, traditional agricultural crops.

Borjesson (2000) uses two types of methods to calculate the environmental benefits: (i) a production function based method, and (ii) a damage avoidance/ substitution method, known as an averted expenditures method, using willingness to pay (WTP). Borjesson stresses that more economic incentives are needed for establishing biomass cultivations with environmental benefits, both for farmers and municipalities.

Another type of methodology is used by Londo et al. (2004). They study a few possible functions of energy crops plantations namely (i) groundwater quality protection, (ii) drinking water protection, (iii) conservation of traditional willow coppice flora and fauna, and (iv) ecological corridor. Their analyses include major uncertainties and are based on so called 'rapid appraisal' technique. This method compares use of different crops on the same type of land and assessing which type of crops offer most functions, besides energy production. They conclude that including the above mentioned possible benefits of willow plantations can significantly increase the potential for increasing the shares of willow-based energy in total energy supply in the Netherlands.

Table 1.3 Overview on multifunctional biomass plantations – a selection of studies

Function	*Type of crops; type of study*	*Environmental benefits*	*Economic characteristics*	*Source*
Carbon sequestration	Forestry; *field study*	0-40 US$ per MgC sequestered	Cost of ha plantation < 15 US$/MgC	De Jong et al. (2000)
	Energy crops (on agricultural land); *field study* (US)	Positive effects	-	Tolbert et al. (2002)
	Forestry; *literature and model study*	Possible positive effects	-	Creedy and Wurzbacher (2001)
	Forestry (on agricultural land); *literature study*	Positive effects	-	Lal (2005)
	Switchgrass; *field study*	0-207% increase in C storage	-	Ma et al. (2001)
Cleaning of drainage water from agriculture	Perennial energy crops; *literature study*	10-70 kg N/ha 1.5-5 kg P/ha	40-390 US$/ha 120 US$/ha	Borjesson (1999b)
	Willow; *field study*	185kgN/ha	-	Elowson (1999)
Cleaning of municipal sludge and waste water	Perennial energy crops; *literature study*	100kg N/ha per year	480-880 US$/ha 2.7-4.9 US$/GJ	Borjesson (1999b)
	Poplar; *field study* (UK)	Positive effects	-	Moffat et al. (2001)
	Willow (on agricultural land); *literature study*	Positive impact		Perttu (1999)
Phytoremediation (heavy metals)	Salix; *literature study* (Sweden)	Positive effects	8 to 63 €/ha	Berndes et al. (2004)
	Willow; *literature study* (Germany)	Positive effects	0-14 850 €/ha (over 20 years)	Lewandowski et al. (2006)
	Willow; *field study* (Sweden)	0.3-0.6 mg Cd (kg dw soil)$^{-1}$	-	Klang-Westin and Perttu (2002)
	Perennial energy crops; *literature study*	Positive effects	0.61 US$/GJ	Borjesson (1999b)
Prevention of soil erosion	Annual and perennial crops, forestry; *literature study* (US)	Not conclusive	-	Kort et al. (1998)
	Poplar and willow; *field study*	Positive impact	-	Wilkinson (1999)
	Energy crops (on agricultural land); *field study* (US)	Positive impact	-	Tolbert et al. (2002)
	Poplar, willow, switchgrass; *Field trials*	Possible positive impact	-	Tolbert and Wright (1998)
Prevention of water erosion	Annual, perennial crops, and forestry; *literature study* (US)	Not conclusive	-	Kort et al. (1998)
Providing habitat to wildlife	Poplar, willow, switchgrass; *Field trials*	Possible positive impact	-	Tolbert and Wright (1998)
Prevention of water erosion	Annual, perennial crops, and forestry; *literature study* (US)	Not conclusive	-	Kort et al. (1998)
Maintaining biodiversity	Perennial energy crops; *literature study*	Not conclusive	-	Borjesson (1999b)
	Willow (on agricultural land); *literature study*	Positive impact	-	Perttu (1999)

Berndes et al. (2004) asses via an indirect revealed preferences method the economic benefits of cadmium removal via the Salix plantations in Sweden. Those benefits are based on the estimation of (i) the 'decadmiation' process of phosphate fertilizers, (ii) the environmental fee of cadmium in fertilizers, and (iii) income losses of farmers due to cadmium-induced price reductions. They calculate that the benefits for farmers for planting Salix instead of traditional agricultural crops can reach 8-63 Euro/ha per year.

Lewandowski et al. (2006) quantify the phytoremediation function of willow plantation on a study field area in Germany, i.e. the fact that willow can clean up contaminated land. By comparing the reference systems, they assess whether biomass crops fulfill more environmental functions than traditional agriculture. They calculate the income loss of farmers that have polluted land and assess it as additional benefit of willow plantation. They use (i) substitution cost method, (ii) contingent valuation method (using WTP for farmers to clean up their land), and (iii) hedonic pricing. The benefit range is provided in Table 1.3.

The phytoremediation function can play in itself a role in decreasing the pressure on productive land, as heavily polluted land cannot be used for food crops production. The production of energy crops, therefore, can take place on contaminated land. At the same time it can be expected that after several years (depending on biomass crop and the level of contamination), this land can be returned to food production. Moreover, heavy metal contaminated areas can be found in most European countries and due to stronger EU regulations it can be expected that the amount of contaminated land taken out of food production may increase.

1.2.3 Material substitution and cascading of biomass resources

'Material substitution' is the replacement of non-renewable materials by bio-based materials (Dornburg, 2004). Recently, there is an increased recognition of the potentials of so-called bio-refinery systems. These systems use the molecular structure of biomass in order to extract high value components that can substitute fossil fuel components commonly used in chemical or petrochemical sectors (Sanders et al., 2005). Often, many of the chemical compounds that have a complex synthesis route in the petrochemical industry can be produced from biomass origin. Combining the bio-refinery system with the so-called cascading system can stimulate the reduction of GHGs via two routes; i) by substituting fossil-fuel based materials (bio-refinery) and ii) by directly substituting fossil fuel input in the electricity sector (cascading).

The word 'cascading' originates from the analogy of water cascade, where the water is descending from one level to another. In the beginning of nineties, Sirkin and ten Houten (1993) used this terminology for the first time in context of biomass resources. During the lifetime of the materials, they are used for different applications, ending up as waste to energy, exploiting full potential of a resource (Reijnders, 2000; Dornburg and Faaij, 2005). Cascading systems were originally proposed to increase the efficiency of virgin materials and to store CO_2 in materials. It turns out that it can also be a possible solution to reduce land requirements and increase the potential of cheap wastes that can be used in e.g. the electricity sector. In addition to reducing land requirements for biomass plantations they reduce the use of the virgin material and increase resource efficiency (Sirkin and Ten Houten, 1993; Fraanje, 1997a, 1998; Reijnders, 2000). Thanks to the cascading mechanism, biomass can be used for both material and energy purposes.

From an environmental point of view, cascading can be a potentially interesting option to reduce and postpone emissions of CO_2. In theory, no CO_2 is emitted when transforming biomass into energy, under the condition that the whole biomass production is devoted to the energy production. An additional benefit of this system is that the carbon, captured in materials, is released with a large time delay. Many scientists refer to it as a carbon sink. However, there is a negative side to environmental performance of a cascade. During the biomass transformation there might be more emissions involved due to additional processing and transport.

There are several studies that analyze different cascading possibilities. Fraanje (1997a,b) analyzes several cascading possibilities for different biomass crops. Fraanje (1997a) proposes the sequential cascading of pine wood in six or seven steps; 1) floor joist, 2a) floor board, 2b) lower quality floor board, 3) window frame, 4) flake boards, 5) fireboards, last step is 6) incineration. He assumes that as a result of the cascade there can be a delay in CO_2 emissions for around 300 years. He argues that with the proper policy measures, e.g. eco-taxation and prohibition of waste wood dumping, the efficiency of raw material use can be improved in favor of cascading. Fraanje (1997b) argues that with a proper cascade of hemp and reed, one can extend a lifetime for example by 3 to 60 years for hemp, and by 30 to 80 years for reed. The cascade for hemp includes the following steps; 1a) hemp based paper, 1b) (lower quality) hemp based paper, 2) newspaper paper, 3) paper-wool insulation and the last step 4) incineration. The cascade for reed is as follows; 1) thatching reed, 2) repaired thatching reed, 3) reed fiber board and 4) incineration.

Borjesson and Gustavsson (2000) describe the situation where concrete can be replaced by wood products in the building sector in Sweden. Moreover, they propose several cascading options for wood-based construction materials. They recognize that once wood materials are re-used, there might be more emissions involved, therefore one can question whether it is better to leave the forest as a carbon sink or to increase the efficiency of wood product technologies. They compare several options of possible wooden cascades against its substitute, a concrete frame. They found out that when demolition wood is used to replace concrete, it might slightly increase emissions, due to loss in forestry area. However, when recycling the demolition wood, overall CO_2 emissions can decrease. When demolition wood is land filled, the overall emissions increase substantially. They did not, however, include an economic analysis of the performance of different cascades nor a possibility of reforestation.

Dornburg and Faaij (2005) analyze several cascading chains of poplar. Depending on the form of cascade they show that in the best case the cascade can contribute to environmental benefits up to 200 Euro/Mg CO_2 per hectare per year, but other cascades may induce substantial damages up to 2 200 Euro/Mg CO_2 per hectare per year. They claim that, in general, long-term cascading decrease the costs and emissions. However, the results crucially depend on the biomass applications. Moreover, they state that cascading can significantly reduce the pressure on productive land.

These studies show a variety of possibilities for substituting non-renewable materials by biomass products and demonstrate that with the proper cascade CO_2 emissions can decrease. This depends, however, on each individual case. Despite the positive influence that cascades have on reducing the pressure on non-renewable materials, the authors concentrate mostly on the environmental impacts of cascades, namely on the emissions balance. Most of these studies do not consider an impact of a cascade system on land use. On the one hand, cascades might increase the pressure on land, if there will be a high demand for biomass substitutes. On the other hand, the cascade might reduce the acreage needed for energy production, since in the end it provides cheap material that can substitute virgin biomass crops. To analyze it the cascading mechanism should be linked to the whole economic system. It is important that the proper system is both efficient in material use and in reduction of emissions.

1.3 Scope and objectives

Recent literature, as described in Section 1.2, provides some insights into several aspects of biomass and bioenergy systems. These studies show various possibilities on how to improve the potential for biomass production or how to reduce the negative effects that biomass plantations might have on the environment. There are, however, some aspects of multifunctional biomass systems that these studies neglect.

The biomass systems are often studied separately from socio-economic systems, omitting the relations that these specific sectors can have with the rest of the economy. They often focus on small-scale applications and they ignore the wider impacts. Moreover, most of these studies focus on one type of multifunctional biomass systems and do not address the possible competition for land between different types of biomass or different types of biomass applications. From a methodological point of view, many agricultural and energy models tend to focus on land use changes within the agricultural sector e.g. Walsh et al. (2003), omitting the relations that agriculture has with the rest of the economy. Other models focus on energy systems and cannot properly assess the land use reallocations e.g. Gielen (2001a).

Therefore, there is a high demand for an in-depth analysis on how the specific biomass and agricultural systems, including the multifunctional biomass systems, can influence both energy and agricultural sectors simultaneously, and also what their secondary impacts are on the other sectors in the economy, and on the environment.

In various chapters of this thesis, different multifunctional biomass systems are integrated with (the rest of) the economic system, namely; i) multi-product crops, ii) multifunctional biomass plantations, iii) material substitution, and iv) cascading. Moreover, the impacts that those systems might have on the economy and on environment are studied on a country level. To this purpose, two different models are applied: (i) a partial equilibrium model, and (ii) a general equilibrium model. For analyzing the effects of specific biomass systems on the economy, we choose an applied general equilibrium (AGE) model.

Furthermore, many studies deal independently with the effects of the implementation of biomass systems on prices, production, trade, or land use. In various chapters of this thesis they are analyzed simultaneously. Thanks to the basic structure of the models, the changes in production and consumption levels, and changes in the relative prices can be assessed.

The main objective of this thesis is to contribute to:

(i) Better understanding of the effects of biomass systems on the economy;

(ii) Analyzing the possible competition for land between the biomass sector and the conventional agricultural sector when different climate policies are implemented;

(iii) Analyzing the effects of diverse climate policies, for GHG emissions reduction and for increasing shares of bioelectricity in total electricity production, on land use allocation, prices, production and consumption levels of different economic commodities, in the context of the implementation of biomass plantations;

(iv) Analyzing the impact of several biomass systems, mainly i) multi-product crops, ii) multifunctional biomass plantations, iii) material substitution, and iv) cascading, on land use allocation, prices, production and consumption levels of different economic commodities;

(v) Providing suggestions to policy makers concerning the development of energy and environmental policies and applications of biomass systems.

These objectives lead to the main research question of this thesis:

"What are the impacts of energy policies and large-scale multifunctional biomass systems on biomass and bioelectricity production, land use, agriculture and the rest of the economy?"

This question can be divided into several sub-questions. First of all, research question 1: "*Which types of multifunctional biomass systems can be applied on a large scale?*" needs to be addressed. A set of possible biomass crops, based on the literature review and personal communication with experts, is chosen. The main criteria for the crop selection are: suitability for a case study country (region), high yields, diversification including both annual and perennial crops, and suitability for multiple land use applications. The criteria concerning the biomass systems include: large market share potentials, substantial potential of CO_2 reduction, and relatively low production costs.

For a quantitative economic analysis, a choice has to be made for the mathematical formulation of the model with which these systems can be investigated. This involves the choice of a model type and specification of the interactions between biomass systems and the rest of the economy, with special attention to agricultural production and land use. Thus, a research question 2, can be formulated as "*What quantitative methodology, including model type and specification, is capable of analyzing the economics of multifunctional biomass systems?*". There are two different promising types of model i) partial equilibrium and ii) general equilibrium models. They will be investigated in more detail in Section 1.4 and in Chapters 2 and 3.

Research question 3: "*To what extent can multifunctional biomass systems improve the efficiency of biomass production and reduce the pressure on productive land?*" addresses the multifunctional biomass systems and their impact on electricity and agricultural sectors, with special attention to land use allocation. As indicated in an earlier section of this chapter, climate policies tend to stimulate the demand for biomass as a source of carbon neutral energy carrier. Therefore, the demand for land might also increase, placing a pressure on productive land. The effects of different climate policies on the production level, prices and land use allocation of energy crops and traditional crops (food and fodder crops) are analyzed. To test the hypotheses that the multifunctional biomass systems are more efficient and reduce the pressure on productive land, different biomass systems are implemented in the AGE model. They are analyzed in terms of the impact they have on the economy and the environment with special focus on the agricultural and energy sectors.

To answer research question 4: "*What are the impacts of multifunctional biomass systems on the allocation of resources in the economy?*" the impacts of energy and climate policies on the other sectors in the economy, and ultimately the utility level of the representative consumer, are analyzed. The AGE model provides the efficient allocation of resources under the different policy scenarios, such that the equilibrium prices can be analyzed in conjunction with the equilibrium production, consumption quantities and international trade patterns. Moreover, the model outcome concerning the level of the GHG emissions is studied.

As a research tool, a partial and an applied general equilibrium model, which are based on solid microeconomic foundations, are developed. The partial equilibrium model is used to lay out the fundaments of the modeling approach; the AGE model can be seen as an important extension of the partial model. The importance of extending to the AGE approach lies in capturing several mitigating mechanisms that influence the impact of environmental policy, that are not captured in a partial equilibrium model.

In the specification of biomass and bioelectricity production in the model, substitution possibilities between (i) biomass-based electricity and 'traditional' electricity, (ii) different inputs in the Bioelectricity sector, and (iii) different types of materials, are implemented. Moreover, different production technologies of biomass and forestry products are analyzed, exploring e.g. the phytoremediation characteristics of willow plantations and forestry. Concerning bioelectricity production, the model can choose between using the dedicated biomass crops, and/or by-products, and/or disposed biomass based materials. Both producers and consumers are able to distinguish between conventional electricity and bioelectricity.

1.4 Agricultural and energy models

This section presents an overview on recent modeling approaches concerning the interaction of energy systems and agricultural sectors and discusses the main characteristics of the modeling approach used in this thesis, neo-classical equilibrium models.

1.4.1 Agricultural and energy systems and their interactions in the existing literature

Though an extensive review of the most relevant part of the literature will be given at the start of each chapter, it is useful to provide a first overview of some existing modeling studies that investigate the links between agricultural, biomass and energy systems.

Generally, agricultural and energy models can be divided into models with a neo-classical, micro-economic foundation and models that use static or dynamic optimization (without securing market closure). Models with a neo-classical foundation can be sub-divided in partial equilibrium models and general equilibrium models. The optimization models may lack the micro-economic foundation, but normally have detailed accounts of economic behavior in the relationships that are specified. Both types of models can focus on agriculture (land use) or on different energy systems, but where the optimization and partial equilibrium models normally assume there is no interaction with the rest of the economy, general equilibrium models taken the interactions between the different sectors into account. A model that contains an economic module as well as an environmental module, and that links both subsystems to each other through feedback links is called an integrated assessment model. General equilibrium models are normally labeled as 'top-down' models, as they take smooth production and utility functions to describe the behavior of producers and consumers. In contrast, optimization model that are based on detailed descriptions of individual technologies are labeled 'bottom-up' models.

Examples of models for analyzing different energy systems are MATerials Technologies for greenhouse gas Emission Reduction (MARKAL MATTER) model (Gielen et al., 2001a), and Biomass Environmental Assessment Program (BEAP) model (Gielen et al., 2001b). These models are solved by linear optimization and focus on a detailed descriptions of the energy systems and their biomass modules restrict themselves to agricultural and forestry residues and waste.

Models that study the possible land shift between agriculture and biomass or forestry and its impact on the economy and environment are e.g. General Optimal Allocation of Land Use (GOAL) model (WRR, 1992), and Policy Analysis Systems (POLYSYS) model (De La Torre Ugarte and Ray, 2000). Those models focus mainly on land allocation between different crops. Walsh et al. (2003) extended POLYSYS by including specific biomass crops (switch grasses, poplar and willow). These models are solved by linear optimization

A model that integrates the interaction between energy and agriculture is the Land Use Change Energy and Agriculture (LUCEA) model (Johansson and Azar, 2004). It is a dynamic non-linear optimization model that deals with competition between biomass and food crops, using a bottom up approach. It determines food and energy prices in case of stringent climate policies in the USA with exogenous CO_2 emission permit prices. Johansson and Azar model different energy carrier possibilities: fossil fuel based, nuclear and different types of renewable energy. Moreover, they model a carbon capture and sequestration options. The base price of carbon of 50 US$ per ton of carbon is introduced in 2010 and grows with 3% per year reaching 800 US$ per ton of carbon. They found out that with stringent policies the prices of food might even double.

An example of a partial equilibrium model used for determining the allocation of food and biomass crops is the Agricultural Sector Model (ASM) by McCarl et al. (1993). This is a model where the agricultural sector in the USA is described in detail. The dynamic Forest and Agricultural Sector Optimization Model (FASOM) is the ASM model, enlarged with a forestry sector (Adams et al., 1996; Van Ierland and Oude-Lansink, 2003). Another successor of the ASM model is the ASMGHG model, which includes emissions of greenhouse gases and mitigation possibilities (McCarl and Schneider, 2001; 2003). This model focuses on the impact of carbon pricing policies on agriculture and environment. The results of the model simulations suggest that with a high carbon price (at least 500 US$/ton carbon equivalents), the prices of agricultural commodities double. The impacts on the environment, however, are positive; e.g. there is an overall decrease in GHG emissions, and less wind and water erosion. These models focus mainly on the agricultural and forestry sectors and they consider different CO_2 reduction options including carbon sequestration. However, the interactions between the agricultural sectors and other sectors in the economy are absent. Moreover, the CO_2 permit price is exogenous. The ASM model is also used as an agricultural-economic module in an integrated assessment model that assesses the impact of different climate policies on a spatial level (Adams et al., 2003).

The Agriculture and Land Use (AgLU) model is a part of an integrated assessment model (ICLIPS – the Integrated Assessment of Climate Protection Strategies) that combines a top-down economic model with a land use model (Sands and Leimbach, 2003). This model was created to simulate changes in land use and the resulting carbon emissions, due to changes in the carbon price. By modeling biomass resources, the model links the energy module with an agricultural module. As most integrated assessment models, this model highly aggregates the world economy and agricultural sectors. They conclude that with high prices of carbon (100-250 US$ per ton of carbon) the industrial CO_2 emissions drop drastically, however the CO_2 emissions related to land use changes might increase, especially in the beginning stage of enforcement of carbon policy. With low carbon prices (around 30 US$ per ton of carbon) the acreages of biomass plantations do not increase substantially.

There are many top-down environmental economic models that involve a detailed economic analysis of the energy sector, and that are able to assess the secondary effects of shifting energy production, including Breuss and Steininger (1998), Nordhaus and Yang (1996), Böhringer et al. (2003), Kumbaroglu (2003), McFarland et al. (2004), and Babiker (2005).

The model developed by Breuss and Steininger (1998), is a general equilibrium model for Austria, with special attention to biomass as a possible solution to reach the goals of the climate change agreements. They analyzed the benefits of including biomass-based technologies in the economy. They found out that biomass energy supply scenario can reduce the CO_2 tax by 50%.

The Regional Integrated model of Climate and the Economy (RICE) model is a regional, dynamic general equilibrium model that integrates economic activity with a sources, emissions and consequences of GHGs emissions and climate change (Nordhaus and Yang, 1996). It allows for calculating the efficient path for reduction of GHGs both in cooperative and non cooperative approaches. This model focuses mainly on existing fossil fuels based energy technologies.

Böhringer et al. (2003) focus on the possibilities to reduce greenhouse gas abatement costs through investments in the energy sectors in developing countries (Joint Implementation or Clean Development Mechanism) and apply their model to the case of Germany and India. They find that these flexible mechanisms can substantially reduce the costs of achieving emission reduction targets in Germany and potentially provide welfare gains for both countries.

Kumbaroglu (2003) studies the effects of environmental taxation on the Turkish economy, with a focus on the energy sector in a dynamic CGE model (ENVEEM). He discusses various energy and emission taxes and expects a double dividend for the NO_x taxation (increased environmental and economic performance simultaneously). This model focuses as well on mainly existing energy technologies.

McFarland et al. (2004) use the Emissions Prediction and Policy Analysis (EPPA) model, a dynamic, multi regional CGE model representing economy wide interactions and at the same time including a lot of detail on different technologies. Their model includes three novel carbon sequestration technologies and also some renewable options for energy production. The policies analyzed are mainly i) carbon taxation and ii) stabilization of GHGs concentration. They conclude that the new technologies with carbon capture options with a current level of production costs, can enter the market only under the assumption of a high carbon price (above 100 US$ per ton of carbon). Using a different version of the same EPPA model, a different focus is presented by Babiker (2005). He analyzes the impact of climate policies induced by Kyoto (CO_2 emission reduction) on trade and domestic production and on the level of GHG emissions. He points out that current policies to reduce the CO_2 emissions in most of the developed countries might lead to an increase in global CO_2 emissions; those increases of emissions can be mainly attributed to developing countries.

1.4.2 Neo-classical equilibrium models

The most commonly used models in the analysis of agricultural sectors and energy systems are partial equilibrium models and general equilibrium models. Both these types of models are based on neo-classical theory. Many economic handbooks give an introduction on each of these types of models, e.g. Varian (2002), and Blanchard and Fischer (1989), and here we only provide a brief overview of the main characteristics, with special focus on the application in the field of agricultural and energy analysis. A different classification could be applied on the basis of the mathematical tools used to solve those models, e.g. linear optimization versus non-linear optimization models. Chiang (1984) provides detailed instructions into the mathematical specification of these methods. Furthermore, there are several other model types encountered in the literature, including for instance Keynesian disequilibrium model (Romer, 1996). For the purpose of the current study, only the neo-classical equilibrium models are going to be dealt with, as this provides the proper basis for the analysis in the later chapters.

Both partial and general equilibrium models are based on neo-classical theory for the behavior of individual agents, i.e. households and firms. The main characteristics of this theory are that agents behave rationally, markets function perfectly, and prices adjust to attain equilibrium on the markets. Each agent takes prices as given, and solves her own optimization problem.

Partial equilibrium models describe only those markets that are relevant for the analysis at hand. They omit the interactions of the sectors chosen with the rest of the economy, even though in reality such situations are rare. However, they allow maximum focus on the sector under investigation and hence are suitable for analyzing the specific objectives and finding answers to certain types of research questions. Partial equilibrium models are often used in analyzing sectors with a relatively small income share in the total economy. Partial equilibrium models are appropriate when the 'shocks' produced by the direct price changes do not cause other prices to change, or when these effects are negligible. An important characteristic of the sector(s) chosen is that its (their) relationship with the other sectors of the economy is weak (Ruijs, 2002). Those models allow for a detailed analysis of 'actors' behavior only in the selected sector(s), keeping the rest of the economy fixed and thereby not having the need to represent the rest of the economy within the model. For each of the markets specified in the model (often just one), an equilibrium price is found for which the market clears, i.e. supply equals demand. More detailed information on partial equilibrium models can be found in Tsakok (1990).

General equilibrium models are also based on neo-classical theory, similarly to partial equilibrium models, but they describe the entire economy and represent the economic cycle. As the name suggests, a general equilibrium model concerns a simultaneous equilibrium on all markets. It has been shown that under certain conditions, such equilibrium exists and is unique (see e.g. Varian (2002)). For numerical analysis, a *computable* or *applied* general equilibrium is used.

A general equilibrium model includes a set of economic agents, each of which demands and supplies commodities. Following Dellink (2005), we distinguish three basic conditions for applied general equilibrium (AGE) models. First, the *zero profit condition* means that under the usual neo-classical restrictions (constant returns to scale, perfect competition, no barriers to entry or exit on the markets), the value of output has to equal the value of all inputs. The intuition behind this condition is that if any profit can be reaped, a new firm enters the market (when there are no entry barriers). This induces a higher supply of the produced good, which in turn leads to a reduction of a price. The process continues until there are no profits to be shared.

Secondly, the *budget condition* means that the consumer’s expenditures cannot exceed income. The income of consumers comes from e.g. the supply of labor and capital and tax revenues. The consumers spend all income (assuming among others non-satiation), dedicating a part for savings and the rest for consuming goods. In a dynamic specification, this restriction can be revised to include the possibility of intertemporal borrowing of funds, i.e. a temporary budget imbalance.

The third condition is called the *market clearance condition*, which means that supply equals demand for each produced good and factor. The basic mechanism behind the general equilibrium works on the basis of adjusting prices and price-responsive quantities of all commodities to reach an equilibrium condition. When at a certain price the demand for a good is higher than supply, i.e. if excess demand exists, the price of good increases, which induces a reduction in demand and increase in supply. Eventually, the equilibrium price emerges where the supply is equal the demand. Similarly, when there is an excess supply, the price decreases until both supply and demand are in equilibrium. Complicating factor is that the changing prices on one market will have repercussions on other markets. Thus, price changes on other markets may also be necessary to restore equilibrium on the analyzed markets. Such price and quantity adjustments are active until all markets are simultaneously in equilibrium.

The main advantage of the AGE model is that it gives a complete description of the economy (in contrast to partial equilibrium models, which describe one or a few markets) and that the economic cycle is closed (i.e. all financial transfers are accounted for in the model; there are no 'leaks' out of the model). All economic agents are taken into account. However, compared to most partial equilibrium models, the level of aggregation is high and/or the data requirements are rather large. Until recently, another disadvantage of AGE models was that they are more difficult to solve numerically, but the increases in computing power have made this a minor issue.

1.4.3 Empirical specification of equilibrium models

Applied partial and general equilibrium models are characterized by a choice of functional forms that can represent a specific situation with real data, and that can be used to calculate a numerical solution of the model. These functional forms describe producer behavior through the specification of a production function and consumer behaviors through the specification of a utility function. Specifying the parameter values of the equations to represent real data is called calibration (Shoven and Whalley, 1992). For consistency, the model should be capable of re-calculating the initial situation using the benchmark data.

Two types of data are needed for the calibration of a comparative-static model: (i) data describing the initial allocation of resources, and (ii) data describing the reaction of agents to changes in circumstances. Moreover, additional information about the policy impulse is needed to carry out actual policy simulations. For a dynamic specification additional assumptions on growth rates are necessary.

For the first type of data, describing the *initial allocation of resources,* information on monetary flows for a historical year is needed. These are often based on the National Accounts, which include expenditures by production sectors and households on the various goods and the division of production factors over producers. In partial equilibrium models, there is no common way of organizing the data on the initial allocation, as the focus of different models diverges substantially. In AGE models, the information is usually represented via a Social Accounting Matrix, which may contain an Input-Output table at the core, augmented with additional accounts for other issues under investigation (such as environmental data). In many models, prices are normalized. This has the advantage that the expenditures in the National Accounts can be used directly in the model without any transformation and quantities can be interpreted as expenditures, valued at benchmark prices.

The second type of data, for modeling the *reactions of the agents* to the impulse given, is usually specified in terms of elasticities. For the households, price and income elasticities govern the change in the demand for a good if a price changes or if the income changes. Note that the demand for one good may not only change due to changes in the price of the same good, but also due to changes in the prices of other goods. For production sectors, price elasticities have to be specified, while for international trade relations, specific trade elasticities are often specified. When CES functions are used as the functional form of a production of utility function, the entire curve is described by three parameters: (i) the initial quantities of inputs to determine a point on the curve; (ii) the initial relative price of the one input in terms of the other input to determine the slope of the curve; and (iii) the elasticity to determine the curvature of the curve.

The data describing the *policy impulse* is the quantitative equivalent of some new policy, *e.g.* the change in a tax rate. Alternatively, an impulse can describe a change in availability of one or more endowments, *e.g.* an increase in total labor supply. Such policy impulses are normally varied in different scenarios.

1.5 The energy sector and energy-related policies in Poland

In order to analyze the research questions in a specific context a central European country – Poland have been chosen, since it is expected that in the future the potentials for energy crop production are especially high in Central and Eastern European countries (CEEC), because they have large land resources and comparatively (to Western European countries (WEC)) low land and labor costs. A recent potential assessment study (Van Dam et al., 2005a) has shown, that several million hectares of agricultural land could become available for the production of energy crops in CEEC if agricultural production in CEEC will rationalize[2] and more efficient production methods are applied. Poland and Romania have the largest biomass production potentials because of the size and quality of their agricultural land. Moderate ethanol production costs of about 6 – 8 Euro/GJ (see Van Dam et al. (2005b)) also opens the opportunity to Poland to become an important exporter of biofuels to markets in WEC.

In addition to its low productive agricultural sector and relatively cheap land resources, Poland possesses large quantities of land currently unproductive due to its high heavy metals

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[2] Rationalization in agriculture means the increasing use of modern machinery, techniques and input, it also includes processes of enlargement of single field size. Generally the rationalization process leads to a decrease in labor demand and reduction of jobs in the agricultural sector

concentrations (Bocian, 2005). These areas can be used for energy crops. Since the late eighties, Poland has been undertaking many socio-economic changes that influence all sectors of the economy and also the land use. In this section, an overview of the recent developments in the energy sector and its impact on bioelectricity and biomass is provided. Moreover, a discussion some of the policies that can affect future shares of renewable energy and have an influence on changes in land use is performed.

1.5.1 Heat and electricity sectors in Poland

Within the last decades, two historical decisions induced many changes in the Polish economy. First, the change of the political system from socialism to a democracy induced a transition towards the decentralized economy. Second, in 2004 Poland became a member of the European Union (EU), which is generating further changes towards unification with the rest of Europe. Those decisions influenced most of the economic sectors, including the energy sector.

Since 1988, the use of primary energy decreased considerably, resulting in 28% drop to 3,812 PJ in 2000. From 1990 till 2000, prices of heat and electricity increased rapidly; namely from 0.25-11.75 Euro/GJ[3] for district heating, and from 0.005-0,075 Euro/kWh for electricity (GUS, 2002a). This was caused mainly by i) a subsidy reduction on energy, ii) restructuring of the energy sector, and iii) obligations to comply with new environmental laws. Energy prices in Poland are at similar level to energy prices in the rest of EU, but the income level is lower than in the rest of EU (Nilsson et al., 2006).

Following the political changes the demand for heat decreases substantially. Many heavy industries closed down and others adapted to new situation by increasing energy efficiency. Moreover, the demand for district heating decreased due to different pricing methods for hot water and due to better isolation techniques used in private houses. It is expected, that the demand for heat will further decrease due to additional efficiency measures and technological progress (Nilsson et al., 2006).

The situation of the electricity sector, compared to the heat sector, is different. The demand for electricity remained stable in last decade. Currently, the annual electricity production per capita in Poland is below 4,000 kWh, but the Ministry of Economic Affairs (Ministry of Economic Affairs, 2000) expects an increase in annual electricity consumption up to around 6,000 kWh per capita, reflecting the average electricity consumption in the rest of the EU.

Coal is a dominant fuel in the production of electricity in Poland. Around 97% of all electricity generated in the country comes from coal-fired plants that are inefficient (Nilsson et al., 2006). In 1997, 135.0 billion kWh of electricity was generated in Poland from which only 0.6 billion kWh from renewable energy. In 2000, the situation was similar; 135.2 billion kWh was produced, from which 0.5 billion kWh from renewable energy. Poland is a net electricity producer; it exports it excess to neighboring countries.

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[3] One zloty (zl) equals around 0.25 Euro.

In 1999 most of the ‘green’ electricity was produced from small hydro plants, but there is not much scope for expansion of this type of electricity in Poland, because most of the hydro potential in Poland is already explored. Other potential renewable sources for electricity production are (i) solar panels, (ii) wind mills and (iii) biomass. Solar energy is relatively expensive compared to other renewable sources. To produce relatively cheap wind energy, the wind parks need to have good geographical conditions. Right now, only in the northern part of Poland there is some development in this field, but both atmospheric conditions and negative community attitude do not encourage further developments. Therefore, biomass has the largest potential in Poland to be used as a renewable energy source in the near future (ESD and ECBREC, 2001). Nilsson et al. (2006) provide the following short and long time potentials for biomass are 150-250 PJ per year and 1,000-1,500 PJ per year respectively.

Currently, in Poland, biomass is used mainly to generate heat. However, following ECBREC (2004a), there are a few working plants combining production of heat and electricity, mostly using forestry products (5 installations of total capacity 500 GWh per year). Additional source of bioelectricity comes from biogas from combined heat and power (CHP) plants (32 installations of total capacity 38 GWh per year), and landfill gas (17 installations of total capacity 22 GWh year). Besides these, willow and hemp are considered to have a high potential for use in electricity production (ECBREC, 2004b).

The costs of biomass-based plants generating electricity are currently 2 to 3 times higher than similar plants fueled by oil or gas (Zurawski, 2004). However, within the coming years, the electricity sector has to undertake serious modernization in order to fulfill both efficiency and polish environmental standards (Lynch, 2005). Most of the old plants need to be replaced due to their lifetime capacity, creating a large scope for development of new and clean biomass-based plants. In Poland, since many years, there is a tendency to develop small-scale plants that can be heated based on availability of crops in the region, thereby minimizing transport costs of biomass (Nilsson et al., 2006).

1.5.2 Environmental, energy, and agricultural policies

Poland takes part in many international agreements concerning the natural environment, and as member of the EU it is obliged to follow European rules. Moreover, it undertakes own initiatives to improve the quality of life within its borders. Concerning the subject of this thesis, here, the focus is laid mainly on the agreements, both international as national, to reduce the emissions of several gases and on policies targeting an increase of bioelectricity shares in total electricity production. Moreover, a short overview on the agricultural policies influencing the energy crops production is provided.

Poland has ratified the Kyoto agreement[4] on the 13th December 2002, agreeing on 6% reduction of GHG emission level from 1990. In 2002, Poland achieved around 17% reduction of the CO_2 emission level (Table 1.4). This gives a scope to investigate the potentials of

[4] Source: UN (1997).

selling the emission rights to other trading countries and provides opportunities to attract many joint implementation (JI) investments. According to Nilssen et al. (2005) Poland's potential is 50–130 Mton of carbon dioxide equivalents, in the first commitment period.

Table 1.4 Total GHG emissions in Poland (in Kton)

	1988	*1990*	*2000*
CO_2	477 584	381 482	314 812
CH_4	3 141	2 801	2 183
N_20	70	63	77[5]

Poland signed a Second Sulphur Agreement and the Gothenburg Protocol, where it commits to 66% (of 1980 level) sulphur reduction by 2010. In 2000, the sulphur emission reduction reached 63% and it further decreases. It is expected to reach the goal by 2020. These agreements are in line with the EU Directive on the limitation of emissions of pollutants into the air from large combustion plants (CEC, 2001). Large sources of SO_2 emissions, accounting to around 50%, are large power plants and large combined heat and power (CHP) plants. In 2001 the emissions from large power plants accounted to 805 kton whereas the total was 1511 kton (GUS, 2002b). The rest of the sulphur emissions are coming mainly from medium and small CHP and power plants, and individual boilers.

The EU has set ambitious targets to increase the use of biomass for energy production; (i) a contribution of 5700 PJ from biomass in 2010 and (ii) an increase in consumption of biofuels (mainly diesel and gasoline) to 5.75% in 2010. These targets are outlined by the so called 'White' and 'Green' papers (CEC, 1997, 2000) and the biofuel directive (CEC, 2003b) adopted by the EU in 1996, 1997 and 2003, respectively. They cannot be met by the use of agricultural and forestry residues alone. That means, that large areas of agricultural land in the EU will have to be dedicated to the production of energy crops (Faaij, 2006).

In 2001, the Polish government set goals concerning an increase of the bioelectricity share in total electricity production to 7.5% by 2010 and 14% by 2020. Those targets are higher than the EU targets. Also in Poland biomass energy is recognized as the most promising and most important renewable energy source in the 10–20 year time-frame (Nilsson et al., 2006). The government acknowledges that the appropriate market conditions and support systems have to be created to reach the targets. The objectives are expected to be met through the implementation of support programs for particular renewable sources and technologies. Unfortunately, until recently this law was not properly enforced; however in 2004 a mechanism has been introduced to secure the compliance (Nilsson et al., 2006).

The EU agricultural subsidies are granted for conventional agricultural production, energy crops and afforestation practices. The Polish government chooses a relatively simple subsidy scheme. Each farmer that owns a land of more than 1 ha acreage receives 61 Euro per ha yearly. Moreover, farmers get 72 Euro, 69 Euro and 45 Euro subsidy per ha if they grow traditional agricultural crops, grass or energy crops, respectively (CEC, 2003a). For a detailed

[5] In this year, the first time the emissions from animals droppings were assessed (20 Mton).

list of crop subsidies see UKIE (2004). Moreover, the EU proposed a long-term program for Poland, regarding afforestation of agricultural land (UKIE, 2004). In present value terms, using a discount factor of 4%, landowners receive 175 Euro per ha for afforested land. Such policies induce an expansion of forest area in Poland (ECE/FAO, 1996; Ericsson and Nilsson, 2006).

1.6 Outline of the thesis

This section presents the outline of this thesis. Chapter 2 focuses on the competition between traditional agricultural production and growing demand for biomass plantations. The aim of this chapter is to investigate the effects of various energy policies, aimed at both reducing the emissions of greenhouse gases and increasing the share of bioelectricity, on the production of biomass and agricultural commodities. For this, a partial equilibrium model is developed to illustrate some of the potential impacts of these policies on greenhouse gas emissions, land reallocation and prices of food and electricity. A partial framework is used, because it provides a transparent and consistent structure and enables to concentrate on only the relevant economic sectors (agriculture, biomass, conventional electricity, and bioelectricity). In the model, GHG emissions depend on 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.

Chapter 3 deals with the impact of climate policies on land use and land cover change and possible impacts on reestablishment of semi-natural areas, mainly forestry and willow plantations. The aim of this chapter is to investigate the impact of climate policies to reduce greenhouse gas emissions by means of promoting biomass and bioelectricity. In this context, the analysis is performed on how these policies might affect production of agricultural commodities and trade patterns of biomass and bioelectricity. To this purpose, an applied general equilibrium model (AGE) is developed with special attention to biomass and agricultural crops for a small open economy, with an Armington specification for international trade.

Chapter 4 focuses on the multiproductivity issues of agriculture, biomass, and forestry sectors resulting in additional production inputs for the Bioelectricity sector. The main questions that are dealt within this chapter are: to what extent the multi-product crops increase the potential of bioelectricity production and how do they affect the prices of agricultural commodities. These questions are analyzed in the general equilibrium framework. This line of analysis is chosen because it allows comprising the bottom-up information about multi-productivity with the general setting of the whole economy in an applied computable general equilibrium (AGE) framework. This is important since energy policy responses influence main economic sectors and via feedback effects they influence the whole economy. The impact of climate policies on land use allocation, sectoral production and consumption levels and prices of land, food, electricity and other commodities, including the multiproductivity of crops is assessed.

Moreover, this chapter provides an analysis to what extent competition for land can be reduced by using multi-product crops.

In Chapter 5, the general equilibrium framework is further explored. The phytoremediation characteristics of willow plantations and forestry, thanks to which contaminated land can be cleaned up, are analyzed. The potentials of additional land for biomass production, which is currently not used due to its poor productivity characteristics or due to its high contamination with heavy metals, are calculated. Such land cannot be used for food production, therefore the analysis of the effects of an increased land quantity for biomass production is performed and an assessment of its impact on the environment and on the economy is done. Moreover, this chapter deals with the question to what extent the competition issues for land can be resolved by using the multifunctional characteristics of biomass and forestry crops.

Chapter 6 deals with material substitution and resource cascading. Two different chemicals are dealt with, that are currently produced using fossil fuels; i) nylon and ii) ethane-diol (1,2EDO). Two novel technologies based on biorefinery principles to produce bio-nylon and propane-diol (1,3PDO), a substitute of 1,2EDO, are explored. Those technologies are: i) the Refiner process and ii) the Press process. Moreover, this chapter analyzes the cascading possibilities of the substituted materials. Disposed biomass-based products are used as a cheap fuel option in the Bioelectricity sector. In such a way, the cascading system is mimicked, where the biomass resources are first used for the production of chemicals, and the end product is later used for electricity production. This chapter analyzes to what extent utilizing large scale cascading systems can influence the sectoral production of other commodities and the related influence on land use.

Finally, Chapter 7 contains the conclusions and policy recommendations that can be drawn from the analyses in the previous chapters. In this chapter, the research questions will also be answered.

CHAPTER 2

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

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.*

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2.1 Introduction

Today, 40% of the European Union’s energy supply depends on oil imported from OPEC countries (CEC, 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 (Tahvonen and Salo, 2001; CEC, 2002; Salameh, 2003). 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 (Gielen et al., 1998a; Fearnside, 1999), 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 (CEC, 2002). Biomass can also have a positive impact on land quality by adding humus to the soil and reducing erosion effects (Borjesson, 1999a,1999b; 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 (WRR, 1992; Tilman et al., 2002; Trewavas, 2002). 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) 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., 2001a; Gielen et al., 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 2.2 describes the model structure. Section 2.3 provides an overview of the current energy policies in Poland and of Poland's environmental performance. Section 2.4 presents the data, model calibration, and the results of the scenarios. Section 2.5 provides some conclusions and recommendations.

2.2 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 Figure 2.1. 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 produce a homogenous good. For simplicity, multifunctionality 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 Figure 2.1 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 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.

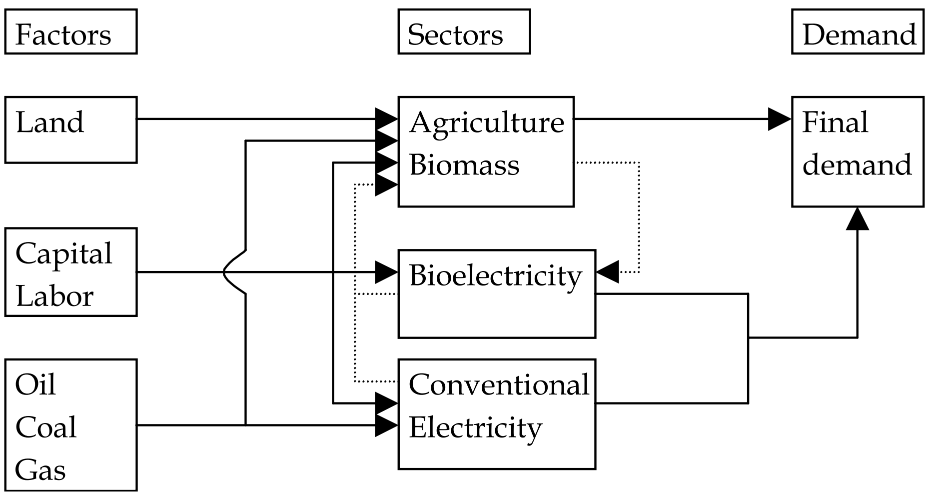

Figure 2.1 Schematic representation of the model

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 Figure 2.2). 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 (Svendsen et al., 2001; Vehmas, 2005) 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:[6]

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

in which U is utility, variable C_i is the consumption of commodities from sector i and $EL^{UN} = CES\left(C_e, C_b; \sigma^{UN}\right)$. 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.

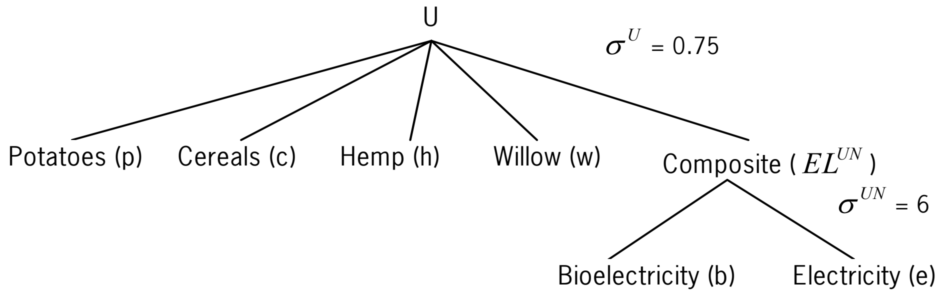

Figure 2.2 Nesting structure of the utility function

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).

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 Figure 2.3. 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

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

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:

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

for $i \in \{p, c, h, w\}$, and with nested CES-functions $Z_i^N = CES\left(Z_{i,w1}, Z_{i,w2}, Z_{i,w3}; \sigma_i^Z\right)$, $G_i^{N_1} = CES\left(K_i, EL_i^N, GAS_i, CO_i, OIL_i; \sigma_i^G\right)$ and $EL_i^N = CES\left(Y_e, Y_b; \sigma_i^E\right)$ 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, and oil input in sector i, respectively. Parameters $\sigma_i, \sigma_i^Z, \sigma_i^G$ and σ_i^E are substitution elasticities.

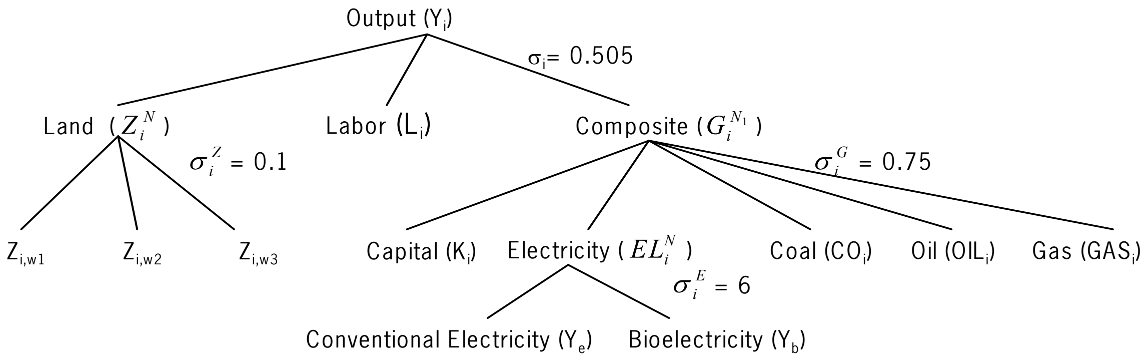

Figure 2.3 Nesting structure of the production functions for potatoes, cereals, hemp and willow

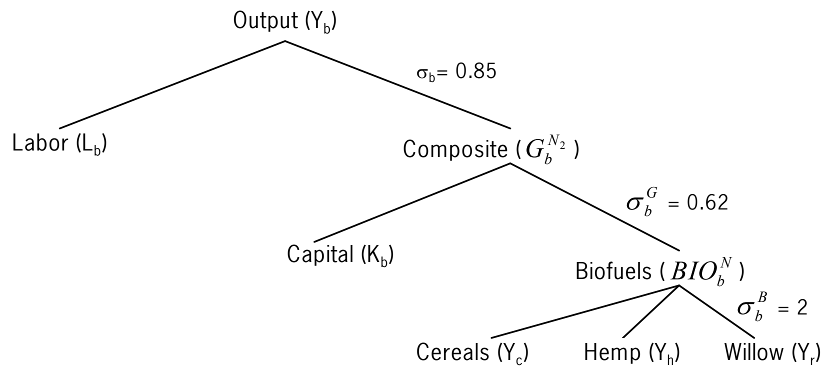

Figure 2.4 Nesting structure of the production function for the bioelectricity sector

The nested production function for the bioelectricity sector is described in Figure 2.4. 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

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

for $i \in \{b\}$ with $G_i^{N_2} = CES\left(K_i, BIO_i^N; \sigma_i^G\right)$ and $BIO_i^N = CES\left(Y_c, Y_h, Y_w; \sigma_i^B\right)$ 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 Figure 2.5. The production function for electricity is

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

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

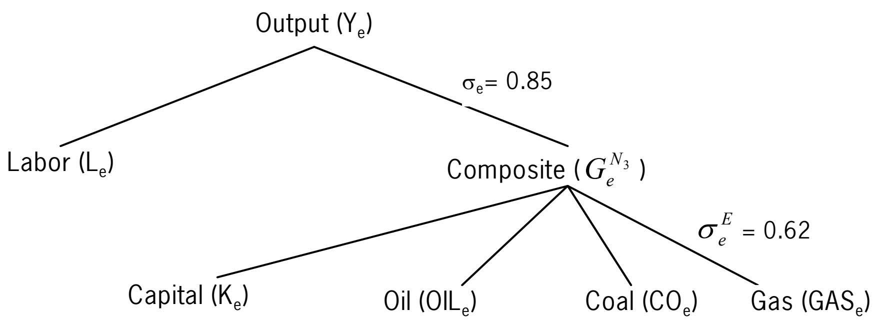

Figure 2.5 Nesting structure of the production function for the conventional electricity sector

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:

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

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}.

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

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}.

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

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.

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 $\varepsilon_{iw}^{N_2O}$.

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:[7]

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

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:

$$TD_i \leq Y_i \,. \tag{13}$$

The marginal value of equation (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 equation (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.

2.3 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, 2002d). Of this share, around 92% came from solid biomass (GUS, 2002d). 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

[7] 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.

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 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 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, 2002d). Further emission reduction, however, will benefit Poland as it will allow the country to increase revenues from the sale of emission permits.

2.4 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 2.4.1. This is followed in section 2.4.2 by a discussion of the policy scenarios. The results of the model simulations are presented in sections 2.4.3 and 2.4.4.

2.4.1 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 FEPFARM 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 Figures 2.2-2.4. 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 *w*1 comprises very good and good land (class I & II), *w*2 reasonably good and average (class III & IV) and *w*3 poor and very low quality (class V & VI). Data on current land use patterns is obtained from Polish statistics (GUS, 2002a).

2.4.2 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%.

Table 2.1 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 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 sub-scenarios are considered, reflecting alternatives for stimulating the biomass and bioelectricity sectors. The scenarios are presented in Table 2.1. 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, 2002). For all six scenarios we analyze changes of GHG emissions, production, prices, and land use as compared to benchmark.

In the model, we adopt a subsidy rate of 25% for bioelectricity production (Scenario 1b and 2b) and a subsidy on biomass production of 90% (Scenario 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 Scenario 2a, 2b and 2c respectively. Gas and coal taxes can be determined as described above.

2.4.3 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 Scenario 1a, 1b and 1c respectively. The results are presented in Table 2.2 to 2.4.

First, as a result of the increase in the 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 2.2). 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.

Table 2.2 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 2.3 Area of biomass and agricultural commodities in benchmark situation and in scenarios 1a, 1b and 1c

	land class w1	*land class w2*	*land class w3*
		thousands ha	
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.

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 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 ha to 600 and from 500 to 4500 (Table 2.3), respectively. Scenario 1c resulted in an increase of plantation area of hemp and willow up to 7700 and 56900 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 2.3). 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.

Table 2.4 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

Next, the emissions of CO_2 and N_2O are affected by the electricity tax. Table 2.4 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 to 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%.

2.4.4 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 2.5 to 2.7.

Table 2.5 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

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 Scenario 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 Scenario 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 Scenario 2a and 2c and 8.4% in Scenario 2b (see Table 2.5). 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.

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 7,510% and 9,778% in Scenario 2c.

Table 2.6 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 Scenario 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.

Table 2.6 Sown area of biomass and agricultural commodities in benchmark situation and in scenarios 2a, 2b and 2c

	*Land class w*1	*Land class w*2	*Land class w*3
	thousands ha		
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
Cereals	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 w1 corresponds to land classes I and II, w2 to III and IV, and w3 to V and VI.

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 2.4.3, 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 2.7).

Table 2.7 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

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.

2.5 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 increases 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.

CHAPTER 3

Impacts of energy policies on biomass and agriculture: an applied general equilibrium analysis*

This paper deals with the economic interactions between biomass and traditional agricultural production, energy policies, and land use allocation. To investigate the possible transition, from conventional electricity to biomass based electricity and its effects on land use, 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 for a unilateral policy, and multilateral policy. The results show that the first Polish policy target of achieving a 7.5% bioelectricity share in total electricity production can be achieved in all three scenarios. Moreover, for a reduction of greenhouse gases with 10%, the emission permit price is around 5 Euro per ton of CO_2. *This price increases to around 50 Euro per ton of* CO_2 *if the emission reduction increases to 50%. Concerning land use allocation, Poland can substantially increase its willow and forestry areas. As expected, prices of agricultural commodities increase due to competition for primary resources such as land.*

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Ignaciuk, A. M., A. Ruijs and E. C. van Ierland, 2005. Impacts of energy policies on biomass and agriculture: an AGE analysis for Poland, *submitted*.

3.1 Introduction

Due to Kyoto and subsequent climate policies, demand for clean energy increases (Azar and Rodhe, 1997). One way to obtain carbon free energy is by using biomass. Since large biomass plantations require a lot of land, current land use and land cover patterns in Europe might change, if a transition is made to more biomass-based economy. This can have an impact on agricultural production.

Next to providing inputs to 'green' energy, biomass plantations can also have positive effects on biodiversity and the environment. Firstly, they can positively effect the quality of land and groundwater, of previously intensively used agricultural land (Makeschin, 1994; Borjesson, 1999a,b; Tolbert et al., 2002). Biomass plantations use less fertilizer, and some of them have the potential to clean up the polluted soils. Under proper management, forest and other biomass plantations, have the potential to sequester CO_2 in the soil (De Jong et al., 2000; Creedy and Wurzbacher, 2001; Lal, 2005). Moreover, they can create a suitable environment for many species and serve as e.g. corridors between separated nature areas (Lewandowski et al., 2000; Londo et al., 2005).

There are, however, many concerns about the land availability for biomass production. On the one hand, some scientists expect that due to changing life style patterns, more land is needed to satisfy human food requirements (Bouma et al., 1998; Gerbens-Leenes and 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 et al., 2003).

To study the possible land shift between agriculture and biomass or forestry and its impact on the economy and environment, different types of models can be applied. First, linear programming has been used often as a tool for analyzing land allocation and energy production. Examples of such models include POLYSYS (de La Torre Ugarte and 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) modify 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. In our paper, we attempt to focus on both agricultural and energy sectors, and to capture their non-linear relations with other sectors in the economy.

Secondly, partial equilibrium models are applied to determine the allocation of food and biomass crops, e.g. an ASM model (McCarl et al., 1993). This model describes the detailed agricultural sector in USA. The dynamic FASOM model is the ASM model, enlarged with a forestry sector (Adams et al., 1996). 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, where often, a policy drive is an exogenous price of emission permit. 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.

There are also a general equilibrium models developed to analyze the impact of climate policies on energy sector and the rest of the economy; often incorporating a global perspective. A good example of a multi-regional model is the EPPA model that includes a bottom up information on many existing and novel energy technologies (McFarland et al., 2004) and the specification as described by Babiker (2005) that focuses on international emission permit trade. Böhringer and Rutherford (2002, 2004) show that international spillovers have a strong effect on the regional welfare impacts of international climate policies. Böhringer and Welsch (2004) use a dynamic general equilibrium model to investigate the role of international emissions trading to reduce the cost of climate policy. These studies do not, however, focus on the competition issues between agriculture and biomass production and the land use allocation.

The aim of this paper is to investigate the impact of energy policies that focus on promoting biomass and bioenergy. We analyze the impact of these policies on greenhouse gas emissions, and land use, and we examine how these policies might affect production of agricultural commodities and trade 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 integrated analysis is performed using data for Poland. We analyze both a unilateral and multilateral environmental policy setting and their impact on trade patterns and the environment.

3.2 Model description

The model is a comparative-static general equilibrium model. It is used to illustrate the medium-term equilibrium state and to analyze 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.

3.2.1 Basic 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* 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[8]:

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

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, labor and capital and consume produced goods.

All markets clear, which means that supply equals demand for all goods through adjusting relative prices (Ginsburgh and Keyzer, 1997). 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:

$$C_i + \sum_{j \in I} ID_{ij} \leq Y_i \quad (2)$$

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 maximize profits subject to the available production technologies. Production technologies are represented by nested CES functions. Following Rutherford and Paltsev (2000) production functions of different commodities have a six-level nesting structure (Figure 3.1).

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

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

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

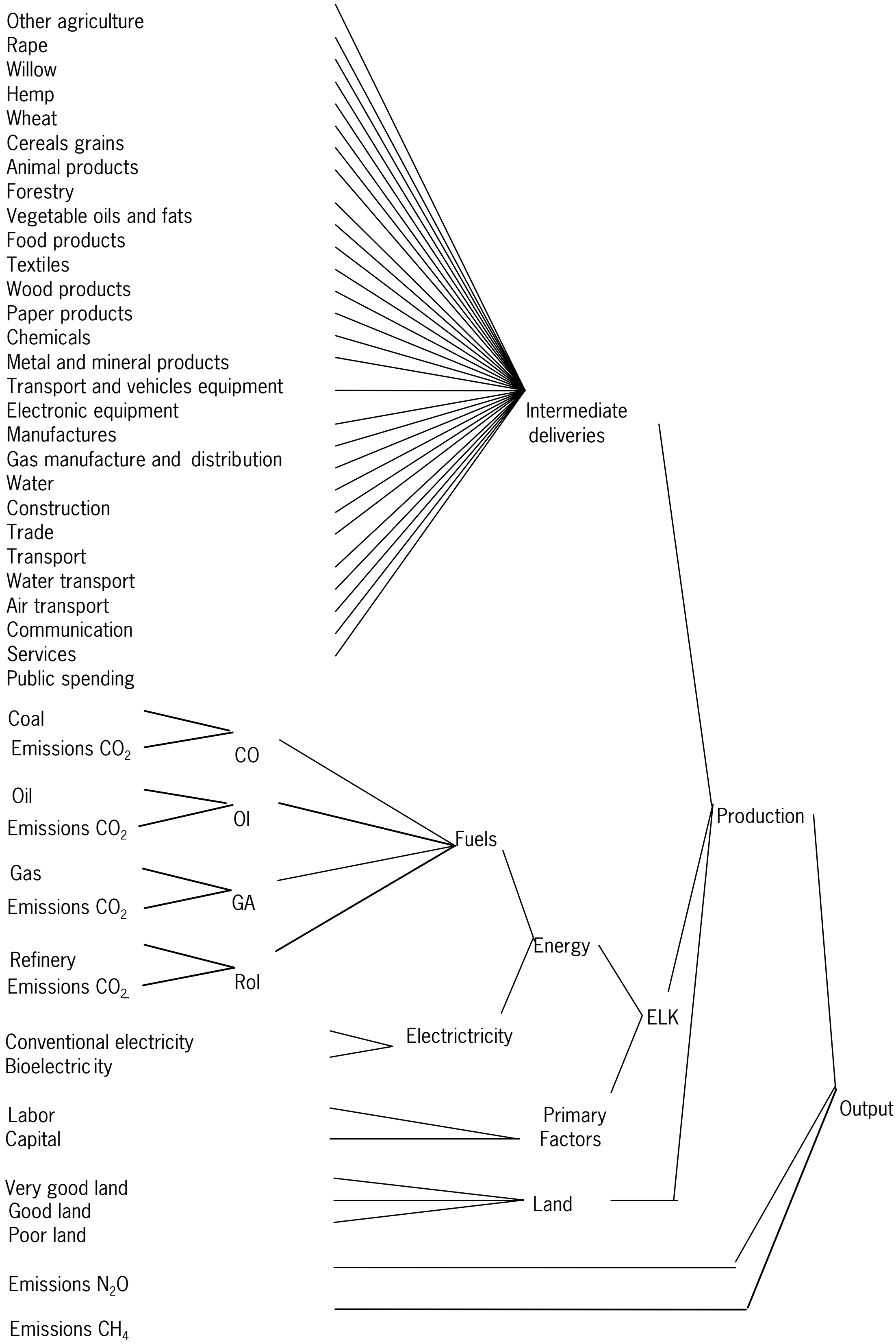

Figure 3.1 Nested structure of the production function (CES)

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.

Government collects taxes on goods and factors and uses them to finance public consumption and pay lump-sum transfers to private households. For government behavior 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).

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

3.2.2 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}.

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

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.

3.2.3 Trade specification

In the model, Poland is treated as 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 modeled 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.

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, domestic price changes will have a limited impact on exports. Demand for export goods will be positive even if domestic prices are above world market prices (Dellink, 2005). Exports are modeled by creating an export good that accounts for additional costs created by transport and storage. To model imports, imported and domestic productions are aggregated 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 trade deficit is kept constant within all policy simulations by adjusting an exchange rate. This rate is not a monetary variable but rather a variable rationing the trade deficit (Dellink, 2005).

3.2.4 Environment

The model includes an emissions module that determines the CO_2 emissions from fossil fuel use and CH_4 and N_2O emissions related to the production per sector. CH_4 and N_2O emissions are expressed in CO_2 equivalents. Data on emissions are obtained from Sadowski (2001). CH_4 and N_2O emissions directly enter the highest nest in the production function (Figure 3.1). CO_2 emissions, however, are disaggregated[9] according to the type and amount of fuel used per sector,

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

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 3.3) and cf_f, ε_f are the conversion coefficient and emission coefficient respectively. The prices used are 1997 world market prices.

As CO_2 emissions mainly originate from fossil fuel combustion, they enter the production function according to the source of emission; emissions related to coal, oil, refined oil, or gas combustion, enter their respective nests (Figure 3.1).

3.3 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 and 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) land use data for Poland. The FEBFARM model

[9] There are some inaccuracies in the calculated total emissions with respect to the total emissions from Polish statistics, due to 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.

provides the shares of production costs. Emission data are taken from Polish statistics (GUS, 2002a).

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, labor and energy, are estimated by Kemfert (1998), Rutherford and Paltsev (2000), Kiuila (2000), and Dellink (2005), see Appendix 1.

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 *z*1 comprises very good and good land (class I & II), *z*2 reasonably good and average (class III & IV) and *z*3 poor and very low quality (class V & VI), further in the paper we refer to *z*1 as a very good, *z*2 as good and *z*3 as poor land. The full data set used in the model can be obtained from the author.

3.4 Biomass in Poland

The share of renewable energy in Poland is low compared to the shares of energy from fossil fuel. In 2001, 0.8% of total energy consumption was considered to be from renewable sources. Of this, 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 potentials for wind energy are rather low and most of the hydropower potentials already reached their limits. Solar power is expensive compared to biomass energy.

The policy scenarios analyzed 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 CO_2 permits market. As a result of policy changes, the share of renewable energy in total 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, a few applications of straw for energy purposes exist and some small scale burning facilities for forestry residuals exist (ECBREC, 2004).

3.5 Scenarios

We present three policy scenarios aimed at increasing the share of bioelectricity in total electricity production and at reducing CO_2 emissions. In Scenario 1 emission permits are introduced. Different levels of emission reduction are analyzed in order to determine whether the policy goals of a bioelectricity share of 7.5% in 2010 and 14% in 2020 can be reached. In Scenario 2 emissions permits are combined with a subsidy rate of 25% for biomass production. In Scenario 3, emissions permits are combined with a subsidy rate of 25% for bioelectricity instead for biomass production. Three scenarios are analyzed in a unilateral and a multilateral setting. An overview of the scenarios is given in Table 3.1.

Table 3.1 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 behavior 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). This 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).

3.6 Results and discussion

This section comprises the results of the policy analysis for the three scenarios, in the unilateral and multilateral setting. In section 3.6.1, we discuss in detail the results of the unilateral specification. Subsequently, we discuss some general results, including the impact of the scenarios on bioelectricity share, utility and prices of emission permits; impacts on production and land allocation; changes in commodity prices, and the trade patterns. In section 3.6.2, we compare some of the core results of the unilateral with the multilateral setting.

3.6.1 Unilateral setting

General results

As presented in Figures 3.2 and 3.3, the results show clear differences between the bioelectricity shares for the different scenarios; however the welfare costs of all policies tend to be similar. 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%. 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%.

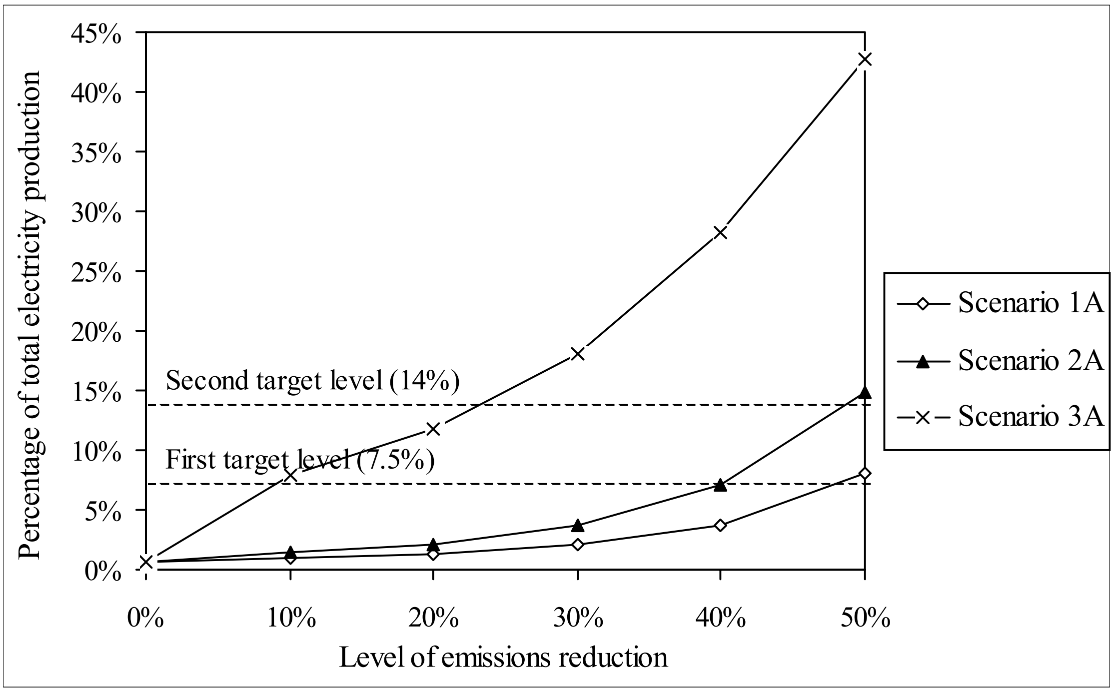

Figure 3.2 Bioelectricity share in all scenarios for different levels of emission reduction

In Scenario 3A, the share of bioelectricity almost reaches 45% if the emission reduction would be 50%. The kink in Figure 3.2 at a 10% emission reduction level is explained by the introduction of the bioelectricity subsidy, which leads to an instant increase in the bioelectricity share compared to the benchmark that does not have such a subsidy.

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 restructures 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 or soil quality.

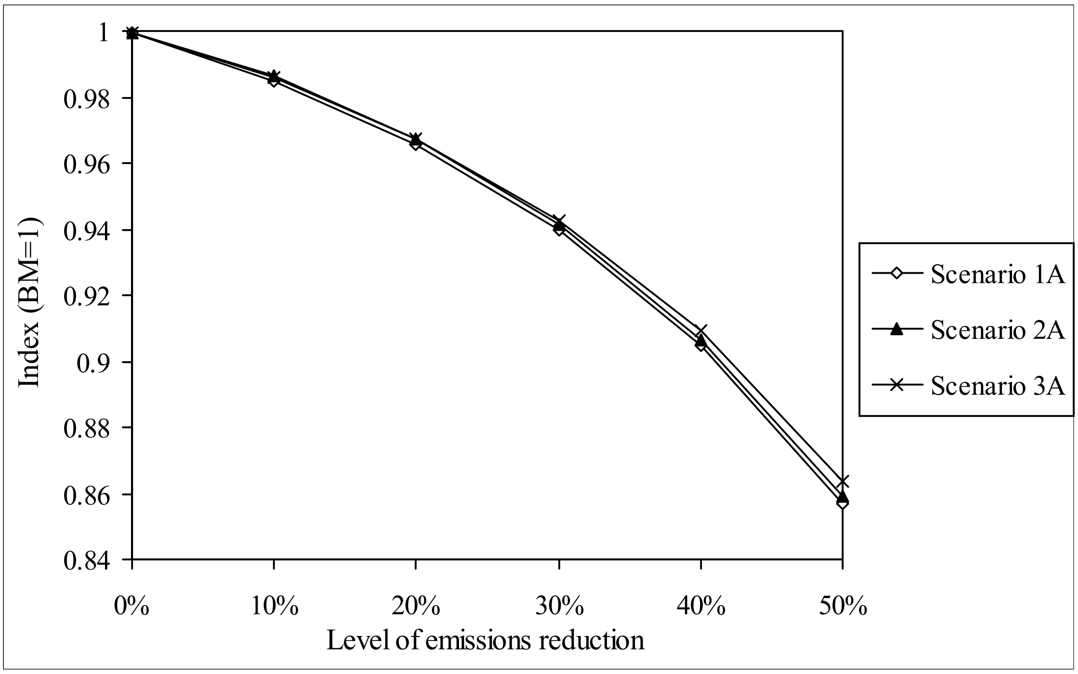

Figure 3.3 Utility change in all scenarios for different levels of emission reduction[10]

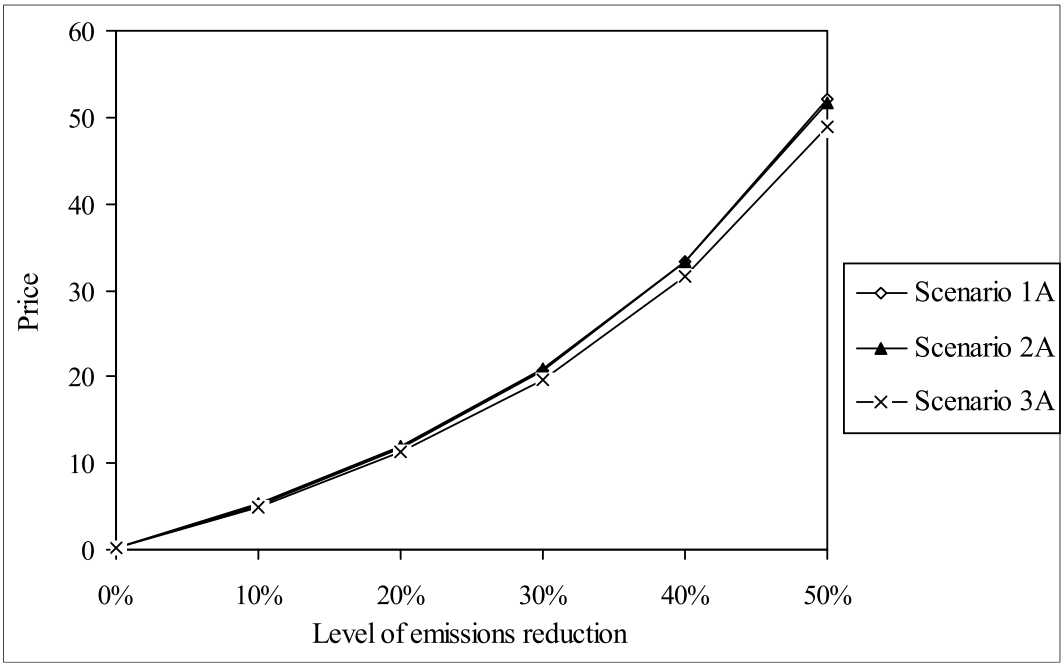

Figure 3.4 Emission permits price (in Euro/t of CO_2) for different levels of emission reduction

[10] The utility level is normalized to unity in the benchmark (BM)

Figure 3.4 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 subsidized, 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 CO_2 for a 50% reduction. This is in line with the integrated assessment models as reported in Weyant (1999).

Comparing Figures 3.2-3.4 shows that the share of the Bioelectricity sector, utility and price levels change in a non-linear manner. Small changes in emission reduction trigger 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.

Production

The impact of different policy scenarios on sectoral production is presented in Table 3.2. 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, respectively.

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.

In all scenarios, production levels of all other sectors decrease. The largest losses occur in the energy sectors: Coal, Oil, Petrochemical, and Gas at all emission reduction levels. The largest changes in production are in Scenario 1A. As expected, higher emission reductions imply larger changes in production. An increase in production of 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, the agricultural sectors decrease their production the least, compared to Scenario 1A and 2A. However, there is larger decrease in production of the dirty sectors. Labor 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 labor 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.

Table 3.2 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 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 sectors; 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 subsidized.

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 3.3 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 acreages. 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 3.3). 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.

Table 3.3 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

As follows from Table 3.3, the size of the biomass and forestry plantations decreases in scenario 1A. With a 10% emission reduction, the reduction in Scenario 1A is 1,700 ha. With an emission reduction of 40%, it increases up to 146,000 ha. The decrease of the forestry area, in favor for an intensified agricultural production, can have a negative impact on the environment, despite the pro renewable energy policy measures. The released labor 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 biomass and forestry areas. In these scenarios, they can benefit from either a direct subsidy on biomass or an indirect subsidy by subsidizing the bioelectricity sector, the main purchaser of biomass. The largest increase in the acreage of forestry 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 forestry and willow plantations. Scenario 3A shows a smaller increase in the amount of forestry and willow 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 9,284,000 ha. This result may seem counterintuitive, realizing 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 labor 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 cause the changes in land use compared to the lower reduction level (Table 3.3).

Prices

The policies adopted in the model induce price changes; the AGE framework allows for an analysis of relative prices, but the absolute price level is undetermined (Consumer Price Index is chosen as numéraire).

Generally, the prices of dirty goods, for which the production costs increase substantially due to the expensive emission permits, increase compared to prices of clean goods (see Table 3.4). We can observe an increase of agricultural commodity prices, of at most 10%, if the emission permit price rises to around 40 Euro per ton of CO_2. This increase is much lower than in other studies, e.g. Azar and Berndes (2000) conclude that with stringent environmental policies the prices of wheat can double.

Table 3.4 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 3.4).

Trade

In Table 3.5, 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.

The trade balance is the largest in the dirtiest sectors such as coal, oil, and gas. Generally the imports of dirty commodities increase, since domestic producers are faced with choice of importing cheaper goods from the RoW or to produce those goods and pay higher price for emission permits.

Changes in exports and imports are larger in Scenarios 2A and 3A than in Scenario 1A. Due to the price decrease of willow, hemp and forestry products (caused by the subsidy), bioelectricity becomes cheaper. 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 3.5). 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 3.5 Changes in imports and exports for a selection of traded goods when 10% and 40% emission reduction is reached for all scenarios (% 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 smallest utility losses. The Polish policy goals are reached faster than in Scenarios 1A and 2A. The price level changes of food crops are similar in all scenarios.

3.6.2 Multilateral setting

A comparison between the unilateral and multilateral specification for a 40% emission reduction level is presented in Table 3.6.

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 changes on the world market that are the same as the price changes in Poland.

Table 3.6 Bioelectricity share (in %), utility change (in % change) and price of emission permits (in Euro /t of CO_2) 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 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. 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.

3.7 Conclusions

This paper discusses a general equilibrium model used to analyze 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 drawing some conclusions, we would like to mention some model limitations, as model results depend crucially on the assumptions made. 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, 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:

In all three scenarios, the policy target of achieving a 7.5% bioelectricity share can be achieved within CO_2 emission reduction of 50%. To achieve a 14% share of bioelectricity, 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.

For a small CO_2 emission reduction of 10%, the emission permit price is low (around 5 Euro per ton of CO_2). This price increases to around 50 Euro per ton of CO_2 if the emission reduction is increased to 50%. This is in line with results from the integrated assessment model of Weyant (1999).

In the first scenario, without subsidies, utility losses are slightly higher than in the other two scenarios that include subsidies. Hence, subsidies on biomass or bioelectricity have positive effects on utility.

The emission permit system induces a transition of the economy towards production of clean goods and clean energy and energy carriers.

Energy policies influence land use allocation. Poland can increase substantially its acreage of forestry and biomass areas that are characterized by better environmental performance (e.g. and increase of the acreage of semi-natural areas, and increased carbon storage capacity in soils) than the traditional agricultural crops. Those benefits can be reaped once the energy policies are designed carefully. The GHG reduction policy does not in itself result in expanding of the forestry and biomass area.

Due to the positive impact of emission reduction policies on biomass production, and due to higher prices for fossil fuels, the prices of agricultural goods increase. Our results show, however, much smaller price increases than some other studies, because of a reallocation of labor and capital that allows for an intensification of agricultural production (a feature of an AGE framework).

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 has a chance to specialize in clean production such as bioelectricity and biomass and becomes an exporting country of those goods.

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.

Appendix

Appendix 1 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

CHAPTER 4

Biomass and multi-product crops for agricultural and energy production*

By-products from agriculture and forestry can contribute to production of clean and cheap (bio)electricity. To assess the role of such multi-product crops in the response to climate policies, we present an applied general equilibrium model with special attention to biomass and multi-product crops. The potential to boost production of bioelectricity in Poland through the use of multi-product crops turns out to be limited to only 2-3% of total electricity production. Further expansion of the bioelectricity sector will have to be based on biomass crops explicitly grown for energy purposes. The competition between agriculture and biomass for scarce land remains limited. In the scenarios, production of agricultural goods decreases at most with 5%, and the largest price increase for agricultural goods amounts to 5%. These changes in production induce substantial changes in land allocation: around 250 thousand ha is converted from agricultural production to forestry and willow plantations.

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* Ignaciuk, A. M. and R. B. Dellink, 2006. Biomass and multi-product crops for agricultural and energy production - an AGE analysis. *Energy Economics*, 28:308-325.

4.1 Introduction

Growing demand for clean energy is one of the responses to (i) stringent environmental policies aimed at reducing greenhouse gas emissions and (ii) declining fossil fuel resource availability. One of the possible solutions is biomass, which can deliver large quantities of energy at low net CO_2 emission levels. However, an often-heard concern is that large-scale biomass plantations might increase pressure on the productive land and might cause a substantial increase of food prices (McCarl and Schneider, 2001; Azar, 2003). In contrast, many scientists claim that the food policies that were established after the 2nd World War resulted in today's overproduction of food (Tilman et al., 2002; Trewavas, 2002; Wolf et al., 2003), and hence the welfare impact of the increased pressure on land may be limited (e.g. McDonald et al., 2006).

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

There are several studies that quantify by-products on the global scale. According to Fisher and Schrattenholzer (2001), the energetic potential of by-products of wheat, rice, grains, protein feed and other crops are between 18-25 ExaJoule per year (EJ/y), equivalent to 4-6% of world energy use. Hoogwijk et al. (2003), based on several studies, give even higher estimates of 10-32 EJ/y for using agricultural residuals in bioenergy production. For forestry residuals, their estimates are between 10 and 16 EJ/y. Another study performed by Smeets at al, (2004) provides even higher estimates for global energy potentials due to agricultural and forestry residuals, namely 58-75 EJ/y. The results of the GLUE-11 simulation model (Yamamoto et al., 2001), where different scenarios concerning exogenous population growth and demand for energy are applied, suggest that biomass residuals can potentially satisfy 30 percent of world energy demand in 1990 i.e. 114EJ/y. According to the IMAGE model (Hoogwijk et al., 2003), the global potentials for bioenergy from biomass and other residuals ranges between 311 and 706 EJ/y in the A2 and B1 scenario, respectively. There are also many studies that establish the biomass and/or biomass by-products potential for individual countries (Radetzki, 1997; Broek van den et al., 2001; Ignaciuk et al., 2005). Most of these studies are based on linear techniques that have a fixed proportion of residuals per process. What lacks is insight in how integrated economic analysis of biomass, and agricultural and forestry by-products can influence energy prices, agricultural prices, production of biomass and the supply of agricultural commodities.

Bottom-up models as the ones described above are characterized by a detailed description of the energy sector and specific technologies, but they do not take into account the interlinkages with the rest of the economy and often assume that energy demand is exogenous and independent of prices (Zhang and Folmer, 1998). The alternative is to specify economic behavior from a top-down perspective. Top-down models are aggregated models that are able to capture the secondary effects of energy policy on other economic sectors and on trade (Springer, 2003). There are many top-down models that involve detailed economic analysis of the energy sector, and that are able to provide the secondary effects of shifting energy production, e.g. Breuss and Steininger (1998), Kumbaroglu (2003), McFarland et al., (2004), Babiker (2005), and Ignaciuk et al., (2005). However, none of these investigate the interaction between multi-product crops and prices and quantities on related markets. Therefore we choose to incorporate essential bottom-up information on multiproductivity in a top-down CGE framework. More detailed discussions of top-down versus bottom-up models can be found in Böhringer (1998), Klinge Jacobsen (1998) and Dellink (2003).

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

This paper is structured as follows. Section 4.2 presents the background information about multi-product crops. In Section 4.3 the model characteristics are described and to the end of this section data and scenarios are briefly described. In Section 4.4 the results are gathered and discussed. The last section concludes.

4.2 Multi-product crops and bioelectricity production in Poland

4.2.1 Multi-product crops

From 1990 onwards, the Polish economy started its restructuralization towards market economy. One of the first observed changes was declining agricultural production. It was caused by (i) a decrease of relative wages and an increase of prices and (ii) an import of cheaper (subsidized by e.g. EU) food products (Okuniewski, 1996). In recent years wages increased, but this fact is not mirrored in an increase in the demand for food. Food is considered to be a basic good, and thus an increase in income results in a less than proportional increase in demand for this commodity. Empirical analysis of the Polish situation confirms this theory (Hunek, 1996).Recent analyses show that the current level of agricultural production in Poland can be obtained from an area that is 14.9% smaller than the current acreage. It means that around 2.8 mln ha can be used for other production than agriculture (Wos, 1998; Gradziuk, 2001).

Such a situation provides scope to develop other activities. One of the options is to use this land for energy crops. Biomass in Poland comes from several sources, including (i) traditional agriculture, (ii) forestry, and (iii) biomass plantations (Kowalik, 1994; Gradziuk, 1999). Currently, however, it is marginally used for energy production. The potentials for using e.g. rape or cereals straw are large. Traditionally, straw is utilized for various purposes: (i) as fodder, or (ii) as lining for live stock, and (iii) as organic fertilizer and insulation material (AEBIOM, 1999). Recently, the share of cereals production in total agricultural production increased, and the animal production decreased. This results in large straw surplus. According to EC Brec (2004), the amount of straw that technically can be used for energy production equals 11.3 mln t (170PJ). Gradziuk (2001) calculates that in the beginning of twenty first century overproduction of straw (from cereals and rape) sums to 11.6 mln ton. The European Biomass Association (AEBIOM) assumes that 22 mln ton of straw can be used for non-agricultural purposes in Poland (AEBIOM, 1999). Straw, that is produced as a by-product of hemp can be also used as an energy source. According to Dornburg (2004), 2.5 ton of straw per ha can be collected resulting in 1.25 thousand ton of hemp straw in Poland that can be used in e.g. Bioelectricity sector. For the analysis in this paper we chose the conservative estimates of excess straw availability, excluding the amount of straw that is used for sustaining the nutrient balance in the soils and for animal production. Based on Gradziuk (2001) we assume that the dry weight of straw equals 50% of the wet weight (presented above). Our selection is presented in Table 4.1.

Table 4.1 Potential use of residuals in Poland

Type of residuals	Potential use Mln ton
Cereals straw	4.46
Wheat straw	4.44
Rape straw	1.4
Hemp straw	0.00125
Forestry residuals	3.27

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

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

4.2.2 Bioelectricity sector

Coal is dominant in the production of electricity in Poland. Around 97% of all electricity generated in the country comes from coal-fired plants that are very inefficient. In 1997, 135.0

billion kWh of electricity was generated in Poland from which only from which 0.6 from renewable energy. In 2000, the situation was similar; 135.2 billion kWh was produced, from which 0.5 kWh from renewable energy. Poland is a net electricity exporter. In 2001, Polish government set goals concerning an increase of bioelectricity share in total electricity production to 7.5% by 2010 and 14% by 2020. Hence, in the future the shares of 'green' electricity are expected to increase drastically.

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

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

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

4.3 Model specification

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

4.3.1 General specification

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

A *representative consumer* maximizes utility under the condition that expenditures on consumption goods do not exceed income. Utility is represented by a nested constant elasticity of substitution (CES) function that combines (i) the consumption of commodities from all sectors except electricity, with a substitution elasticity equal 0.5, and (ii) an aggregate of Electricity and Bioelectricity, also specified as a CES function, with a substitution elasticity equal 0.75. Consumers own production factors and consume produced goods. Labor supply is fixed, while the wage rate is fully flexible. All taxes are collected by the government that uses them to finance public consumption and pay lump-sum transfers to private households.

Producers maximize profits subject to the available production technologies. Production technologies are represented by nested CES functions. Following Rutherford and Paltsev (2000), production functions of different commodities have a six-level nesting structure (cf. Figure 4.1). This specification allows for varying substitution possibilities between different inputs. For instance, in the Electricity sector, substituting coal inputs by capital mimics the installation of more expensive but more efficient production technologies. The substitution elasticities are sector specific and represent alternative production technologies within the sector.

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

The interactions between the various production sectors are relevant, as the agricultural and energy sectors have strong links with the rest of the economy. An economy-wide model, such as the AGE-framework provides, allows us to take these interlinkages into account.[11] Moreover, the indirect impacts of environmental policies are incorporated (cf. (Dellink, 2005)), ensuring a consistent assessment of the economic costs of environmental policy.

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[11] Though it should be noted that the necessary aggregated representation of sectors limits the possibilities to specify the interlinkages between individual crops within the aggregated sector.

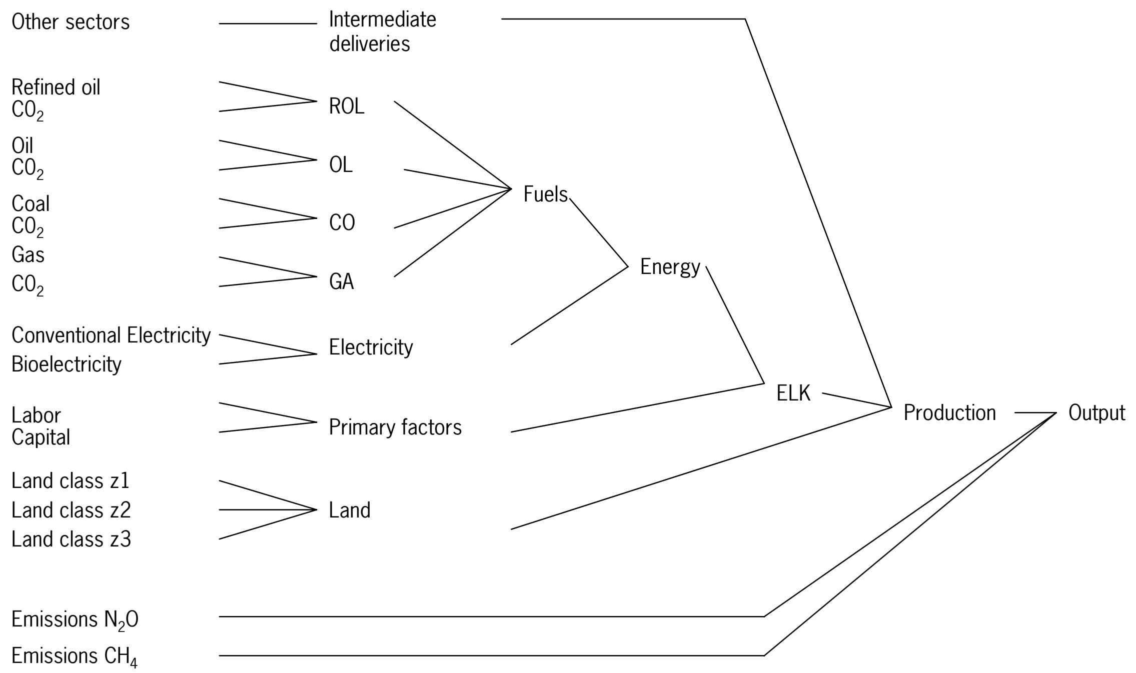

Figure 4.1 Nested CES function

4.3.2 The biomass module

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

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

The emissions of the major greenhouse gases, CO_2, N_2O and CH_4, are included, all expressed in CO_2 equivalents. Data on emissions is obtained from Sadowski (2001). CH_4 and N_2O data are directly linked to output. As CO_2 emissions come mostly from fossil fuel combustion they enter the production function assuming a fixed relation with fossil fuel use (cf. Figure 4.1). In our model, we deal with multiproductivity characteristics of cereals, rape, hemp and forestry products by including straw or residuals as a by-product, as explained in Section 4.2. The by-products are produced in fixed proportions to the production of the main product, and can be used only by the bioelectricity sector. Besides using labor and capital, the bioelectricity sector has the choice between using willow, hemp, wood, and straw and residuals as inputs, with high elasticity of substitution. In the benchmark, straw is not available as input, which allows us to analyze the impact of using by-products in the scenarios.

4.3.3 The EU subsidy on land use

In May 2004, Poland joined the EU. This historical moment initiated some changes in the agricultural and forestry sectors. Since the entry date Polish farmers are subjects to extensive European subsidies. These subsidies cover traditional agricultural crops, energy crops and afforestation practices. The Polish government chooses a relatively simple subsidy scheme. Each farmer that owns a land of acreage of more than 1 ha receives on yearly basis 61 Euro per ha[12]. Moreover, farmers get 72 Euro subsidy per ha if they grow traditional agricultural crops and 69 Euro subsidy per ha if they grow grass on their land. The energy crops are subsidized in the amount of 45 Euro per ha (CEC, 2003). For a detailed list of crop subsidies see UKIE (2004).

The EU proposed a long-term program for Poland, regarding afforestation of agricultural land (UKIE, 2004). In present value terms, using a discount factor of 4%, landowners receive 175 Euro per ha for afforested land. The EU subsidies are paid from external sources, namely EU. The traditional agriculture and biomass sectors are directly subsidized, but the Forestry sector only gets subsidy on land that is converted into forestry.

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

4.3.4 Data

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

Substitution elasticities between the different inputs in the production and utility functions are specified based on Kiuila (2000) as far as possible as they directly apply to the Polish economy. They are supplemented by estimates from Kemfert (1998), Rutherford and Paltsev (2000), and Dellink (2005) when information for Poland was lacking; in this way, the best available in formation is used in the model.

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

[12] One zloty (zl) equals around 0.25 Euro.

4.3.5 Scenarios

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

The following scenarios are adopted

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

4.4 Results and discussion

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

General results

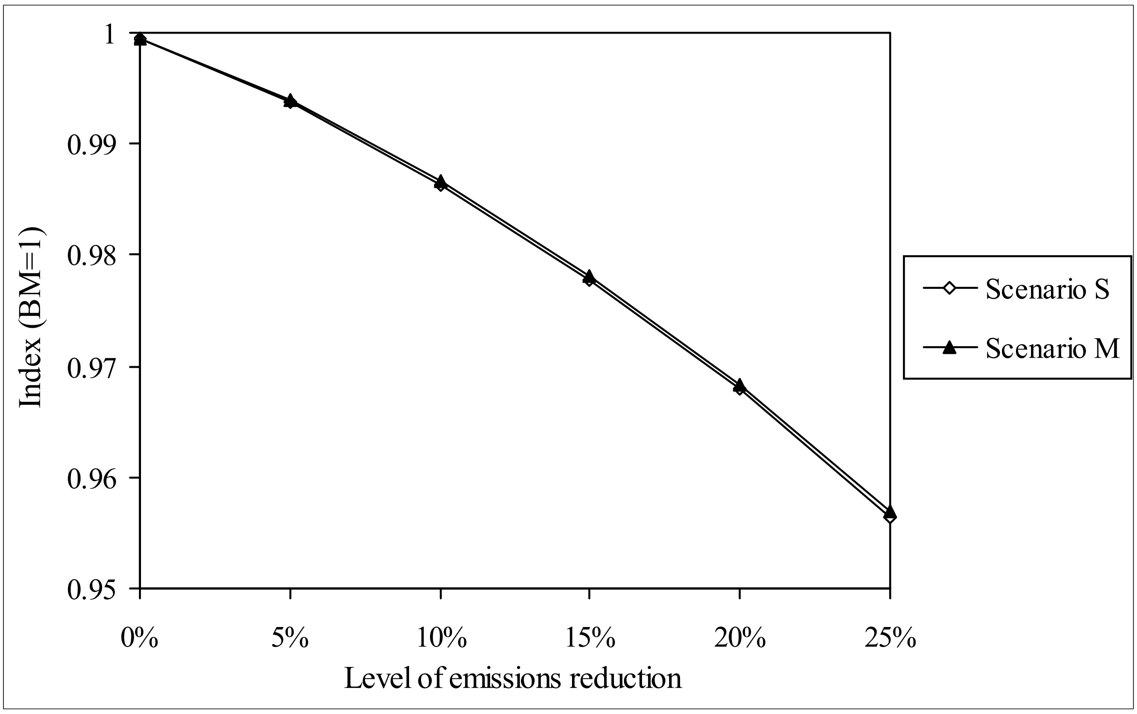

Figure 4.2 Utility change for single-product (S) and multi-product (M) scenarios for different levels of emission reduction in unilateral setting

Figure 4.2 presents the welfare impacts for scenarios S and M, at different levels of emission permit reduction. Clearly, the environmental policy leads to welfare costs. It should be stressed that the environmental benefits of these policies are not taken into account in this measure of welfare, and hence it cannot be concluded whether these policies are justified. The welfare costs of these policies tend to be decreasing more than proportionately with increasing stringency of environmental policy, and the impacts are virtually the same for the single- and multi-product settings, showing that using by-products cannot mitigate the welfare costs of renewable energy policies.

Production

Table 4.2 comprises the results of production changes in a unilateral setting for different emission reduction levels. The economy adapts to the reductions in allowed emissions by switching towards (i) 'clean' energy; (ii) 'clean' production; and (iii) 'clean' consumption.

Since the Bioelectricity sector is very small compared to conventional Electricity, it has to grow considerably to achieve the policy target: more than 1000 percent in both scenarios. Labor and capital, released primarily from the declining Electricity sector, are used to intensify the production of Bioelectricity sector. In the multi-product setting scenario, these changes are stronger than in the single-product setting. Since the by-products are cheap, the Bioelectricity sector demands them in large quantities, and the availability of multi-product crops can keep production costs in the Bioelectricity sector relatively low. This allows for an additional increase in production of bioelectricity of roughly one third (1342% vs. 1023%, at 10% emission reduction level).

Table 4.2 Changes in the production in selected sectors for all scenarios for an emission reduction of 10% and 25% (% change compared to benchmark)

	Benchmark	*10% Emission reduction*		*25% Emission reduction*	
	(mln Euro)	Scenario S	Scenario M	Scenario S	Scenario M
Other Agriculture	6123.9	-1	-1	-5	-5
Rape	96.3	29	35	56	64
Willow	0.029	1086	1457	2060	2656
Hemp	0.14	92	108	168	195
Wheat	1514.3	-2	-2	-5	-5
Other Cereals	1440.7	3	4	3	4
Forestry	1109.9	4	5	6	7
Coal	5268.2	-9	-9	-23	-23
Oil	1395.8	-17	-16	-40	-40
Gas	373.7	-14	-14	-34	-34
Electricity	6441.7	-10	-12	-22	-24
Bioelectricity	44.7	1023	1342	1840	2333
Industry	118739.6	-2	-2	-5	-5
Services	133587.8	-1	-1	-4	-4

The biomass sectors such as the sectors producing rape, willow or hemp increase their production substantially in both scenarios to meet the demand for biomass in the

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

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

In both scenarios, S and M, the dirty sectors decrease their production substantially (see Table 4.2). In the multi-product setting, these losses are slightly smaller, as the availability of the by-products reduces the need to use scarce production factors to produce biomass.

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

Bioelectricity shares

Figure 4.3 presents the influence of the implementation of the scenarios on the share of bioelectricity in electricity production. The results show clear differences between the bioelectricity shares for single-product and multi-product settings. Notably, for every level of emission reduction, in multi-product setting there are higher shares of bioelectricity than in single-product setting. This does not come as a surprise, considering the fact that in the multi-product setting bioelectricity producers can benefit from the availability of cheap biomass in the form of straw. The picture clearly confirms the main impact of the availability of multi-product crops as discussed above: the existing by-products are used in the Bioelectricity sector even at low rates of emission reductions, but beyond that, these by-products can only provide a limited contribution to the expansion of the Bioelectricity sector.

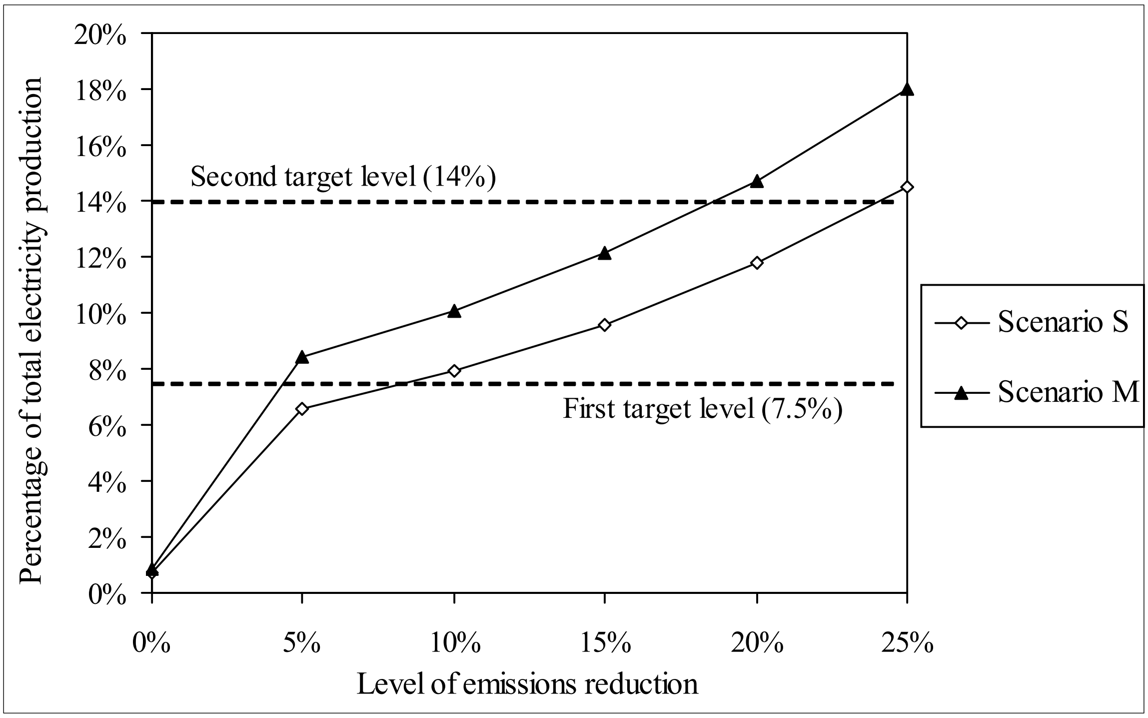

Figure 4.3 Bioelectricity share for single-product (S) and multi-product (M) scenarios for different levels of emission reduction in unilateral setting

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

Both lines observe a kink at a 5% emission reduction level, which can be attributed to the introduction of the biomass subsidy in the scenarios that does not exist in benchmark. This leads to an instant increase in the bioelectricity share and is an essential part of the strategy to achieve the national policy targets for the share of bioelectricity (this issue is investigated in more detail in Ignaciuk et al., 2005).

Prices

The policies adopted in the model also induce price changes. The impact of the emission reduction policies on the relative price level for a selection of goods is presented in Table 4.3. Generally, the prices of dirty goods go up compared to the prices of cleaner goods, as the production costs for the dirty sectors increase substantially due to the expensive emission permits; the emission permit prices for two policy levels are reported in Table 4.3. The price of bioelectricity decreases relatively to other prices, because it benefits from a subsidy and cheap by-products.

Table 4.3 Prices of selected commodities for both scenarios in unilateral setting

	BM	*10% Emission reduction* Scenario S	Scenario M	*25% Emission reduction* Scenario S	Scenario M
Prices of selected commodities (in % change compared to benchmark)					
Other Agriculture		1.7%	1.6%	4.9%	4.8%
Rape		-0.5%	-0.5%	-0.8%	-0.8%
Willow		-1.1%	-1.2%	-2.0%	-2.1%
Hemp		0.0%	-0.1%	0.5%	0.5%
Wheat		0.4%	0.3%	0.9%	0.9%
Other Cereals		0.7%	0.6%	1.7%	1.7%
Forestry		0.3%	0.4%	0.1%	0.3%
Electricity		3.3%	3.2%	9.4%	9.3%
Bioelectricity		-20.2%	-22.1%	-20.7%	-22.6%
Price of emission permits (in Euro per ton of CO_2)					
Emission permit		4.8	4.7	15.0	14.8
Prices of land (in Euro per ha, referred to benchmark prices from 1997)					
Very good land (z_1)	91.4	82.7	81.8	71.7	70.8
Good land (z_2)	66.4	68.6	69.3	67.3	67.3
Poor land (z_3)	37.1	48.5	51.8	54.4	59.8
Forestry land (z_4)	37.1	47.4	50.5	53.1	58.4

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

We can observe an increase of agricultural commodity prices. However, this increase is low, at most 5%, even though the emission permit price rises to around 15 Euro per ton of CO_2. Such small increase in prices, despite the competition for land, shows that the competition between agriculture and biomass is less strong in our CGE setting than commonly encountered in a partial equilibrium framework.[13] Table 4.3 also presents the price levels of different land types; we observe an increase in prices for good (type z_2), poor (type z_3), and forestry (type z_4) land types. This increase is caused by several factors. First, there is increased competition for land, as more biomass crops are demanded to fuel the clean Bioelectricity sector. Second, in the multi-product setting (Scenario M), the productivity of land increases due to the availability of by-products. Perhaps more surprisingly, the price of very good land (type z_1) decreases, though it remains the most expensive land type. This can be explained by the fact that in the CGE only relative prices matter: as the demand for very good land increases less than demand for lower class land types, or even decreases, the relative price of very good land decreases compared to lower quality land. The price decrease in absolute terms has to be interpreted as a decrease compared to the numéraire, the consumer price index.

The large demand for biomass crops primarily increases the pressure on z_2 and z_3 and the additional production of the Forestry sector puts an upward pressure on z_4. With increasing stringency of climate policy, all the land prices tend towards the same price. This effect is governed by the possibilities to use different land types for producing different crops: biomass

[13] Furthermore, farmers that produce both food and biomass will be able to mitigate the loss in food revenues with increased revenues from biomass.

crops will start out on poor land, but can also use better land types, and agricultural land can be converted to forestry land. These substitution possibilities tend to even out the differences in land prices between the different types.

The permit price increases nonlinear with the stringency of the policy; with 10% emission reduction a permit for a ton of CO_2 costs 5 Euro and with 50% emission reduction it costs 15 Euro. This is more or less in line with the results obtained in integrated assessment models as reported in Weyant (2004).

Land use

Table 4.4 presents the land allocation for scenarios S and M at 10% and 25% emission reduction levels. In the single-product scenario, there is less reallocation of land than in the multi-product scenario, in line with the changes in economic activity of the related sectors.

In the multi-product setting, a climate policy of 25% emission reduction induces a conversion of agricultural land in Forestry area of 237 thousands hectares. Adding the acreage gained by willow plantation, the acreage increases with 250 thousands hectares. This large increase is caused by (i) the EU subsidy, (ii) the fact that Forestry sector produces fuel for bioelectricity and, (iii) related to that, by increased demand for clean electricity.

Table 4.4 Land use (in 1000 ha) with 10% and 25% emission reduction for scenario S and M

			10% emission reduction		*25% emission reduction*	
		BM	Scenario S	Scenario M	Scenario S	Scenario M
Other Agriculture	Z1	102.4	100.6	100.5	98.6	98.3
	Z2	1839.5	1784.1	1778.8	1726.2	1717.7
	Z3	1051.6	997.1	988.7	952.0	939.6
Rape	Z1	0.0	0.0	0.0	0.0	0.0
	Z2	349.4	443.5	458.9	534.8	557.6
	Z3	87.3	108.3	111.5	128.9	133.3
Willow	Z1	0.0	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	0.0	0.0	0.0
	Z3	0.5	6.2	8.1	11.2	14.2
Hemp	Z1	0.0	0.0	0.0	0.1	0.3
	Z2	0.0	0.0	0.0	0.0	0.0
	Z3	0.1	0.3	0.3	0.2	0.0
Wheat	Z1	87.4	85.2	84.7	83.5	82.7
	Z2	1570.1	1510.6	1499.1	1461.8	1444.5
	Z3	897.7	844.2	833.3	806.2	790.2
Other Cereals	Z1	218.6	222.6	223.1	226.2	227.0
	Z2	3894.5	3915.2	3916.6	3930.7	3933.8
	Z3	2301.1	2261.3	2249.8	2240.3	2223.9
Forestry	Z4	8769.0	8890.0	8915.7	8968.7	9006.2

4.5 Sensitivity analysis

The reactions of producers and consumers depend on the calibrated elasticities as used in the CES functions. We conduct a sensitivity analysis on the values of these elasticities by de- and increasing the values of one elasticity at a time with 50%, using a policy level of 25% in scenario M as reference. The main results of these additional simulations are reported in Table 4.5 and briefly discussed here.

The original values of the substitution elasticity between energy and primary production factors in the production function are adopted from Kemfert (1998) where applicable and from Rutherford and Paltsev (2000) for the remaining sectors. The first estimates are based on data for Germany and the second are estimated for the world. Thus, the elasticitiy value for Poland may be different, and therefore the calibrated value has to be subjected to a sensitivity analysis.

Table 4.5 Main results of the sensitivity analysis on 25% emission reduction in scenario M

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

When the substitution elasticity between energy and primary production factors is reduced (e.g. for Other Agriculture from 0.5 to 0.25), welfare costs as measured by the change in utility increase substantially to 6.5%. This shows that in the reference scenario producers can limit the costs of the environmental policy by substituting away from energy towards labor and capital. This is a clear example of the importance of the feedback effects that occur in the CGE setting. Essentially, the lower elasticity implies that there are fewer possibilities to avoid an impact of the policy on behavior of all producers and consumers. Thus, there is more demand for bioelectricity (the share increases to 26.4%), a higher emission permit price, more competition for the agricultural sector (as indicated by the stronger increase in the price of Other Agricultural goods) and more conversion of land to forestry.

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

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

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

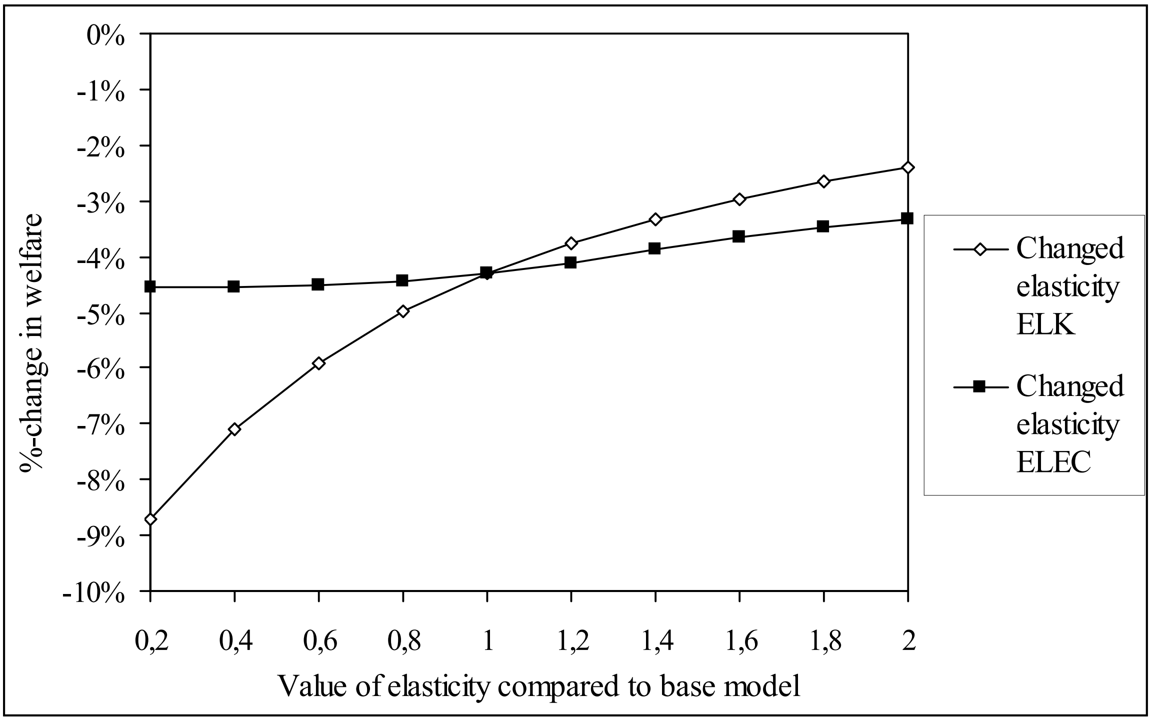

Figure 4.4 Change in utility for 25% emission reduction in Scenario M for varying levels of σ_{ELK} and σ_{Elec}

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

The impact of changing the substitution elasticity between (i) energy and primary production factors (σ_{ELK}) and (ii) between electricity and bioelectricity (σ_{Elec}) is represented graphically in Figure 4.4. It is clear that the substitution possibilities between energy and the primary production factors have the largest effect on welfare. When producers have hardly any possibility to shift away from energy use, *i.e.* when the elasticity is very low, welfare losses are very substantial (up to 9%). Evidently, at high levels of required emission reduction, reducing energy use is cheaper than fully switching energy supply towards bioelectricity. Thus, when available production technologies in Poland are much less diverse than in Germany (where the calibrated elasticities are largely based upon), the main model results underestimate the welfare costs of the energy policies. However, we believe that the flexibility in Polish production sectors is not lower than in Germany, and hence the main model results give at least a reasonable approximation of the welfare impacts.

For the elasticity between electricity and bioelectricity, the welfare changes are more sensitive for higher elasticity values. The larger the possibilities to switch between both goods, the less the welfare impacts will be, in line with expectations.

4.6 Conclusions

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

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

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

Despite the increased demand for biomass, the adverse effects on the agricultural sector are limited[14]. Production of agricultural goods decreases to a limited extent, at most 5%, and the associated price increase also remains below 5%, in the analyzed scenarios, a result also observed by McDonald et al. (2006) in their analysis of biofuels. These changes in production induce changes in land allocation: around 250 thousand ha is converted from agricultural production to forestry and willow plantations. This result can be explained by several mechanisms. First, the GHGs emission levels in this sector are relatively low. Secondly, the biomass sectors are very small compared to the agricultural sector, and hence a relatively small reduction in land use by the agricultural sector is consistent with a huge boost in biomass production. Thirdly, the biomass sectors have large potentials to grow on the poorer land types, which are much cheaper. Fourth, the agricultural sector can to some extent substitute away from land to labor and capital, which is released from the industrial sectors, and so intensify its production per hectare. Finally, the CGE framework incorporates essential feedback effects that are absent in partial equilibrium studies. The importance of these feedbacks is illustrated by the sensitivity of the price of agricultural products for the elasticity of substitution between energy and primary factors.

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

[14] For farmers that produce both food and biomass the impact will be a combination of a positive and a negative effect.

CHAPTER 5

Economic analysis of the impact of energy policies and the use of contaminated and degraded land*

Biomass based energy is seen as one of the options to substitute fossil fuels and mitigate greenhouse gas emissions. To reduce the impact of increasing demand for biomass on land prices, multifunctional land use systems can be explored. In this paper, we assess the importance of the use of contaminated and degraded land for willow and forestry plantations on the economic potential for bioelectricity. To this purpose, we use an applied general equilibrium model (AGE) with special attention to biomass and bioelectricity, calibrated to Poland, and extended with contaminated and degraded land. We conclude that the amount of contaminated land that can be used for biomass production is too limited on a national scale to substantially influence the bioelectricity shares and welfare. However, the production of willow and forestry increases in all scenarios, and especially the production of willow is substantially enhanced when the additional land is available, though marginally suitable land remains excluded from production as the yield from this land type are too low. The utilization of the additional land in Poland supports internal Polish policy goals and Poland becoming biomass exporter. In all scenarios, Poland increases substantially its export of bioelectricity, and in some scenarios it exports a substantial quantity of willow. This, however, depends on the stringency of internal Polish policies. Interestingly, a small increase in willow productivity can induce substantial changes in export quantities.

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* Ignaciuk, A. M. and I. Lewandowski, 2006. Biomass production in Poland – an economic analysis of the impact of energy policies and the use of contaminated and degraded land, s*ubmitted*.

5.1 Introduction

Bioenergy is seen as a future key option to substitute fossil fuels and mitigate greenhouse gas emissions (Faaij, 2006). The European Union (EU) has set ambitious targets to increase the use of biomass for energy; (i) a contribution of 5700 PJ from biomass in 2010 and (ii) an increase in consumption of biofuels to 5.75% of the diesel and gasoline consumption in 2010. These targets are outlined by the so-called 'White' and 'Green' papers (CEC, 1997, 2000), and by the biofuel directive (CEC, 2003b) adopted by the EU in 1996, 1997 and 2003, respectively. They cannot be met by the use of agricultural and forestry residues alone. That means that large areas of agricultural land in the EU will have to be dedicated to the production of energy crops (Faaij, 2006).

Future potentials for energy crop production are especially high in Central and Eastern European countries (CEEC), because they have large land resources, and comparatively to Western European countries (WEC) low land use and labor costs. A recent potential assessment study (see van Dam et al. (2005a)) has shown that several million hectares of agricultural land could become usable for the production of energy crops in CEEC if agricultural production in CEEC will rationalize[15] and more efficient production methods are applied. Poland and Romania have the largest technical biomass production potentials because of the size and quality of their agricultural land. Moderate ethanol production costs of about 6 – 8 Euro/GJ (see van Dam et al. (2005b)) also opens the opportunity to Poland to become a potential important exporter of biomass and bioenergy to markets in WEC.

We expect that the increasing demand for land for biomass production puts pressure on agricultural land and may lead to competition between different land uses, e.g. food and fodder production and e.g. areas that are currently dedicated to nature conservation. Cost analysis of biomass production for Poland has shown that the biomass production costs decrease with an increasing quality of land (van Dam et al., 2005a). This is due to the fact that despite higher total production costs per ha of land, the production costs per ton biomass decrease significantly with better land quality because higher yields per hectare (ha) are achieved. This means that competition might occur especially for good quality land and can lead to an increase of agricultural commodity prices, e.g. Azar and Berndes (2000) conclude that with stringent energy policies the prices of wheat can double, similar results are obtained by McCarl and Schneider (2001).

Multiple land use (MLU) systems are discussed as an approach to reduce the pressure on agricultural land. MLU systems combine the generation of different goods or services on the same area (LNV et al., 2000). Hence, by combining e.g. biomass production and the phytoremediation (cleaning of soil by plants) of land, MLU can contribute to a reduction of pressure on agricultural land by (a) utilizing the contaminated land for biomass production,

[15] Rationalization in agriculture means the increasing use of modern machinery, techniques and input; it also includes processes of enlargement of single field size. Generally, the rationalization process leads to higher yields and lower labor demand, with the consequence of job losses in the agricultural sector.

and (b) regenerating this land for future food production (see Lewandowski et al. (2006)). Only a limited number of studies exist where the different land use functions, combined with biomass production, are assessed on the national level; e.g. Berndes et al. (2002) assess a value of carbon sequestration by willow plantations in Sweden, and Fredrikson et al. (2002) assess a value of Cd removal from soil by willow plantations in Sweden. They extrapolated the field studies results to the country level.

The novelty of this study is that it assesses the use of contaminated and degraded land in an elaborated economic setting. The focus lies on the competition for agricultural land for different purposes such as food, fodder and energy production, when the interactions with the rest of the economy are taken into account. It aims at recommendations for optimal land use allocation with respect to both welfare and fulfillment of national targets on the use of bioelectricity. Moreover, special attention is paid to MLU systems and the phytoremediation function. This study builds upon Ignaciuk and Dellink (2006) that investigate the economic potential for bioelectricity on a national level. In our study, the importance of the use of contaminated and degraded land for the economic potential for bioelectricity is assessed for Poland. For this purpose, an applied general equilibrium model (AGE) with special attention to biomass and bioelectricity, calibrated to Poland, is used and extended with phytoremediation.

In Poland, large areas of agricultural land are contaminated by heavy metals, especially due to mining and industrial activities (Bocian, 2005). This land has to be set aside, because contaminated land is not suitable for food production. Heavy metals can accumulate in food crops and impose health risks to the consumers. It is expected that there will be further reduction of productive land due to contamination, since stricter EU regulations are implemented in the near future. This land could be used for biomass production and integrated into MLU systems with the aim to clean and reclaim degraded land for food production.

The specific objective of this study is to analyze the impact of the availability of additional land on (i) land use patterns, (ii) prices of land, agricultural and other commodities and (iii) production and use of bioelectricity in Poland. Different scenarios are formulated for energy policies and analyzed in order to determine the optimal strategies for dedicating land to agriculture, biomass and forestry, and to reach the Polish targets on bioelectricity share.

5.2 Model specification

The model used in our analysis is an applied general equilibrium (AGE) model that describes the entire economy, with explicit detail in the representation of production of conventional agricultural and biomass crops. It distinguishes 35 sectors, including 6 agricultural and biomass sectors (Willow, Hemp, Rape, Wheat, Other Cereals, and Other Agriculture) and it differentiates between conventional electricity (Electricity sector) and biomass-fueled electricity (Bioelectricity sector). In the model, all markets clear, which means that supply equals demand for all goods through adjusting of the relative prices (Ginsburgh and Keyzer, 1997). A detailed description of the model can be found in Ignaciuk and Dellink (2006) and Ignaciuk et al. (2005).

In the general equilibrium model, the representative consumer maximizes utility under the condition that expenditures on consumption goods do not exceed income. Consumers own production factors and consume produced goods. Labor supply is fixed, while the wage rate is fully flexible. On the contrary, capital supply is assumed to be flexible, adjusting to the fixed rental price. The taxes and subsidies, except of EU subsidies, are collected by the government that uses them to finance public consumption, and pay lump-sum transfers to the consumer. The EU subsidies are financed by European Union, and are granted for conventional agricultural production, energy crops and afforestation practices. The Polish government chooses a relatively simple subsidy scheme. Each farmer that owns a land of more than 1 ha acreage receives 61 Euro[16] per ha yearly. Moreover, farmers get 72 Euro, 69 Euro and 45 Euro subsidy per ha if they grow traditional agricultural crops, grass and energy crops, respectively (CEC, 2003a). For a detailed list of crop subsidies see UKIE (2004). Moreover, the EU proposed a long-term program for Poland, regarding afforestation of agricultural land (UKIE, 2004). In present value terms, using a discount factor of 4%, landowners receive 175 Euro per ha for afforested land. The foreign financing of the EU subsidies is simulated in the model by endowing the rest of the world (RoW) with assets that exactly cover the payments involved in the subsidies.[17]

Producers maximize profits subject to the available production technologies. Production technologies are represented by nested constant elasticity of substitution (CES) functions. In our model, we include the standard production function for most of the commodities; however we include also the latent technologies for e.g. Bioelectricity sector and agricultural and biomass sectors. Besides using labor and capital, the Bioelectricity sector has the choice between using willow, hemp, wood, traditional agricultural products and/or straw from agricultural production and forestry residuals as inputs. In our model, we include the multi-product characteristics of cereals, rape, hemp and forestry, by explicitly including in their production structure the straw or other residuals, as a by-product. These by-products are produced in fixed proportions to the production of the main commodity, and can be used only by the Bioelectricity sector. In the benchmark, by-products are not available as input to reflect the current situation as accurately as possible; presently by-products are marginally used.

The model is applied to Poland; we assume that Poland is a small open economy. We choose the Armington specification for traded goods, assuming that domestic and foreign goods are imperfect substitutes, to allow for a difference in prices between domestically produced goods and their international substitutes and to avoid full specialization.

The emissions of the major greenhouse gases (GHGs), CO_2, N_2O and CH_4, are included, all expressed in CO_2 equivalents. Carbon dioxide (CO_2) emissions enter the production and utility function assuming a fixed relation with fossil fuels, differentiated by fuel, since the CO_2 is mainly related to the fossil fuel use. In contrast, CH_4 and N_2O emissions are directly linked to output, since they are output specific. Environmental policies targets are

[16] One zloty (zl) equals around 0.25 Euro.

[17] See Ignaciuk and Dellink (2006) for more details.

implemented as a restriction of the number of emission permits. The government auctions the permits and recycles the revenues to the consumers via lump-sum transfers.

In the benchmark, four land classes are identified to capture differences in productivity from different land types that are currently used for agricultural and forestry production. Agricultural and biomass crops can grow on three different land use classes *z1*, *z2*, *z3*, which correspond to the six land classes used in the Polish land classification system (GUS, 2002c). Section 5.3 provides more detail on the land classification.

In this paper, we introduce twelve additional land use classes that are currently not classified for food production due to (1) high heavy metal contents (eight classes) or (2) poor production potential (four classes). The first group is divided into (i) land potentially to be cleaned (*z5VS, z5S, z5MS, z5mMS*) and (ii) heavily contaminated land (*z6VS, z6S, z6MS, z6mMS*). In the second group, we include degraded and devastated land (*z7VS, z7S, z7MS, z7mMS*). Willow can be grown on all twelve land classes and it is recognized as having high potential for phytoremediation. Moreover, it can be used in Bioelectricity sector. Forestry can be grown on heavily polluted, and degraded and devastated land. We include these twelve land classes as inputs in the alternative production technologies for willow. Eight classes out of the twelve additional land types can be used as inputs in the latent technologies for forestry production. The detailed description of the different land types is provided in Section 3.

5.3 Data and assumptions

5.3.1 Economic model

To determine the benchmark equilibrium, a Social Accounting Matrix (SAM) for Poland is adopted, based on GTAP5 data for 1997 (Dimaranan and McDougall, 2002). In the SAM, agricultural and biomass data are disaggregated based on the FEPFARM model built by Mueller (1995), using FAO (2005) and EUROSTAT (2003) land use data for Poland. The FEBFARM model provides the shares of production costs. Data on land use pattern and emissions are obtained from Polish statistics (GUS, 2002a,2002b). Data on agricultural and biomass residuals are taken from Gradziuk (2001), Dornburg et al. (2005) and ECBREC (2004b). For more details see Ignaciuk and Dellink, (2006).

Substitution elasticities between the different inputs in the production and utility functions are specified based on Kiuila (2000) as far as possible as they directly apply to the Polish economy. They are supplemented by estimates from Kemfert (1998), Rutherford and Paltsev (2000), and Dellink (2005) when information for Poland was lacking; in this way, the best available information is used in the model.

5.3.2 Land classes and availability and biomass yields

Polish classification system distinguished 6 land types, on the basis of land productivity. Class I represents the highest value for agricultural production and Class VI the lowest. 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 land (class V & VI). Forestry grows on the *z4* type of land; this is the land with the lowest productivity for the agricultural goods. The following categories of land *z5*, *z6* and *z7* are newly introduced in this paper. Category *z5* includes land that is contaminated by heavy metals, but can be cleaned by the process of phytoremediation within a period of 1 – 20 years. Heavily contaminated land that cannot be cleaned within a reasonable period belongs to the category *z6*. The *z7* type is devastated and degraded land. The classifications into *VS* (very suitable), *S* (suitable), *MS* (moderately suitable) and *mMS* (marginally suitable) of the *z5, z6, z7* land categories refer to the yield that can potentially be harvested. In Table 5.1 the additional costs for willow production for *z5* and *z6* land are presented, in comparison to the production costs on clean land (*z3*). To make the calculations consistent, required input quantities are calculated per Euro of output and normalized with respect to input requirements when using clean land type *z3*. Thus, e.g. the additional labor input on type *z5S* equals 38%, which reflects both differences in input requirements and lower productivity (and hence lower yield) of the contaminated land. The yields on *z7* type land are around 30% lower compared to *z5* and *z6*, which is modeled by increasing the additional production costs accordingly. Identical input requirements (in relative terms) are assumed for forestry.

Data on agricultural land use are taken from EUROSTAT (2003). Arable land and grassland are the land categories, which are considered as land suitable for willow production. On this land, willow production competes with food and fodder production. Furthermore, we asses the amount of heavy metal contaminated and/of degraded land, both categories we consider as only available to energy crop production.

Table 5.1 Input requirement of land, labor and capital per Euro of willow production (compared to clean land type *z3*) for different land use types in relation to clean land type *z3*

	clean *z3* (index)	*z5VS & z6VS*	*z5S & z6S*	*z5MS & z6MS*	*z5mMS & z6mMs*
Land	1	1.01	1.13	1.36	3.01
Labor	1	1.01	1.38	2.09	6.40
Capital	1	1.01	1.23	1.67	4.34

Source: own calculation.

Heavy metal contaminated land is not suitable for food and fodder production because the heavy metals are taken up by the crops and impose health risks to humans. The Polish Act on Protection of the Environment (from April 27th 2001, Dz.U. 2001 No 62 pos. 627) contains regulations on soil quality and pollution. Based on this act soil and land quality standards are elaborated (Dz.U. 2002 No 165 pos. 1359). According to these regulations maximal values of 4 mg cadmium (Cd) per kg dry matter soil[18] can be tolerated in agricultural and forestry soils. In Poland a system with six (0 – V) classes of soil heavy metal contamination was developed and applied to assess the share of Polish agricultural soils with different contamination levels. The information on the share of heavy metal contaminated agricultural soils were provided by

[18] Note that the regulations in other EU countries are stricter. The German soil protection regulation of 1999 prescribes that soil with a concentration of more than 0.1 mg cadmium per kg dry matter soil has to be taken out of food production.

the Institute of Soil Sciences and Plant Cultivation in Pulawy (Bocian, 2005), and are here used to assess the amount of contaminated land available for willow and forestry production. The soils of the classification III-V exceed the threshold value of 4 mg Cd per kg dry matter soil and have to be taken out of food production. In Poland 0.29, 0.17 and 0.08% of the agricultural land belong to the contamination levels III (average contamination), IV (strong contamination) and V (very strong contamination), respectively. That means about 66,000 ha would have to be taken out of food production due to heavy metal contamination. This land can be used for willow production and be cleaned in the same time. Specific willow varieties can on heavy metal contaminated land withdraw 20 - 45 mg Cd/kg dry matter stem wood (Schremmer et al., 1999). That means that, at a yield level of 10 t dm/ha per year, up to 450 g Cd can annually be removed per ha. To reduce the Cd content of soils from the contamination class III to a level of <4 mg Cd/kg soil would require about 10 - 20 years (depending on exact Cd content and the willow biomass yield attainable). Based on these calculations we here differentiate into heavy metal contaminated land that can be cleaned by willow production and be taken back into food production after 20 years and land that would require more time than 20 years to be cleaned. About 36 000 ha "cleanable" and 30 400 ha "uncleanable" heavy metal contaminated land were assessed for whole Poland (see Table 5.2). For cleanable land a 20 years period willow production is assumed. Uncleanable land can be used for willow and forestry production.

Additionally about 70,000 ha so-called degraded and devastated land is found in Poland (Bocian, 2005). Degradation of agricultural and forestry land means the reduction of the production potential through worsening of eco-physiological conditions by anthropogenic activities, both industrial activities and non sustainable agricultural production methods. The Polish law demands that such areas should be reclamated and taken into agricultural and forestry use again. Table 5.2 shows the amounts of degraded and devastated land in the NUTS-2 regions of Poland (status of 2003), which needs to be reclamated according to the Polish law.

The willow biomass yield strongly depends on the eco-physiological conditions of a site. Therefore no average number can be taken for all land areas in Poland. For the assessment of willow biomass yields we here used land suitability[19] specific yields received by IIASA. These range on very suitable land from 11.8 to 13.3 t dm/ha per year in the different Polish NUTS-2 regions. The ranges for suitable, moderately suitable and marginally suitable land are 8.8 – 9.8, 5.7 – 6.5 and 1.8 – 2.2 t dm/ha per year, respectively. We here calculated a weighed willow biomass yield (see Table 5.2) for all NUTS-2 regions. This was done by assessing the share of very to marginally suitable agricultural land in all NUTS-2 regions and by multiplying the share of land with the respective dry matter yields on the lands with different suitabilities. Because degraded and devastated land has reduced productivity we took the

[19] Suitability reflects the yield potential for a certain crop in a grid cell, six suitability classes from very suitable to not suitable are formulated (see Fischer et al. (2005)).

average productivity of moderately and marginally suitable land to determine the biomass yield on this land. The yield differences are combined with the additional input requirements to calculate the additional costs per Euro of output as shown in Table 5.1, i.e. the additional costs per hectare are divided by the average yield per hectare.

Table 5.2 Contaminated, degraded and devastated land available for willow production and the weighed willow biomass yields for the NUTS-2 regions of Poland

	Heavy metal contaminated land		*Degraded land*	*Devastated land*	*Sum of land*	*Weighed willow yield*
	cleanable	un-cleanable				
	ha	ha	ha	ha	ha	t dm/ha per year
Lódzkie	2900	2007	233	4255	9395	7.94
Mazowieckie	0	0	68	5228	5296	5.66
Malopolskie	7378	2920	147	3000	13445	6.66
Slaskie	22188	21259	955	4745	49147	5.61
Lubelskie	1071	0	212	3252	4535	5.96
Podkarpackie	0	0	209	3212	3421	6.38
Swietokrzyskie	0	312	64	3151	3527	5.40
Podlaskie	0	0	91	2766	2857	6.09
Wielkopolskie	0	705	185	10546	11436	5.87
Zach-Pom.	419	0	606	2630	3655	4.52
Lubuskie	0	0	465	793	1258	6.80
Dolnoslaskie	0	0	2275	6094	8369	7.41
Opolskie	1912	3206	303	3132	8553	7.20
Kujawsko-Pom.	0	0	15	4420	4435	4.87
Warm.-Maz.	0	0	114	4897	5011	5.78
Pomorskie	343	0	372	2257	2972	6.22
Poland	*36210*	*30409*	*6314*	*64378*	*137311*	

5.4 Scenarios

Polish policy makers set goals concerning an increase of the share of bioelectricity in total electricity production to 7.5% by 2010 and 14% by 2020. We present three policy scenarios aiming at increasing this bioelectricity share and at reducing CO_2 emissions, using two different settings: a) without considering additional land (types *z5*, *z6* and *z7*), and b) with contaminated and degraded land (types *z5*, *z6* and *z7*) available for willow and forestry production.

Currently, there are no specific policy recommendations for Poland on how to increase bioelectricity shares, neither on how to further reduce the CO_2 emissions. Many experts, including Nilsson et al. (2006) and Ericsson et al. (2006), agree that without additional policy impulses, these governmental targets are not going to be reached. Ignaciuk et al. (2005) analyze several energy/environmental policies to increase the share of the bioelectricity in the total electricity production in Poland. They conclude, based on their analysis, that a tradable emission permit system combined with a bioelectricity subsidy scheme provides better incentives to reach Polish policy goals than i) only the emission permit reduction policy, or ii) when the emission permit reduction policy is combined with the subsidy on biomass production, are envisaged. The subsidy on biomass production stimulates the growth of the biomass sector more effectively, but the Bioelectricity subsidy provides a better stimulus to the Bioelectricity sector and provides additional incentives to the biomass sector to expand its production as well. Since one of the major goals of Polish policy makers is to stimulate bioelectricity production, we choose to further analyze the policy option favoring the bioelectricity subsidy combined with emission permits, and we propose different options to finance the subsidy. Both the internal agricultural subsidy scheme and the EU subsidies for agricultural, biomass and forestry sectors implemented in the model are in line with current policy lines. In each scenario, we adopt a restriction on the number of emission permits of 10% below the benchmark level, and apply bioelectricity subsidy rates. The bioelectricity subsidy is given in steps of 5%, ranging from 5% to 25%. The government auctions the emissions permits and it recycles the revenues as a lump-sum transfer to the consumers. The bioelectricity subsidy is financed in each scenario in different ways: (1) by a lump-sum transfer from the households to the government, (2) by an endogenous tax on traditional electricity, and (3) by an endogenous further restriction of the number of emission permits. An overview of the scenarios is given in Table 5.3.

The differences between specifications 'a' and 'b' allow us to interpret the role of phytoremediation. Based on these scenarios, we can specify the amount of land that can return into the agricultural production, can be cleaned up by willow, and the land that can be further used for biomass production. Moreover, we expect that the use of contaminated and degraded land for biomass production can have an influence, not only on land allocation, but also on prices of several commodities and production quantities in the rest of the economy.

Table 5.3 Overview of the financing mechanisms for Bioelectricity sector; note that for each scenario a restriction of emission permits of 10% is implemented

The bioelectricity subsidy is financed by:	*No additional land*	*With contaminated and degraded land*
A lump-sum transfer from the government	Scenario 1a (sc1a)	Scenario 1b (sc1b)
An endogenous tax on electricity	Scenario 2a (sc2a)	Scenario 2b (sc2b)
An endogenous restriction of emission permits	Scenario 3a (sc3a)	Scenario 3b (sc3b)

All scenarios describe alternative policies that can be implemented by the Polish government in order to achieve the policy targets. They are analyzed with respect to a common benchmark that describes the initial situation of the Polish economy. As the model is static, we do not adopt any scenarios for exogenous future developments, e.g. we assume that the population is stable in Poland, which reflects current trends. The model does, however, capture possible changes in production and consumption activities, represented in the model via different combinations of production inputs, including those technologies that are implementable, but not yet implemented. For instance, bioelectricity can be produced using the technologies that are currently applied but could switch to novel technologies such as the use of contaminated biomass[20] and different agricultural by-products when these become profitable (due to changes in relative prices). Note that the production technologies are described through continuous production functions which mimic the situation that there are several producers within a sector that use different technologies.

5.5 Results and discussion

Bioelectricity shares

Figure 5.1 presents the share of bioelectricity in electricity production under different scenarios. The results show differences between the bioelectricity shares for all scenarios, for an increasing bioelectricity subsidy rates. The first policy goal of 7.5% bioelectricity share is reached with around 20% bioelectricity subsidy level for Scenarios 2 and 3, and 22% bioelectricity subsidy level for Scenario 1 (both 'a' and 'b' specifications). The more stringent goal of 14% is not reached within the analyzed range of policies. What can be noticed is that the use of the contaminated and degraded land virtually does not influence the bioelectricity shares substantially in any of the scenarios.

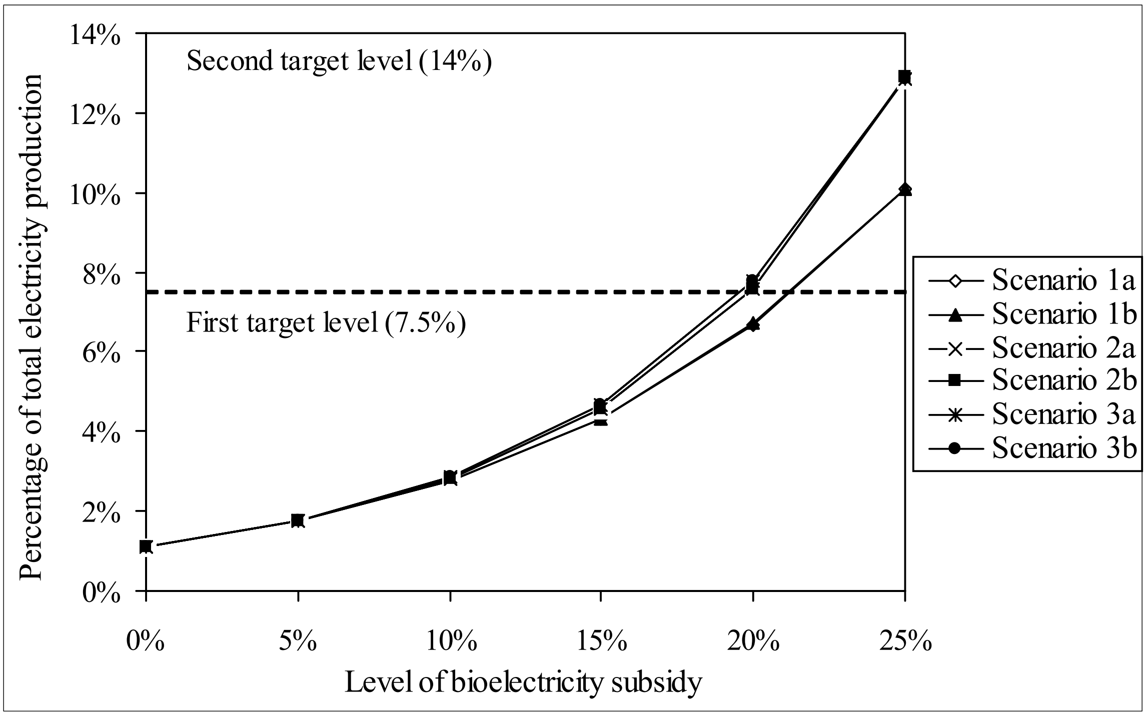

Figure 5.1 Bioelectricity share for all scenarios for different levels of bioelectricity subsidy; note that for each scenario an additional restriction of 10% emission permits reduction holds

[20] Note that specific combustion technologies are needed to accumulate the heavy metals in the fly ash fraction, which has to be disposed (Dahl et al., 2002).

In scenarios 1a and 1b there are two incentives to increase the bioelectricity production: reduction of the emission permits by 10%, and the bioelectricity subsidy; the lump-sum financing of the subsidy does not affect relative prices. In scenarios 1a and 1b we observe the smallest shares of bioelectricity, since this scenario provides the least incentive to increase the production of bioelectricity, compared to the other two scenarios.

In scenarios 2a and 2b, and 3a and 3b we observe additional incentives, governed by the fact that the bioelectricity subsidy is financed via an electricity tax, in Scenario 2a and 2b respectively, or via emission permits, in Scenario 3a and 3b respectively. In Scenario 2 (both ‘a’ and ‘b’ specifications) the economy adapts to higher prices of electricity, and in Scenario 3 (both ‘a’ and ‘b’ specifications) the economy adapts to the changes induced by higher permit prices. Despite different financing structure, the effect on the bioelectricity share is practically the same; the share increases with up to 3 percent-points. In the one case (Scenario 2), the electricity price increase is direct, through a tax, while in the other (Scenario 3) it is indirect, through higher prices for fossil fuels. Thus, scenarios 2 and 3 deliver similar shares of bioelectricity, for each level of bioelectricity subsidy. In Scenario 2 the electricity price is the highest, compared to Scenario 1 and 3 (both ‘a’ and ‘b’ specifications), as the additional tax is directly imposed on the electricity sector.

Utility change

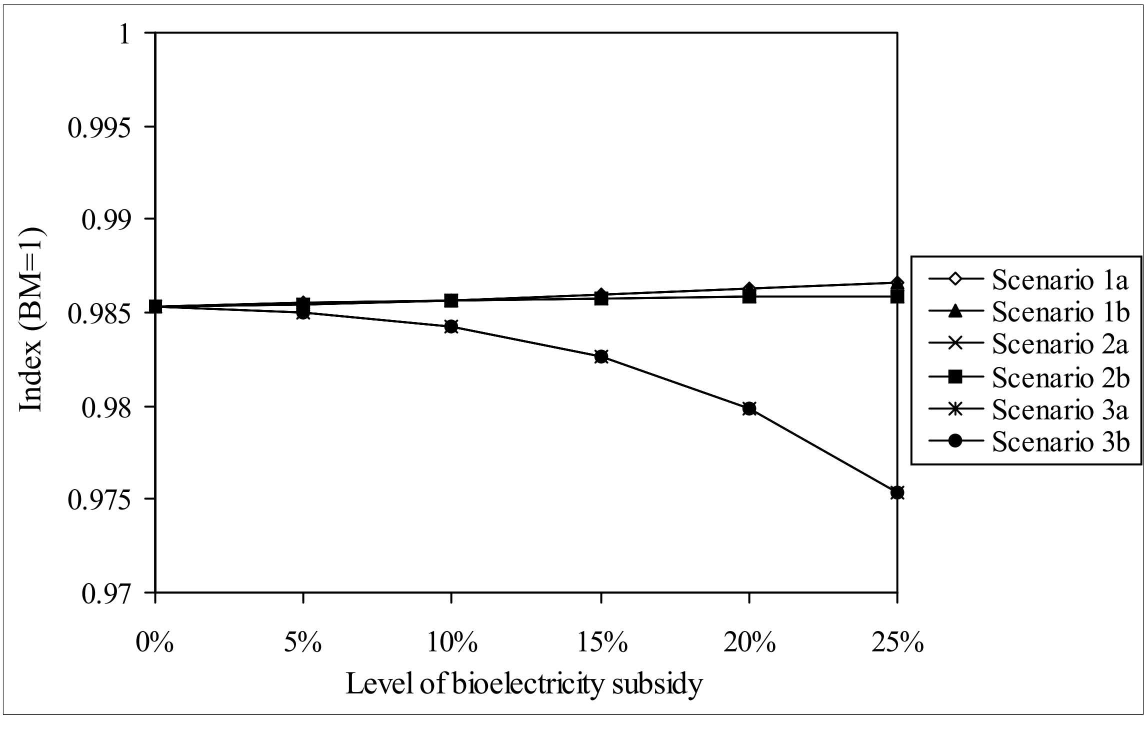

Figure 5.2 Utility changes for all scenarios for different levels of bioelectricity subsidy: note that for each scenario an additional restriction of 10% emission permits reduction holds

The welfare costs of the proposed policies are presented in Figure 5.2. It should be stressed that the environmental benefits of these policies are not taken into account in this measure of welfare, and hence it cannot be concluded whether these policies are justified.

The welfare costs of all three scenarios tend to be different. For Scenarios 1 and 2 (both ‘a’ and ‘b’ specifications), there is hardly a difference between the welfare costs. The bioelectricity subsidy tends to have a negligible impact on welfare, while the reduction of the number of emission permits of 10%, which is common to all scenarios, reduces welfare with a little less than 1.5%. In Scenario 3, utility decreases more than proportionately with increasing level of bioelectricity subsidy, as a result of the distortional effects of the carbon permit reduction on the economy, which affects households directly as they also need emission permits. This scenario, however, results in the highest emission reduction levels (not shown in Figure 5.2), and hence environmental quality is higher than in the other scenarios.

There is, again, no difference between the ‘a’ and ‘b’ specifications. This means that the availability of land that is currently excluded from agricultural production, practically, does not influence overall welfare costs. The use of contaminated land largely replaces biomass plantations on clean land, rather than extending biomass production. The macroeconomic impacts of such a replacement are limited. Again, one has to remember that the environmental benefits of the e.g. phytoremediation are not included in the utility function and hence it is difficult to conclude which policy is the most desirable from an environmental point of view.

Land use and prices

Table 5.4 presents the changes in land use patterns observed in the scenarios for two levels of bioelectricity subsidies, 10% and 25%. The 10% subsidy level indicates the direction of the changes, whereas the subsidy level of 25% is required to achieve the policy target, of increasing the shares of bioelectricity in total electricity production up to 7.5%, in all scenarios. For comparison, the benchmark land allocation is also presented. The large land use reallocations are noticeable under Scenario 2. In Scenario 2a and 2b, for a 10% bioelectricity subsidy, both willow and forest production areas increase by 6 and 45 thousands ha, respectively. For a 25% bioelectricity subsidy, in Scenario 2a and 2b, both willow and forestry acreages increase by 199 and 257 thousands ha, respectively. Under scenarios 3a and 3b, for 25% bioelectricity subsidy, there are slightly smaller additional areas dedicated to willow and forestry plantations, namely 183 and 239 thousands ha. Smaller increase in acreage is visible under Scenarios 1a and 1b, namely 152 and 208 thousands ha, respectively, for 25% bioelectricity subsidy.

This land reallocation is caused mainly by an increasing demand for biomass for the Bioelectricity sector. As explained above, the highest demand for bioelectricity is observed under scenarios 2 and 3, hence those scenarios result in the largest land use reallocations. Both the Forestry and Willow sectors benefit from the additional land that is available for their production in the ‘b’ specifications. In all scenarios, the most productive land (*VS*) is used for willow and forestry production and in most cases the suitable land (*S*) as well. From the devastated and degraded land (*z7*), the very suitable (*7VS*) and suitable (*7S*) land is taken into production.

Moderately suitable land (*MS*) is used for forestry production when the bioelectricity subsidy is high; with 25% bioelectricity subsidy, *z6MS* land is utilized. Marginally suitable land (*mMS*), is not taken into production, because of relatively high cost per tonne of biomass produced, despite the EU subsidies given to both willow and forestry producers. Notice that both *z6* and *z7* types of land are suitable for both willow and forestry production. Due to the higher subsidy level that forestry receives compared to willow plantations, this land is dedicated most profitable to forestry.[21]

Utilizing the contaminated and degraded land is beneficial not only for willow and forestry plantation, but also for traditional agricultural commodities producers. In the policy scenarios, where the additional land is included (specification 'b'), the agricultural producers have more land available for production compared to the specification without additional land (specification 'a').

For instance, with the 25% subsidy level, in the Scenario 2b, the agricultural producers have 3.5 thousands ha more for Other Agriculture and Wheat production compared to Scenario 2a. Thus, we can observe that the utilization of the additional land can reduce the pressure on the agricultural production. However, one has to keep in mind that the utilization of the degraded and devastated land is not a solution to increase the land capacity for biomass production sufficiently enough to reach the goals of policy makers. Moreover, the amount of land that becomes available for traditional agriculture via the use of contaminated land is rather small compared to the current acreage used by agriculture. Thus, the macroeconomic impact of using contaminated and degraded land remains limited.

Table 5.5 presents prices of land for 10% and 25% subsidy levels. Similar to capital, we express the price as a rental price i.e. it is the payment to the service that provide the land, not for a resource itself. For a 25% bioelectricity subsidy level we observe a clear tendency towards a price increase of *z2*, z*3* and z*4*.[22] The highest increase is noticeable under Scenario 2, where also the highest pressure for biomass crops is encountered. In the policy scenarios where additional land is included (specification 'b'), the agricultural producers have more land available for production compared to the specification without additional land (specification 'a') and this lowers the price level for currently productive land, especially of *z3* and *z4* land types.

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[21] Remember that the additional costs for producing on z6 and z7 were calculated to be identical for forestry and willow per Euro output; see Section 3.

[22] The small reduction in the price of land type z1 is due to the fact that only relative prices matter in the AGE framework: as other resources become relatively scarcer compared to this resource, the *relative* price of z1 decreases. Absolute price levels cannot be calculated in the model, as the money market is not specified and money only serves as accounting unit (cf. Ginsburgh and Keyzer, 1997).

Table 5.4 Land use (in 1000 ha) with 10% and 25% subsidy on bioelectricity for all scenarios

Sectors	Land types	BM	*10% Subsidy* sc1a	sc1b	sc2a	sc2b	sc3a	sc3b	*25% Subsidy* sc1a	sc1b	sc2a	sc2b	sc3a	sc3b
Other Agriculture	*Z1*	102.4	101.7	101.7	101.7	101.7	101.6	101.6	100.5	100.5	100.2	100.2	99.8	99.8
	Z2	1839.5	1820.8	1820.8	1820.5	1820.5	1819.6	1819.6	1778.8	1778.9	1764.7	1764.8	1757.0	1757.0
	Z3	1051.6	1041.5	1042.8	1041.1	1042.4	1041.2	1042.2	989.2	991.0	972.6	974.5	972.4	974.3
Hemp	*Z1*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2
	Z3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.0
Willow	*Z1*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	Z3	0.5	2.3	0.0	2.3	0.0	2.4	0.0	6.0	0.0	6.6	0.0	7.4	0.0
	Z5VS			5.3		5.3		5.3		5.3		5.3		5.3
	Z5S			0.0		0.0		10.4		10.4		10.4		10.4
Wheat	*Z1*	87.4	86.9	86.9	86.9	86.9	86.9	86.9	84.7	84.7	83.9	83.9	84.0	84.0
	Z2	1570.1	1556.5	1556.5	1556.0	1556.0	1555.9	1556.0	1499.2	1499.2	1478.9	1478.9	1480.0	1480.0
	Z3	897.7	890.3	891.4	889.9	891.0	890.4	891.2	833.7	835.2	815.1	816.6	819.1	820.7
Other Cereals	*Z1*	218.6	219.8	219.8	219.8	219.8	219.8	219.8	223.1	223.1	224.3	224.3	224.6	224.6
	Z2	3894.5	3903.5	3903.7	3903.6	3903.8	3904.2	3904.3	3916.7	3916.9	3920.7	3921.0	3923.6	3923.9
	Z3	2301.1	2307.5	2310.4	2307.2	2310.1	2308.9	2311.2	2251.0	2255.1	2233.2	2237.6	2244.3	2248.8
Rape	*Z1*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	349.4	372.6	372.5	373.3	373.2	373.7	373.6	458.8	458.5	488.9	488.6	492.7	492.4
	Z3	87.3	93.1	93.2	93.3	93.4	93.5	93.5	111.5	111.6	117.8	117.9	119.2	119.3
Forestry	*Z4*	8813.5	8816.9	8813.8	8817.9	8814.9	8815.4	8813.5	8960.1	8958.6	9006.6	9005.2	8989.4	8988.7
	Z6VS			4.7		4.7		4.7		4.7		4.7		4.7
	Z6S			8.4		8.4		8.4		8.4		8.4		8.4
	Z6MS			0.0		0.0		0.0		9.4		11.9		9.7
	Z7VS			7.8		7.8		7.8		7.8		7.8		7.8
	Z7S			17.5		17.5		17.5		17.5		17.5		17.5

Table 5.5 Prices* of land (in Euro per ha) with 10% and 25% subsidy on bioelectricity for all scenarios**

Land		*10% Subsidy*						*25% Subsidy*					
type	BM	sc1a	sc1b	sc2a	sc2b	sc3a	sc3b	sc1a	sc1b	sc2a	sc2b	sc3a	sc3b
z1	91.4	87.8	88.0	87.8	88.0	87.5	87.7	81.9	82.2	79.8	80.2	77.7	78.0
z2	66.4	66.1	66.2	66.1	66.3	66.0	66.1	69.4	69.7	70.5	70.8	69.0	69.3
z3	37.1	37.0	36.7	37.1	36.8	36.8	36.5	51.5	50.8	57.3	56.4	53.7	52.9
z4	37.1	36.3	36.0	36.4	36.1	36.1	35.7	50.6	49.9	56.2	55.4	52.7	51.9
z5VS	N/A		11.9		12.4		12.7		41.0		44.7		44.6
z5S	N/A		0.0		0.0		0.0		1.1		2.1		2.3
z6VS	N/A		33.9		33.9		33.6		47.5		53.0		49.6
z6S	N/A		0.3		0.3		0.2		3.4		5.9		4.6
z7VS	N/A		33.0		33.0		32.7		46.6		52.0		48.6
z7S	N/A		0.0		0.0		0.0		0.1		0.4		0.2

* Source: GUS (2002b); note that in reality the land prices increased substantially since the benchmark year (1997).

** Note that the numeraire, the Consumer Price Index, as assumed constant through all simulations in the AGE framework.

Prices of contaminated land, available for biomass production, increase with the level of subsidy on bioelectricity, since the demand for this land increases. In the benchmark, there is no demand for this land due to its poor characteristics; the land price is assumed to be almost zero. The largest increase is noticeable for the best quality of land (*z6VS* and *z7VS*), where both forestry and willow can grow: these lands become almost as expensive as clean land of a comparable quality (*z3*). The price increase of land type *z5VS* remains limited despite its high quality, since we assume that only willow can grow on this land.

Production

The policy intervention via the emission reduction and bioelectricity subsidy scheme influences each sector of the Polish economy. Generally, we can observe an overall decline of 'dirty' goods (relatively high emissions of GHGs) production and increase of 'clean' goods (relatively low emissions of GHGs) production (see Table 5.6). The bioelectricity production increases substantially, reaching almost 4 times its benchmark production level for a 10% subsidy rate and around 14 to 18 times its benchmark level for a 25% subsidy rate.

This of course has an influence on the production of biomass: the sectors producing willow and hemp increase their production substantially in all scenarios. Moreover, the Rape sector that also contributes to the Bioelectricity sector, by providing straw, increases its production considerably. Note that around 2 %-points of the bioelectricity share come from the by-products of agriculture and forestry.

Between the scenarios, the largest differences are notable in the Willow sector. The production of willow increases substantially under all scenarios. The largest changes are visible in Scenario 3, since in this scenario there is the largest incentive to decrease 'dirty' goods production. Also the agricultural sector, that uses more fertilizers compared to biomass sector, decrease its production slightly more than in scenarios 1 and 2, allowing cleaner sectors (biomass) to intensify their production.

It is interesting to compare the production structure between specifications 'a' and 'b' in all three scenarios. Thanks to the phytoremediation characteristic of willow that allows it to grow on contaminated, hence cheaper, land, the production of this sector can boost. For instance, for 10% bioelectricity subsidy level, willow production increases by 330% and 774% in Scenario 2a and 2b, respectively. With a higher level of bioelectricity subsidy the production of willow increases to 1,174% and 1,517% in Scenario 2a and 2b, respectively. In absolute terms, the increase in production of willow is more or less constant across the different subsidy levels, as the amount of contaminated land is limited and very suitable land (*z5VS*) will already be fully used at low subsidy levels (cf. Table 5.4). The Forestry sector can also benefit from cheap contaminated and degraded land. It indeed increases its land area but this is not reflected in the production quantities for two reasons. First, this sector is very large, and hence the production of forest goods on contaminated land is only a small fraction of total forestry production, and, second, the production on contaminated land to a large extent replaces forestry production on other land types (cf. Table 5.4).

Table 5.6 Changes in the production and trade of selected sectors with 10% and 25% subsidy on bioelectricity (% change compared to benchmark)

	10% Subsidy						*25% Subsidy*					
	sc1a	sc1b	sc2a	sc2b	sc3a	sc3b	sc1a	sc1b	sc2a	sc2b	sc3a	sc3b
Production												
Other Agriculture	-2.3	-2.3	-2.3	-2.3	-2.6	-2.6	-0.7	-0.7	-0.1	-0.1	-2.3	-2.3
Rape	6.1	6.1	6.4	6.4	6.4	6.4	34.8	34.8	45.2	45.2	44.9	44.9
Willow	322.1	770.0	330.5	773.7	339.8	776.0	1050.0	1302.2	1173.8	1517.0	1310.3	1550.2
Hemp	8.0	8.3	8.8	9.1	7.5	7.7	87.5	88.8	120.0	119.5	79.6	79.2
Wheat	-1.7	-1.7	-1.7	-1.7	-1.8	-1.8	-1.5	-1.5	-1.5	-1.5	-2.8	-2.8
Other Cereals	-0.7	-0.7	-0.6	-0.6	-0.8	-0.8	3.6	3.7	5.2	5.2	3.8	3.8
Forestry	-0.2	-0.1	-0.1	-0.1	-0.2	-0.2	4.8	4.8	6.5	6.5	5.6	5.6
Coal	-9.3	-9.3	-9.3	-9.3	-10.1	-10.1	-9.4	-9.4	-9.3	-9.3	-15.3	-15.3
Oil	-16.8	-16.8	-16.8	-16.8	-18.3	-18.3	-16.5	-16.5	-16.0	-16.0	-26.9	-27.0
Gas	-13.8	-13.8	-13.8	-13.8	-15.0	-15.0	-13.9	-13.9	-13.8	-13.8	-22.6	-22.6
Electricity	-6.5	-6.5	-6.7	-6.7	-7.0	-7.0	-11.6	-11.6	-15.0	-15.0	-16.5	-16.5
Bioelectricity	284.7	284.9	293.4	293.6	296.4	296.6	1341.9	1342.5	1733.2	1734.4	1693.4	1694.4
Industry	-1.8	-1.8	-1.8	-1.8	-2.0	-2.0	-1.7	-1.7	-1.8	-1.8	-3.0	-3.0
Services	-1.5	-1.5	-1.5	-1.5	-1.6	-1.6	-1.4	-1.4	-1.5	-1.5	-2.5	-2.5
Trade												
Import Willow	298	438	307	446	313	450	1222	1326	1497	1646	1564	1666
Export Willow	343	1227	352	1221	364	1219	922	1282	952	1414	1126	1458
Import Bioelectricity	135	135	140	140	142	142	432	432	576	576	556	556
Export Bioelectricity	528	528	542	542	547	548	3781	3783	4835	4839	4768	4772

It is clearly visible that thanks to the utilization of contaminated and degraded land, the scope of production for biomass increases. This happens without compromising the land availability for other land-intensive sectors. Hence, it can slightly decrease the competition for land between sectors producing energy crops and food, though the utilization of additional land brings only marginal benefits to the agricultural sector.

Trade

Table 5.6 also presents the results of the scenario simulations on the trade of bioelectricity and willow. In the benchmark, levels of imports and exports of both commodities are very small and imports equal exports. Hence, it is relatively easy to compare the trade levels, looking at percentage changes. In all scenarios, the export of bioelectricity exceeds the import. This is easily explained by the fact that due to the subsidy on this product the price of bioelectricity produced in Poland is lower than the price of bioelectricity on the world market; given the fixed exchange rate this directly translates into a comparative advantage of Polish bioelectricity producers on the world market and hence higher exports. The European Union and other trade partners can benefit here from the internal Polish policies as more bioelectricity becomes available at a low price. There is virtually no change in the trade level between the 'a' and 'b' specification, which means that the utilization of the contaminated and degraded land has almost no influence on domestic production and hence also the trade pattern of bioelectricity.

According to our analysis, when the level of the bioelectricity subsidy is relatively low, net exports of willow to the rest of the world increase, and, when the contaminated and degraded land are productive, net exports of willow increase substantially for all three scenarios. This means that exploring the phytoremediation function of willow (use of contaminated and degraded land for) can have an important influence on the willow production for internal Polish market and also for other European markets. At increased levels of the bioelectricity subsidy however, Poland becomes a net biomass importer as imports increase more drastically than exports. This counter-intuitive result can be explained by a combination of (i) a high demand for biomass by the Bioelectricity sector and (ii) a relative price increase for domestically produced willow compared to the fixed world market price of willow. This second effect only occurs at high subsidy levels and reflects the huge increase in demand for willow. Utilizing the degraded and devastated land stimulates exports more than imports and thus decreases the net imports of willow. Moreover, the levels of exports of willow are hardly affected by the subsidy level, reflecting the assumed rigidity on the world market.

It should be stressed that these results depend on the model assumptions, which include a fully absorbing world market with fixed prices, a fixed exchange rate with fluctuating balance of payments and limited substitution possibilities between domestic and foreign goods. Moreover, we do not explicitly investigate any additional foreign policy that might lead to an increase demand for biomass. Thus, the trade patterns for willow as presented here substantially differ from more detailed partial analyses as presented in e.g. Van Dam et al. (2005a,b). When the European Union adopts energy policies that stimulate the efficient production and use of biomass in the EU, Poland can benefit from this by exporting large quantities of biomass when it aligns its own energy policies to the changes in the international context; the large increase in production levels of biomass as observed in our scenarios confirms this. In the current model setup and scenarios, it seems, however, that without utilizing the additional land, Poland will not be able to produce enough cheap biomass to fulfill both its own targets and export large quantities.

Prices

The impact of the energy policies on the relative output prices for a selection of goods is presented in Table 5.7. Generally, the prices of 'dirty' goods go up compared to the prices of cleaner goods, as the production costs for the 'dirty' sectors increase substantially due to the expensive emission permits. For example, the price of hemp increases substantially, due to its, relatively to other biomass crops, high fossil fuel intensity production structure and an increased demand for this type of biomass. Moreover, it is a very small sector, sensitive to changes in the market structure.

The price of bioelectricity decreases relatively to other prices, because it benefits from the subsidy and cheap by-products of agricultural and forestry sectors; for changes in user (demand) prices of bioelectricity one needs to subtract the subsidy. Despite the fact that the Bioelectricity sector does not have to pay for the CO_2 emission permits, one can argue that the inputs into this sector are not always as clean as desired. A way to compensate for emissions is to use the emission permit system to correct for the emissions, as proposed in the Scenario 3. In such way, we assure that the emissions coming from e.g. hemp sector are compensated for. However, looking at the current situation, the Biomass sector should be looking at the least energy intense inputs, to reduce its costs and overall emissions; first using the residuals, than the products of forestry and willow and later more dedicated energy crops, like hemp.

Table 5.7 Output prices of selected commodities with 10% and 25% subsidy on bioelectricity for all scenarios (% change compared to benchmark)

	10% Subsidy						25% Subsidy					
	sc1a	*sc1b*	*sc2a*	*sc2b*	*sc3a*	*sc3b*	*sc1a*	*sc1b*	*sc2a*	*sc2b*	*sc3a*	*sc3b*
Other Agriculture	1.7	1.7	1.7	1.7	1.9	1.9	1.6	1.6	1.5	1.5	2.9	2.9
Rape	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-0.4	-0.4	-0.6	-0.6
Willow	-1.4	-11.3	-1.4	-11.1	-1.6	-11.0	3.5	0.4	5.8	1.9	4.2	1.7
Hemp	17.3	17.1	17.3	17.1	18.3	18.1	20.3	20.0	20.1	20.2	27.7	27.8
Wheat	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.6
Other Cereals	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	1.1	1.1
Forestry	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.4	0.3	0.6	0.6	0.3	0.3
Electricity	3.4	3.4	3.7	3.7	3.7	3.7	3.2	3.2	5.8	5.8	5.6	5.6
Bioelectricity	-11.6	-11.6	-11.6	-11.6	-11.6	-11.6	-22.1	-22.1	-22.1	-22.1	-22.2	-22.2

We can observe an increase of agricultural commodity prices. However, this increase is small, at most 3%, even though the emission permit price rises to around 9 Euro per ton of CO_2, and land prices increase. Such small increase in prices, despite the competition for land, shows that the competition between the production of food and fodder and of biomass is less strong in our general equilibrium setting than commonly encountered in a partial equilibrium framework.

Despite the increased demand for willow, its price decreases at low levels of the bioelectricity subsidy, especially when contaminated land is available. This can be explained by the fact that the sector does not need emission permits, since in itself id does not produce additional emissions. Moreover, the presence of additional land types for willow production decreases the price of willow further. The presence of land types *z5*, *z6* and *z7* also has a small impact on the prices of other commodities, such as hemp prices, which decrease, showing that all markets are linked.

For a higher level of bioelectricity subsidy the differences in willow prices between 'a' and 'b' specifications are smaller, between 2.5%-3.9%. Willow producers can still benefit from cheap contaminated land. The price of forestry products is hardly different between the 'a' and 'b' specifications, even though forestry can also grow on contaminated land. This indicates that the share of land costs in total production costs and the amount of contaminated land are too small to have a substantial impact on the sector.

Impact of a higher biomass yields

One of the parameters that can influence the results is an increase of the yields of willow on contaminated land. This reflects a rationalization of the biomass production sectors as is envisaged in the literature (see van Dam et al. (2005a) and the discussion in Section 5.1). Breeding activities of the Swedish breeding company Svalöf Weibull AB have already resulted in willow varieties with a 10%-20% higher yield in potential (Larsson, 1998). These results and breeding success with other trees species show that an increase of willow yields of up to 20% can be realized on short term. As a sensitivity analysis, here the yield of willow is increased in small steps. Thus, the required increases in productivity can be calculated that make production of willow on more heavily contaminated and less suitable lands profitable. Table 5.8 shows the results of this analysis. In the base case, denoted as "100% yield", *z5VS* and *z5S* are already fully used by willow and *z6VS*, *z6S*, *z7VS* and *z7S* are fully used by forestry. Furthermore, *z6MS* is already partially used by forestry.

A small increase in willow yield of 5% is sufficient to induce full production on *z5MS* by the willow sector. A further increase of 5%, to 10% yield increase, has an impact on *z7VS* that starts to be partially used by willow sector; hence the Forestry sector has to shrink. Further increase in productivity, induce more changes. With 15% yield increase more *z7VS* is dedicated to willow plantation and with 20% yield increases the total of *z7VS* is used for willow production and a part of *z6VS* starts to be dedicated to willow, further reduction of forestry plantations take a place. With 25% yield increase, willow covers the total acreages of *z5VS, z5S, z5MS, z6VS*, and *z7VS*. Moreover, it starts to grow again on *z3* land type. Those increases in productivity, however, are insufficient to make production on marginally suitable land types (*mMS)* profitable, neither for willow neither for forestry; this is because the land productivity is too low.

Table 5.8 The influence of a yield increase for willow on the land use allocation (for Scenario 2b and a 25% bioelectricity subsidy - base)

	100% (base)	*105%*	*110%*	*115%*	*120%*	*125%*
z3	0.0	0.0	0.0	0.0	0.0	5.6
z5VS	5.3	5.3	5.3	5.3	5.3	5.3
z5S	10.4	10.4	10.4	10.4	10.4	10.4
z5MS	0.0	12.8	13.8	13.8	13.8	13.8
z6VS	0.0	0.0	0.0	0.0	4.1	4.7
z7VS	0.0	0.0	3.0	6.9	7.8	7.8

This yield increase has also an impact on the trade pattern of biomass; with already 5% willow yield increase, despite Polish high internal demand for biomass (Scenario 2b (25% bioelectricity subsidy)), Poland becomes net willow exporter. For 25% willow yield increase the total willow import increases by around 3,200% but export rises by almost 13,000%. Such technology broadens substantially the Polish potential of being a biomass exporting country to e.g. other European Union countries.

5.6 Conclusions

In this paper, we focus on the impact of energy policies and multifunctional land use on production and trade of biomass and bioelectricity, land use and on the competition between traditional agriculture and energy crops. For this purpose, we use an applied general equilibrium model and calibrate it to Poland, a central European country with high biomass potentials.

Before drawing the conclusions, we would like to mention some of the major caveats of our model. First, we address the issue in a comparative-static manner that does not allow us to describe the transition of the regenerated land from willow towards traditional agricultural (food) production. Secondly, environmental benefits, such as additional benefits coming from the regenerated land e.g. cleaner ground water table, or additional benefits of increased air quality are not taken into account, and hence it cannot be properly assessed which policies bring the most desirable environmental effects. Thirdly, the economy adapts to the changes induced by the policy measures by the means available in the model. There are other possible ways to reduce greenhouse gas emissions that are not included in our model, e.g. use of tree planting for pure CO_2 sequestration purposes, or joint implementation mechanisms in order to reduce CO_2 emissions, or implementation of solar panels. However, the choice of the possible energy developments is in line with the policy expectations for Poland. Fourthly, one should keep in mind that the model is a stylized representation of the economy, and though it is calibrated using the best available data, numerical results from the simulations should be interpreted with sufficient care. Moreover, due to a lack of data for the latent technologies for forestry production (production on *z5*, *z6* and *z7* land types), we assumed that the same additional cost percentages hold in the forestry sector as for willow. This may influence which crops are grown on this land, especially when additional costs turn out to be higher for forestry. Despite these limitations, we would like to highlight some interesting results.

First, the proposed policy measures are adequate to reach the Polish policy goal of increasing the bioelectricity shares to 7.5% in total bioelectricity production, regardless of whether contaminated land is available for biomass production. The second policy goal for Poland that aims to reach 14% bioelectricity shares cannot be achieved in proposed settings.

Second, when introducing emission permits the prices of ‘dirty’ goods go up compared to the prices of cleaner goods, as the production costs for the ‘dirty’ sectors increase substantially due to the expensive emission permits. The price of bioelectricity decreases relatively to other prices, because it benefits from a subsidy and cheap by-products of agricultural and forestry sectors. We observe a small increase of agricultural commodity prices, at most 3%, while the emission permit price rises to around 9 Euro per ton of CO_2.

Third, following the policy impulses, the economy adjusts in all scenarios, reducing the production of dirty commodities and increasing the production of clean ones. As expected, the Bioelectricity sector increases its production substantially. The biomass sectors such as the sectors producing, willow or hemp increase their production considerably in all scenarios, to meet the higher demand for biomass by the Bioelectricity sector. A part of the biomass comes from the multifunctional agricultural and forestry sector, but a part of biomass comes from specific energy plantations on good quality, non-contaminated agricultural land. Despite the fact that the Bioelectricity sector in itself does not emit CO_2, one can argue that the inputs into this sector are not always as clean as desired. Looking at the current situation, the Biomass sector should be looking at the least energy intense inputs; first using the residuals, than the products of forestry and willow and later more dedicated energy crops, like hemp, in order to reduce the overall GHG emissions.

Fourth, the influence of using contaminated and degraded land for willow and forestry plantations is restricted on the national scale. The amount of contaminated land that can be used for biomass production is too limited to substantially influence the bioelectricity shares and welfare. The welfare function does not include, however, the additional environmental benefits coming from the phytoremediation characteristics of willow and forestry plantations.

Fifth, utilizing contaminated and degraded land significantly influences the production of willow. Also the Forestry sector can benefit from cheap contaminated and degraded land. It indeed increases its land area but since this sector is very large, this increase is limited in terms of percentage production change. Utilizing the contaminated and degraded land is beneficial not only for willow and forestry plantation, but also for traditional agricultural commodities producers. In the policy scenarios, where the additional land is included (specification ‘b’), the agricultural producers have more land available for production compared to the specification without additional land (specification ‘a’). Thus, we observe that utilizing the additional land can reduce the pressure on the agricultural production, though the impact is small. The availability of contaminated land induces mostly a reallocation of resources among the sectors; for instance, less willow and forest is grown on clean lands.

Sixth, by looking at the trade patterns of bioelectricity we can conclude that net export of bioelectricity increase substantially for all scenarios. This is easily explained by the differences in price of bioelectricity in Poland and on the world market. The European Union and other trade partners benefit here from the internal Polish policies as more bioelectricity becomes available at a low price. There is virtually no change in the trade level between the 'a' and 'b' specification, which means that the utilization of the contaminated and degraded land has almost no influence on the trade pattern of bioelectricity.

Seventh, in the current model setup and scenarios without foreign environmental policy, it seems that without utilizing the contaminated land, Poland will not be able to produce enough cheap biomass to fulfill both its own targets and export large quantities. This situation changes with technology development, e.g. the breeding of willow that leads to increased biomass yields per hectare. According to our simulations, moderate increases in yields may induce large changes in exporting quantities of willow. Moreover, when the European Union adopts energy policies that stimulate the use of biomass in the EU, Poland can benefit from this by exporting large quantities of biomass when it aligns its own energy policies to the changes in the international context; the large increase in production levels of biomass as observed in our scenarios confirms this. According to our analysis, in the present situation of agricultural productivity in Poland the net export of willow can be assured only when the contaminated and degraded land is taken into the production, and/or the level of the bioelectricity subsidy is relatively low. With an increased level of bioelectricity subsidy, Poland becomes a net biomass importer as the high demand for fuel by the Bioelectricity sector is partly fulfilled by an import of cheap biomass from abroad. This result is different to the result presented in e.g. van Dam et al. (2005a,b). They performed scenario analysis for future (2030) biomass potentials, some of the scenarios assuming a strong intensification and rationalization of Polish agriculture, resulting in high availability of land for biomass production and high biomass production and export potentials. Moreover, they did not analyze the impact of the economic incentives that are currently given to agricultural and forestry producers. The EU subsidies scheme in Poland favors afforestation practices over the production of dedicated biomass crops, moreover the internal Polish policy goals aim in afforestation of most of the marginal areas (UKIE, 2004; Nilsson et al., 2006; Ericsson et al., 2006).

Finally, we conclude that the option to grow biomass on very suitable and suitable contaminated land is a profitable one: the policies implemented in the base version of the model lead to a full adoption of these lands, whether they are lightly contaminated, heavily contaminated or devastated. Furthermore, only small increases in productivity in the biomass sectors suffices to make production on moderately suitable contaminated land profitable. This implies that only marginally suitable contaminated land will not have an economic potential, but that all other land categories can be used in the pursuit of a transition to sustainable energy.

CHAPTER 6

Economic impacts of biomass based material substitution and resource cascading systems*

Due to more stringent energy and climate policies, it is expected that several traditional chemicals will be replaced by biomass-based substitutes. These innovations, however, can influence land allocation, since the demand for land dedicated to specific crops might increase. Moreover, it can have an influence on traditional agricultural production. In this paper, we use an applied general equilibrium framework, where we include two different bio-refinery processes, namely i) Press and ii) Refiner, and biomass cascading mechanism. The bio-refinery processes use grass to produce bio-nylon and 1,3PDO to substitute currently produced fossil fuel-based nylon and 1,2EDO. We examine the impact of specific climate policies on the bioelectricity share in total electricity production, land allocation, and production and prices of selected commodities. The novel technologies become competitive, with an increased stringency of climate policies. This switch, however, does not induce a higher share of bioelectricity. The cascade does stimulate the production of bioelectricity, but it induces more of a shift in inputs in the bioelectricity sector (from biomass to the cascaded bio-nylon and 1,3PDO) than an increase in production level of bioelectricity. We conclude that dedicated biomass crops will remain the main option for bioelectricity production; the contribution of the cascade system remains limited. Given the parameters used in the model, the Bioelectricity sector looses a competition with bio-refineries for biomass inputs.

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* Ignaciuk, A. M. and J. Sanders, 2006. Economic impacts of biomass based material substitution and resource cascading systems, s*ubmitted.*

6.1 Introduction

The increasing pressure of climate agreements to reduce CO_2 emissions, and expected negative trends of fossil fuel energy supply call for alternatives that decrease the overall use of fossil fuels (Azar and Rodhe, 1997; Schneider and McCarl, 2003). One has to remember, that fossil fuels used for electricity and heat purposes account for more than 65% of total fossil fuel consumption. The rest is used for transportation fuels (~20%) and for chemicals and fertilizers production (~15%). Many developments are taking place in the energy sector to substitute fossil resources by alternative energy sources e.g. biomass, wind or solar. It is expected that besides fossil fuels for the energy sector also fossil fuels for traditional chemicals production are going to be replaced by biomass based substitutes (Boeriu et al., 2005). As consequence, the demand for land dedicated to specific crops might increase. This pleas for a more detailed analysis of how innovations in the biomass production and multifunctional biomass systems can influence land allocation, food production, land and food prices and bioelectricity and chemical sectors.

Recently, there is an increased recognition of the potentials of so-called bio-refinery systems. These systems use the molecular structure of biomass in order to extract high value components that can substitute fossil fuel components commonly used in chemical or petrochemical sectors. Often, many of the chemical compounds that have a complex synthesis route in the petrochemical industry can be produced from biomass origin. Sanders et al. (2005) claim that especially functionalized chemicals, chemicals containing apart of carbon and hydrogen, also nitrogen, oxygen, sulphur, phosphate and/or other types of elements, are most suitable for bio-based production.

In our paper, we focus on two issues. First, we analyze the impact of climate policies on the substitution process of fossil fuel based chemicals; namely ethane-diol (1,2EDO), and nylon by their respective grass-based substitutes: propane-diol (1,3PDO), and bio-nylon. Second, we investigate whether incinerating disposed 1,3PDO and bio-nylon can influence the potential of bioelectricity production. Specifically, we focus on the influence of the so-called cascade system on land allocation, and we examine whether indeed cascading can reduce the pressure on productive land. Moreover, we examine how those systems affect agricultural and biomass production and prices of food and energy.

Two different types of bio-refinery systems are studied here namely 1) the Press process, and 2) the Refiner process. They use grass as a main input to produce animal food, 1,3PDO and bio-nylon. It is important to mention that both processes analyzed in this paper, the ‘Press’ process and the ‘Refiner’ process, are in the experimental phase. We do not envisage that in the near future these processes can be operated on a large scale without further steps in their development. Is expected, that the first small-scale factory to produce bio-nylon is accomplished in 2006 (Kamm and Kamm, 2004). Similar technology, also based on press techniques, but using corn instead of grass is currently running in the USA. The production costs are, however, too high for European conditions to further develop this technique. The input of grass instead of corn is anticipated to substantially influence the production costs.

The innovative aspect of this study lies in the analysis of two different types of multifunctional biomass systems: i) material substitution, and ii) cascading, within a general equilibrium framework. We hope to improve understanding of how these processes can influence the electricity market and to what extent they indeed can increase the overall environmental performance and decrease the pressure on productive land.

An interesting characteristic of a bio-refinery system is its multiproductivity. It is often possible to produce two or more products, using one type of biomass. For over 150 years bio-refinery systems were built mainly for food applications e.g. starch from potatoes or wheat, but also sugar from beet or cane, and they produced a relatively high amount of waste products. Currently, with high prices for waste dumping and relatively low prices of food products, there is a need to explore the stream of bio-refinery residuals. The firm Nedalco developed a technology that allows for the production of ethanol, additional to wheat starch production (Balogh et al., 2005). Cargill produces a polylactic acid (PLA) additionally to sugar from corn (Boswell, 2001). Both chemicals, ethanol and PLA, can be produced on a large scale to substitute products currently manufactured using oil derivatives; ethanol is used in the chemical sector and PLA is used as a polymer for packaging purposes of e.g. electronic equipment. In such a manner the bio-refinery systems increase the efficiency of biomass products and substitute fossil fuel based materials.

New promising technologies are developed, using the principles of bio-refinery processes, to produce two different chemicals; 1,3PDO and bio-nylon. 1,3PDO can substitute oil-based 1,2EDO that is currently used on large scale in polymer polyethylene terephthalate (PET). 1,3PDO has similar properties to 1,2EDO and can be used as a building block of a polymer polypropylene terephthalate (PTT), which in the future can be a main building bloc of plastic bottles known as PET bottles (Dupont/Genecor, 2001). Bio-nylon can substitute traditional nylon that is commonly used in e.g. the textile industry. Cheap raw materials from biomass refineries are required for different type of processes e.g. for Caprolactam from sugar, developed by DSM. It is anticipated that these processes could also use grass material as an input and separate the valuable proteins (used as a feed material) from a liquid fraction containing the leftover chemicals (Hulst et al., 1999; Ketelaars, 1999) from which both 1,3PDO (Dupont/Genecor, 2001) and bio-nylon (Raemakers-Franken et al., 2005) can be extracted after fermentation processes. The use of grass in these processes is desired due to it’s relatively low costs as compared to e.g. sugar beet and wheat (both of similar properties), low price and is commonly abundant resource (Andersen and Kiel, 2000; Kamm and Kamm, 2004; Wachter et al., 2004).

Combining the bio-refinery system with the so-called cascading system can stimulate the reduction of GHGs via two routes; i) by substituting the fossil-fuel based materials (bio-refinery) and ii) by directly substituting fossil fuel input in the electricity sector (cascading). The word 'cascading' originates from the analogy of water cascade, where the water is descending from one level to another. In the beginning of nineties, Sirkin and Ten Houten (1993) used this terminology for the first time in context of biomass resources. During the lifetime of the materials, they are used for different applications, ending up as waste to energy, exploiting full potential of a resource (Reijnders, 2000; Dornburg and Faaij, 2005). Cascading systems were originally proposed to increase the efficiency of virgin materials and to store CO_2 in materials. It turns out that it can also be a possible solution to reduce land requirements and increase the potential of cheap wastes that can be used in e.g. the electricity sector.

The potential effects of a number of cascades on CO_2 emission reduction has been analyzed in a number of studies. Fraanje (1997b; 1997a) analyzes several cascading possibilities for different biomass crops. He proposes the sequential cascading of pine wood in five or six steps that allows for a delay in CO_2 emissions for around 300 years (Fraanje, 1997a). Two other biomass crops for which cascades design are proposed are hemp and reed. Fraanje (1997b) argues that with a proper cascade, one can extend a lifetime of hemp from 3 to 60 years and of reed from 30 to 80 years. More detailed analyses of a wood-based cascade were performed by Borjesson and Gustavsson (2000). They describe the situation where concrete can be replaced by wood products in the building sector in Sweden. They focus, as well, on the emission delay aspect during the whole life time of a wooden product. They found out that under certain circumstances the cascading options do not reduce the overall CO_2 emissions, and on the contrary, the emissions might increase. Dornburg and Faaij (2005) analyze different type of wood-base cascades and compare them to their reference systems, systems that are currently used. They conclude that one of the most important factors in the methodology is the choice of a reference system. They found out that only in the shade of a reference system one can conclude whether the CO_2 emissions increase or decrease. Moreover, they conclude that the implementation of a cascade might potentially increase land prices.

6.2 Model specification

To analyze the specific objectives of our study, we extended the applied general equilibrium model (AGE) described in Ignaciuk et al. (2005). It distinguishes 37 production sectors, including 8 agricultural and biomass sectors, and the traditional electricity and the bioelectricity sectors. As is typical in AGE models, all markets clear, which means that supply equals demand for all goods through adjusting relative prices (Ginsburgh and Keyzer, 1997).

In the model *producers* are assumed to maximize profits subject to the available production technologies. Production technologies are represented by nested constant elasticity of substitution (CES) functions, following Rutherford and Paltsev (2000); for more detail see Ignaciuk et al. (2005). In the model, bioelectricity is almost a perfect substitute to traditional electricity. The main difference is that bioelectricity uses biomass, agricultural and forestry products instead of fossil fuels as inputs.

The representative *consumer* in the model is assumed to maximize utility under the condition that expenditures do not exceed income. Consumers own production factors, consume produced goods, and respond to changes in relative prices and their income. Labor supply is fixed, while the wage rate is fully flexible. In contrast, capital supply is assumed to be flexible, adjusting to the fixed price. All taxes are collected by the government, which uses them to finance public consumption and pay lump-sum transfers to the consumer. EU subsidies for Polish farmers are modeled as well, for more detail see Ignaciuk et al. (2005) and Ignaciuk and Dellink (2006).

The model is specified for a small open economy and applied to Poland. We choose the Armington specification for traded goods. It is based on the assumption that domestic and foreign goods are imperfect substitutes, to allow for a difference in prices between domestically produced goods and their international substitutes and to avoid full specialization (De Melo and Robinson, 1989; Devarajan and Go, 1998).

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

The emissions of the major greenhouse gases (GHGs), CO_2, N_2O and CH_4, are included, all expressed in CO_2 equivalents. CO_2 emissions enter the production and utility function assuming a fixed relation with fossil fuel use, differentiated by fuel. In contrast, CH_4 and N_2O emissions are directly linked to output. For more detail see Ignaciuk et al. (2005). Environmental policy is implemented by auctioning a limited number of emission permits by the government. The government collects the revenues and recycles them as a lump-sum transfer to the consumers. This way of modeling environmental policy ensures that a cost-effective allocation is achieved (Dellink, 2005).

6.2.1 Bio-refinery

To represent the new technologies, the Press process and the Refiner process, two latent technologies are implemented in the model. In the benchmark, these production functions are inactive, because those technologies are currently not available in Poland. The Press process uses the produced goods (intermediate deliveries) grass (ID_{grass}^{press}), oil (ID_{oil}^{press}) and electricity (ID_{elec}^{press}) and production factors labor (L^{press}) and capital (K^{press}) to produce the multiple outputs: i) bio-nylon ($Y_{bio-nyl}^{press}$), and ii) feed for animal sector (Y_{anim}^{press}).[23] To produce these goods also emission permits ($E_{CO_2}^{press}$) are needed, due to the oil requirements needed in the production process.

$$CET(Y_{bio-nyl}^{press}, Y_{anim}^{press}; \sigma_{CET}^{press}) = CES(ID_{grass}^{press}, OL_{oil}^{press}, ID_{elec}^{press}, KL^{press}; \sigma_{CES}^{press}) \quad (1)$$

[23] We use a stylized notation for constant elasticity of transformation (CET) and constant elasticity of substitution (CES) functions by identifying the outputs and inputs, respectively; each separated by a comma and then providing the elasticity, separated by a semicolon. This completely describes the function; see Ignaciuk et al. (2005). The notation is extended here to account for the fact that different processes may produce the same outputs. The novel processes are indicated in the functions via a superscript.

with lower level CES functions $OL_{oil}^{press} = CES(ID_{oil}^{press}, E_{CO_2}^{press}; \sigma_{oil}^{OL})$, and $KL^{press} = CES(K^{press}, L^{press}; \sigma_{press}^{KL})$.

The CET function is represented with elasticity equal to zero, to reflect that the multiple outputs are created in fixed proportions. This process can be used on a small scale and it requires relative low investment costs, at least compared to the Refiner process. The transportation distances can be minimized, and thus the emissions related to the transportation process. The efficiency of the Press process is however smaller than the efficiency of Refiner.

The second process, the Refiner process, uses the same inputs as the Press process, and it produces besides the animal feed and bio-nylon additionally 1,3PDO ($Y_{1,3PDO}^{refiner}$). As mentioned this process requires high investment costs, however it is very efficient, and one factory can transform large quantities of grass (Sanders, 2006).

$$CET(Y_{bio-nyl}^{refiner}, Y_{1,3PDO}^{refiner}, Y_{anim}^{refiner}; \sigma_{CET}^{refiner}) = CES(ID_{grass}^{refiner}, OL_{oil}^{refiner}, ID_{elec}^{refiner}, KL^{refiner}; \sigma_{CES}^{refiner}) \quad (2)$$

with embedded CES functions $OL_{oil}^{refiner} = CES(ID_{oil}^{refiner}, E_{CO_2}^{refiner}; \sigma_{refiner}^{OL})$, and $KL^{refiner} = CES(K^{refiner}, L^{refiner}; \sigma_{refiner}^{KL})$.

Nylon and bio-nylon are almost perfect substitutes, and similarly 1,2EDO is almost perfectly substituted by 1,3PDO. Substitution elasticities between the traditional nylon and 1,2EDO with their biomass substitutes are very high; we have chosen a value of 10 in both cases.

6.2.2 Cascading

Grass can also be one of the inputs into the Bioelectricity sector, but with the current cost structure of grass production, and its relatively high content of water, it is not the most desired input. However, if we explore the full value of grass and grass products, the disposed 1,3PDO and bio-nylon products can be used for bioelectricity production. Both bio-nylon and 1,3PDO can be used after a certain life span as a cheap fuel for bioelectricity production.

As our model is static, we do not model the introduction of the cascade, but rather simulate the ‘steady-state’ that will emerge after some time, by assuming that the production of these products equals the disposal.

In Poland most of the plastic PET bottles are currently dumped, but we envisage that it can be possible to recover part of the PTT bottles and use them as an input in the bioelectricity. One of the possible solutions is to introduce a deposit system for such bottles and collect them back at the shops. Such a system works for most glass bottles in Poland. Similarly, the bio-nylon products can also be recovered at e.g. special recovery stations. It is unlikely that all 1,3PDO and bio-nylon can be recovered with such systems; therefore, we incorporate a recovery rate that is less than one.

Taking the ‘steady-state’ situation together with the recovery rate, we have a new output from the bio-refinery processes, which consists of organic matter. It can be used as a substitute for biomass in the production of bioelectricity. If we label this new output from the cascade as $Y^{j}_{cascade}$, then we can link that to the production of 1,3PDO and bio-nylon:

$$Y^{j}_{cascade} = rr_{1,3PDO} \cdot ec_{1,3PDO} \cdot Y^{j}_{1,3PDO} + rr_{bio-nyl} \cdot ec_{bio-nyl} \cdot Y^{j}_{bio-nyl} \quad (3)$$

where *rr* represents the recovery rate and *ec* the energy content of commodity *i*, respectively and $j \in \{press, refiner\}$. Note that this equation is different for both processes because the amounts of 1,3PDO and bio-nylon produced are different (the Press process does not produce 1,3PDO at all); the recovery rates for both processes are assumed equal though, as these are not related to the production process, but to the produced good. The recovery rates of bio-nylon and of 1,3PDO are different, though.

Furthermore, equations (1) and (2) become:

$$CET(Y^{press}_{bio-nyl}, Y^{press}_{anim}, Y^{press}_{cascade}; \sigma^{press}_{CET}) = CES(ID^{press}_{grass}, OL^{press}_{oil}, ID^{press}_{elec}, KL^{press}; \sigma^{press}_{CES}) \quad (1')$$

$$CET(Y^{refiner}_{bio-nyl}, Y^{refiner}_{1,3PDO}, Y^{refiner}_{anim}, Y^{refiner}_{cascade}; \sigma^{refiner}_{CET}) = CES(ID^{refiner}_{grass}, OL^{refiner}_{oil}, ID^{refiner}_{elec}, KL^{refiner}; \sigma^{refiner}_{CES}) \quad (2')$$

where $Y^{j}_{cascade}$ represents the new outputs through the cascade for both processes. This new output enters the production function of the Bioelectricity sector as a potential input.

6.3 Data and parameters

To determine the benchmark equilibrium, a Social Accounting Matrix (SAM) for Poland is adopted, based on GTAP5 data for 1997 (Dimaranan and McDougall, 2002). In the SAM, agricultural and biomass data are disaggregated based on the FEPFARM model built by Mueller (1995), using FAO (2005) land use data for Poland. The FEPFARM model provides the shares of production costs. Substitution elasticities between the different inputs in the production and utility functions are specified based on Kemfert (1998), Rutherford and Paltsev (2000), Kiuila (2000) and Dellink (2005). Data on land use patterns and emissions are obtained from Polish statistics (GUS, 2002b,2002a,2002d).

The parameters and characteristics that we use on the latent technologies, for the Press and the Refiner processes are summarized in Table 6.1. These data are based on own calculations as derived from Kamm and Kamm (2005) for the Press process, and from Sanders (2006) for the Refiner process. The assumption are based, to a large extent, on the data obtained from currently running large-scale factory Agro-Ferm A/S in Denmark, where the nylon precursor, *lysine*, is produced by fermenting the grass juice (Kiel, 2005). 1,3PDO is a by-product in the production processes from the grass fibers that are obtained in the Refiner process. The first bio-refinery that will produce 1,3PDO starts up in 2006 (Reardon and Adams, 2005). Due to our model specification we assume that the production costs are equal to the market prices. Both proteins and fodder go to the Animal sector.

Finally, we assume a recovery rate for 1,3PDO of 70% and of bio-nylon of 50%. The recovery rates implicitly capture the costs involved with transporting the cascade products by assuming that only a portion of the materials can be sold to the Bioelectricity sector.

Table 6.1 Cost and output structure of the Press and the Refiner processes

	Press process	Refiner process
	Input in Euro per t DW of grass	
Grass	25.5	25.5
Oil	4.2	10
Electricity	4.5	12.5
Labor	14	23
Capital	23	95
	Output per t of grass (in kg DW)	
Nylon precursor	100	100
1,3PDO		125
Proteins	180	350
Fodder for animals	550	

6.4 Scenarios

We present four policy scenarios aimed at increasing the share of bioelectricity in total demand for electricity and at reducing CO_2 emissions. There are two policy mechanisms for each scenario. For the first mechanism, we adopt a restriction on the number of emission permits auctioned by the government. This way of modeling environmental policy is not meant as policy recommendation but ensures that a cost-effective allocation is achieved (Dellink, 2005). For the second mechanism, we apply a bioelectricity subsidy rate for bioelectricity production. This allows us to investigate at which level of climate policy the national targets for bioelectricity use are achieved. Polish policy makers set goals concerning an increase of bioelectricity share in total electricity production to 7.5% by 2010 and 14% by 2020. Following Ignaciuk et al. (2005), we consider the introduction of the tradable GHGs emission permits for various policy levels (in reduction steps of 10%), combined with the adoption of a bioelectricity subsidy of 25%.

The following scenarios are investigated:

- **Scenario 1**: Policy simulation *without Press and Refiner*
- **Scenario 2:** Policy simulation *with Press and Refiner without cascade*
- **Scenario 3:** Policy simulation *with Press and Refiner with cascade*
- **Scenario 4:** Policy simulation *with clean Press and Refiner with cascade*

The clean processes assumed in scenario 4 differ from the processes described in Section 2 by assuming that the processes do not need emission permits and that they use bioelectricity instead of 'traditional' electricity.

6.5 Results and discussion

Activity of the new processes

As shown in Table 6.2, the Press process produces only a minor part of all nylon; the cascade and clean production method (scenarios 3 and 4) and a more stringent environmental policy (50% emission reduction) do stimulate the production in the Press process, but this process is clearly dominated by the Refiner process. The Refiner process takes over all nylon production, even at relatively low levels of environmental policy (20% emission reduction) and without the cascade. Note that at a policy level of 10% emission reduction, the Refiner process is not competitive. Thus, we can conclude that the better environmental characteristics of this process explain its success at more stringent policy levels. Moreover, it is also producing large amounts of 1,3PDO and can replace the traditional 1,2EDO process. Thus, we can conclude that the new technologies clearly have a chance to become competitive.

Table 6.2 Shares of different processes in total production of nylon (&bio-nylon) and 1,2EDO (&1,3PDO) (in %)

	20% Emission reduction				*50% Emission reduction*			
	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4
Share of the conventional nylon production	100	0	0	0	100	0	0	0
Share of Press in nylon production	0	0	0	1	0	0	4	8
Share of Refiner in nylon production	0	100	100	99	0	100	96	92
Share of the conventional 1,2EDO production	100	10	0	0	100	0	0	0
Share of Refiner in 1,3PDO production	0	90	100	100	0	100	100	100

Bioelectricity shares

Figure 6.1 presents the influence of the implementation of the scenarios on the share of bioelectricity in total electricity production. The results show that for all scenarios, the shares of bioelectricity in total electricity production are virtually the same.

The first Polish policy goal of 7.5% bioelectricity share in total electricity production is reached with around 10% emission reduction and 25% subsidy level for bioelectricity, for all scenarios. The more stringent goal of 14% requires more ambitious climate policy of 25% emission reduction and 25% subsidy level for bioelectricity.

All the lines in Figure 6.1 have a kink at a 10% emission reduction level, which can be attributed to the introduction of biomass subsidy that does not exist in the benchmark. This leads to an instant increase in the bioelectricity share and is an essential part of the strategy to achieve the national policy targets for the share of bioelectricity in total electricity production (see Ignaciuk et al., 2005). For Scenarios 3 and 4, the Refiner process starts to produce nylon and 1,3PDO that can be used in the Bioelectricity sector (via the cascading mechanism), also in the benchmark situation. This explains why the bioelectricity shares are slightly higher for those two scenarios, than for scenarios 1 and 2 at the beginning.

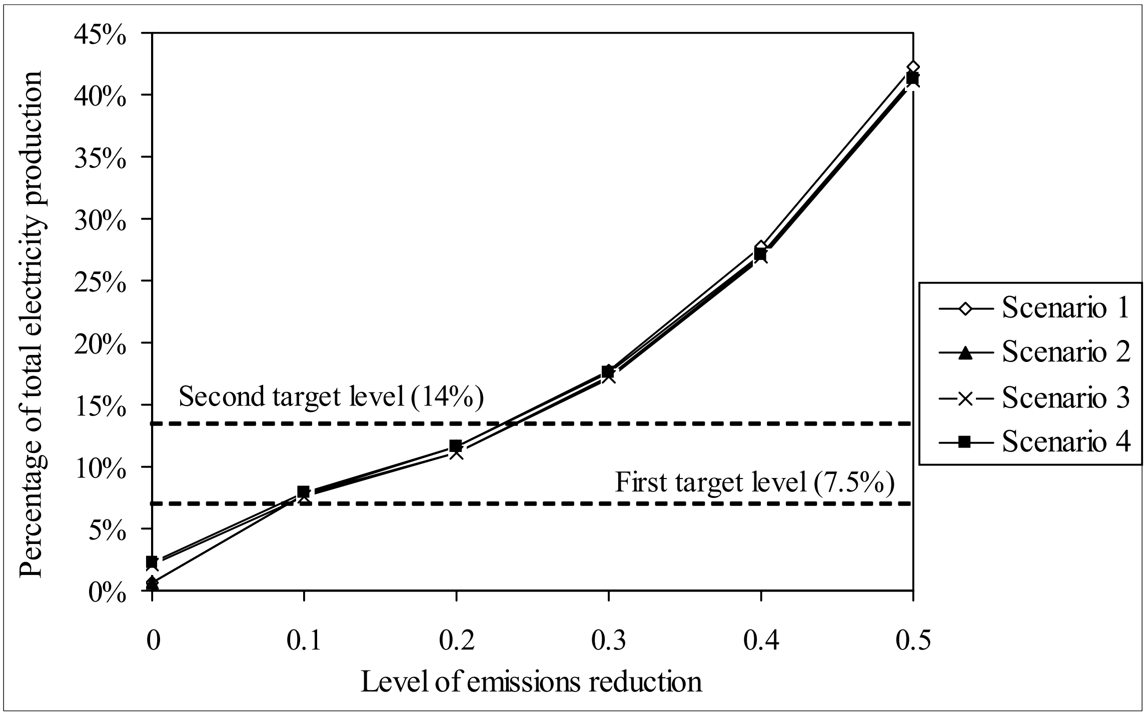

Figure 6.1 Bioelectricity share for all scenarios for different levels of GHGs emissions reduction

Utility change

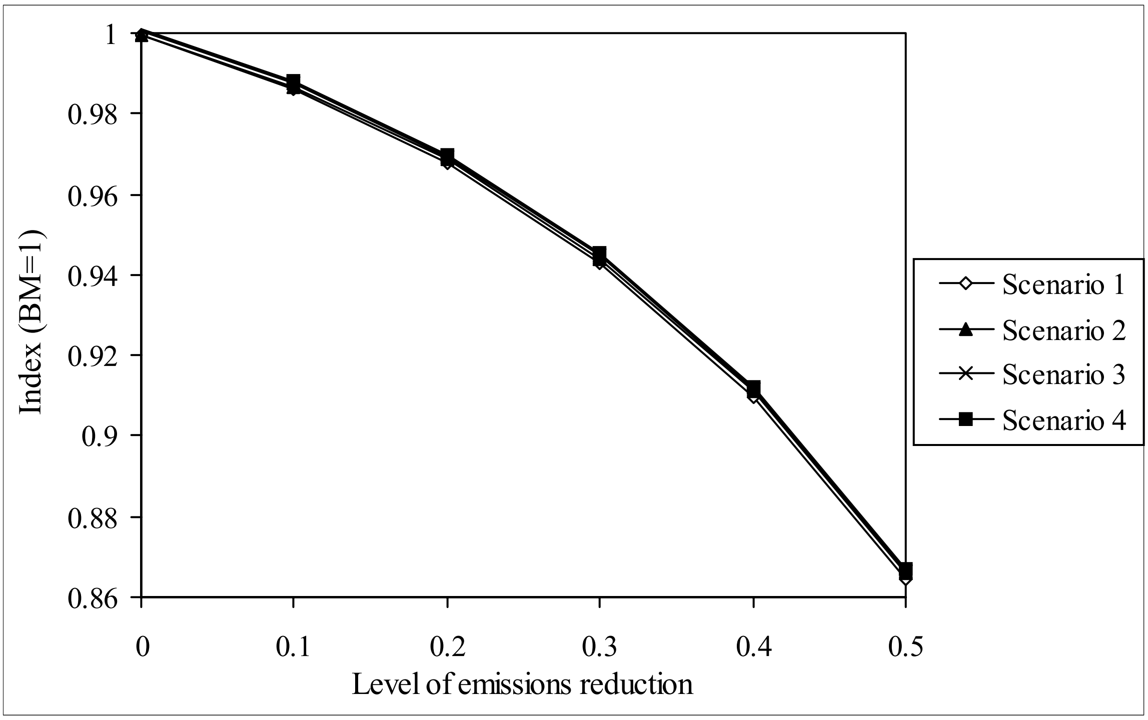

Figure 6.2 Utility change for all scenarios for different levels of GHGs emission reduction

Figure 6.2 presents the welfare impacts for all scenarios, at different levels of emission permit reduction. Clearly, the environmental policy leads to welfare costs. It should be stressed that the environmental benefits of these policies are not taken into account in this measure of welfare, and hence it cannot be concluded whether these policies are justified. The welfare costs of these policies tend to be decreasing more than proportionately with increasing stringency of environmental policy.

The impacts are virtually the same for all scenarios, showing that substituting oil intensive materials and using cascades cannot mitigate the welfare costs of renewable energy policies, in the cases analyzed.

Production

Table 6.3 comprises the results of production changes for two emission reduction levels. The economy adapts to the reductions in allowed emissions by switching towards (i) 'clean' energy; (ii) 'clean' production; and (iii) 'clean' consumption. Since the Bioelectricity sector is very small compared to conventional Electricity sector, it has to grow considerably to achieve the policy targets. It increases to around 1500% of its benchmark production for a 20% emission reduction, for all scenarios. Note that for all scenarios a subsidy on bioelectricity of 25% is foreseen. The production factors such as labor and capital, which are used to intensify the production of the Bioelectricity sector, come mainly from the declining Electricity sector.

For a 20% emission reduction level, it is interesting to compare the results between Scenario 1 and Scenario 2. For Scenarios 1 and 2, the total production of nylon (traditional nylon and bio-nylon) decline with 5%, and production of 1,3PDO (sum of 1,2EDO and 1,3PDO) decline with 3%. In Scenario 1 both nylon and 1,2EDO are produced using oil-intensive technologies, in Scenario 2 there is a mixtures between old and new technologies (a combination of 1,2EDO and 1,3PDO is produced). Because the Refiner process is activated in Scenario 2, we can see a strong increase in grass production, an input that substitutes oil for bio-nylon and 1,3PDO production. Since grass is produced using land, its production increases at the expense of other land intensive sectors e.g. forestry, rape, willow and hemp. Because those sectors decrease their production, the total production of bioelectricity in Scenario 2 is smaller than in Scenario 1. Being able to exploit the cascading mechanism, and obtain, cheap disposed nylon and disposed 1,3PDO, from the Refiner process, in Scenario 3 the total bioelectricity production increases, compared to Scenario 2. The demand for cheap old products (bio-nylon and 1,3PDO) increases further the production of grass and decreases the production capacity of more traditional biomass crops. The Bioelectricity sector substitutes further the traditional biomass inputs for the 'old' products of the Refiner process.

Since the Refiner process uses oil, with more stringent environmental policies, it decreases its production. With a 50% of emission reduction, despite the 'new' technology for nylon and 1,3PDO production, the total production of those commodities decreases. In Scenario 1, where traditional nylon and 1,2EDO are produced, the decrease in production is the strongest, 18% for both nylon and 1,2EDO. In Scenario 2, the production of those goods declines as well, but since the traditional nylon and 1,2EDO can be replaced by their respective substitutes, the overall decline in production is smaller, 7% and 17% for nylon and 1,3PDO, respectively.

Table 6.3 Changes in the production in selected sectors with 20% and 50% emission reduction for all scenarios (% change compared to benchmark)

		20% Emission reduction				*50% Emission reduction*			
	BM	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4
	mln €		in %	change			in %	change	
Other Agriculture	6123.1	-4	-4	-4	-4	-17	-17	-17	-17
Grass	373.7	-4	5692	6823	7032	-15	5493	6449	7119
Rape	96.3	44	41	26	27	179	173	158	157
Willow	0.007	1205	396	346	344	2785	1455	1447	1334
Hemp	0.002	42	17	0	0	22	4	0	-2
Wheat	1514.3	-4	-4	-4	-4	-14	-15	-15	-15
Other Cereals	1440.7	2	2	0	0	6	5	4	4
Forestry	1109.9	5	4	2	2	20	17	15	15
Petrochemicals	3888.3	-29	-29	-29	-29	-71	-71	-71	-71
Chemicals	18335.0	-3	-3	-3	-3	-11	-11	-11	-11
Nylon	102.3	-5	-3	16	19	-18	-7	8	16
1,2EDO &1,3PDO	138.6	-3	-5	2	4	-18	-17	-9	-6
Electricity	6441.7	-18	-17	-17	-18	-54	-53	-52	-53
Bioelectricity	44.7	1469	1419	1427	1479	4950	4806	4813	4838
Industry	125777.3	-5	-5	-5	-5	-16	-15	-15	-15
Services	140074.2	-3	-3	-3	-3	-13	-13	-13	-13

As expected, with the cascading mechanism (active in Scenario 3), the production of both bio-nylon and 1,3PDO decreases the least, compared to Scenarios 1 and 2. Assuming that the bio-refinery processes, instead of fossil fuels and traditional electricity, use biomass based oil and bioelectricity (Scenario 4), the production of bio-nylon and 1,3PDO increases, in case of a 20% emission reduction policy. With a 50% emission reduction, the overall production of bio-nylon and 1,3PDO decreases as well, though less strongly compared to the other scenarios. To substitute oil in the Refiner and Press processes, a relatively large productive area is used for grass production, initiating a strong competition for this resource. Other land intensive sectors have to decrease their production.

The Bioelectricity sector uses different types of biomass in all scenarios. In Scenarios 1 and 2 it uses mainly traditional agricultural and biomass crops with an input of forestry products, and in Scenarios 3 and 4 a combination of those crops with the disposed products of the Refiner process (old bio-nylon and 1,3PDO). The disposed products of the Refiner process are not an addition to the overall biomass supply to the Bioelectricity sector, as expected. The production of grass influences substantially the production of the dedicated energy crops. The production of willow, hemp, or forestry in Scenarios 2-4, decreases relatively to their production levels from Scenario 1, where the Refiner process is inactive, and where the grass production is on a similar level to its benchmark level. This does not support the hypothesis that the availability of cheap disposed bio-nylon and 1,3PDO can reduce the competition for land. On the contrary, an increasing demand for grass reduces production potentials of dedicated biomass crops and traditional food crops, since they loose a competition for land with grass.

At the end, substituting the fossil fuels by grass in the Refiner process reduces the overall GHGs emissions. Using the disposed products of this process as an input in the Bioelectricity sector, however, induces more emissions related to the land use, since the grass production is more energy and fertilizers intensive compared to e.g. willow or forestry production. It seems that this type of cascading mechanisms does not contribute to the overall GHGs reduction, as strongly as was originally expected, to a reduction of the pressure on productive land, but it just offers different trade-off possibilities to use current agricultural land.

Prices

The policies adopted in the model induce price changes. The impact of the emission reduction policies on the relative price level for a selection of goods is presented in Table 6.4. Generally, the prices of dirty goods rise compared to the prices of cleaner goods, as the production costs for the dirty sectors increase substantially due to the expensive emission permits. The price of bioelectricity decreases relatively to other prices, because it benefits from a subsidy.

Table 6.4 Prices of selected commodities (after taxes and subsidies) with 20% and 50% emission reduction for all scenarios (% change compared to benchmark)

	20% Emission reduction				*50% Emission reduction*			
	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4
Other Agriculture	4	4	4	4	13	13	13	13
Grass	3	16	17	18	7	15	15	16
Rape	-1	0	0	0	-1	-1	-1	-1
Willow	3	20	22	23	12	24	24	26
Hemp	31	39	41	41	67	77	77	78
Wheat	1	1	1	1	2	3	3	3
Other Cereals	1	2	2	2	5	5	5	5
Forestry	0	0	0	0	0	1	1	1
Petrochemicals	8	8	8	8	33	33	33	33
Chemicals	-1	-1	-1	-1	-2	-2	-2	-2
Nylon	6	2	-37	-41	25	-11	-38	-49
1,2EDO &1,3PDO	6	6	-15	-19	25	21	-10	-19
Electricity	7	7	7	7	25	25	25	25
Bioelectricity	-20	-20	-20	-20	-22	-22	-22	-22

The large decrease in the price of bioelectricity, compared to electricity, drives the large switch in demand for electricity to bioelectricity, as can be observed from the production changes reported in Table 6.3. This switch is not, however, complete, as we assume both goods are imperfect substitutes.

The price of willow increases substantially in Scenarios 2-4. This price increase is dictated mainly by an increase in the land prices. Hemp price is higher than the price of willow; it increases additionally because the Hemp sector uses more fertilizers, and hence, has to pay for the emission permits. Due to an increased demand for grass, the grass production increases. Since, there is no extra land available, it starts to grow on the land currently attributed to biomass and traditional agricultural crops. Despite this increased pressure on productive land, the prices of agricultural commodities increase to a limited extent. Since the agricultural sector is generally much larger, compared to the biomass sector, the changes in the land use have smaller effect on the prices of food. Moreover, the arable agricultural sector in Poland is relatively clean in terms of GHGs emission (the use of fertilizers is relatively low in Poland) in comparison to most industrial sectors. Hence, it requires few emission permits and so there is a relatively small need for reducing demand for these goods. Absolute levels of employment in the agricultural sector will remain roughly equal, and capital use will decline less than output. Thus, agricultural production intensifies. Smaller sectors, like Hemp and Willow, cannot accommodate so easily the changes in the land price level. They are much more influenced by changes on other markets.

The price of bioelectricity falls with the same percentage across different scenarios, at particular emission permit reduction levels. As mentioned, the price decreases compared to its benchmark level due to the subsidy this sector receives. There are, however, other mechanisms that play a role in price establishment. In Scenario 1 the traditional agricultural and biomass crops are relatively cheap. In the Scenarios 3 and 4 the prices of traditional biomass crops increase, however, substantially. The Bioelectricity sector, partially substitutes from the input of relatively expensive traditional biomass crops by using the cheap old products of the refiner process.

Table 6.5 Prices of land with 20% emission reduction for all scenarios (in Euro per year)

		20% Emission reduction			
	BM	sc1	sc2	sc3	sc 4
Very good quality land (z1)	91.4	76.0	96.8	102.6	104.8
Good quality land (z2)	66.4	67.5	96.8	102.6	104.8
Poor good quality land (z3)	37.1	50.4	96.8	102.6	104.8
Forestry land (z4)	37.1	49.0	56.4	45.5	46.6

Table 6.5 presents the price levels of different land types; we observe an increase in prices for good (type z_2), poor (type z_3), and forestry (type z_4) land types in Scenario 1 and of all land types in Scenarios 2-4. Note that in the general equilibrium setting only relative prices matter: as the demand for very good land increases less than demand for lower class land types (or it even decreases), the relative price of very good land decreases compared to lower quality land. The price decrease in absolute terms has to be interpreted as a decrease compared to the numéraire, the consumer price index. Generally, however, the mechanism of the price increase is caused by several factors. First, as mentioned, the increased demand for grass induces larger pressure on productive land, and more biomass crops are demanded by the Bioelectricity sector.

Table 6.6 Land use (in 1000 ha) with 20% and 50% emission reduction for all scenarios

			20% Emission reduction				*50% Emission reduction*			
		BM	sc1	sc2	sc3	sc4	sc1	sc2	sc3	sc4
Other Agriculture	Z1	102.4	99.4	84.8	82.9	82.3	82.1	71.8	71.7	70.6
	Z2	1839.5	1750.0	1476.5	1442.8	1432.6	1429.1	1249.8	1248.1	1229.0
	Z3	997.8	922.8	756.2	738.9	733.7	731.9	640.1	639.2	629.4
Hemp	Z1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Z2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z3	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Willow	Z1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	2.5	2.2	2.2	14.5	7.7	7.6	7.0
	Z3	0.5	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wheat	Z1	87.4	84.3	71.8	70.2	69.6	69.6	60.8	60.7	59.7
	Z2	1570.1	1484.5	1249.8	1221.1	1211.4	1211.9	1058.0	1056.4	1039.4
	Z3	897.7	825.1	674.7	659.2	653.9	654.2	571.1	570.3	561.1
Other Cereals	Z1	218.6	224.7	190.7	182.5	181.4	217.2	188.8	185.5	182.5
	Z2	3894.5	3925.8	3292.6	3151.6	3131.9	3750.0	3259.0	3202.9	3151.1
	Z3	2301.1	2255.1	1836.9	1758.2	1747.2	2092.0	1818.1	1786.8	1757.9
Rape	Z1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	349.4	493.2	413.1	361.2	361.7	880.3	754.4	712.1	699.8
	Z3	87.3	119.8	97.5	85.2	85.3	207.7	178.0	168.0	165.1
Grass	Z1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z3	53.9	46.3	2252.9	2644.0	2706.7	34.6	2051.7	2400.0	2611.9
Forestry	Z4	8769.0	8931.2	8769.0	8769.0	8769.0	9794.1	9259.7	9059.7	9004.5

The large demand for biomass crops primarily increases the pressure on z_2 and z_3 and the additional production of the Forestry sector puts an upward pressure on z_4. However, due to the fact that the demand for z4 type land depends on the forestry sector itself, generally the prices of forestry land stays on lower level than on the other types of land. With increasing stringency of climate policy, all the land prices tend towards the same price. This effect is governed by the possibilities to use different land types for producing different crops: biomass crops will first be grown on poor land, but can use better land types as well, and agricultural land can be converted to forestry land. These substitution possibilities tend to even out the differences in land prices between the different types.

Land use

Table 6.6 presents the land allocation for all scenarios at 20% and 50% emission reduction levels. In Scenarios 3 and 4, there is the highest reallocation of land compared to the other scenarios, in line with the changes in economic activity of the land intensive sectors, for the 20% emission reduction. For the 50% emission reduction, the Refiner process is active also in Scenario 2, and it influences strongly the land allocation as well.

With an impact of climate policies, of 20% emission reduction, there are small differences in land use allocation between Scenario 1 and Scenario 2. However, in Scenario 3, there are large changes in land use, due to a large increase in demand for grass by the Refiner process. This increase is caused mainly by an increased demand for fuels by Bioelectricity sector, and since the cascade delivers cheap used bio-nylon and 1,3PDO, there is an increased demand for these products. The situation looks different with the stringent policy impact, 50% emission reduction. In Scenario 2, the demand for cleaner chemicals, like bio-nylon and 1,3PDO, induces large demand for grass, despite the fact that no cascading mechanism is possible in this scenario. The substitution mechanisms, which are allowed between traditional nylon and 1,2EDO with their respective substitutes, compromise the use of the energy crops.

Because the production of grass increases drastically, the production area of other crops is restricted. Willow and Hemp ‘lose’ the competition for land with grass, but other traditional agricultural sectors also became smaller. The forestry area stays on a level similar to the benchmark level, for 20% emission reduction. For 50% emission reduction it increases slightly.

6.6 Conclusions

In this paper, we analyzed the effects of GHGs emission reduction policies combined with a subsidy on Bioelectricity production, on the Polish economy. We focus on the impacts of material substitution and cascading mechanisms, of grass based substitutes of nylon and 1,2EDO, on production and prices of various commodities and resulting land use allocation. For this purpose, we use an applied general equilibrium model and calibrate it to Poland. We incorporate two latent technologies that allow for bio-nylon and 1,3PDO production, the Press and the Refiner processes (that are still in the development phase), to monitor the changes in the economy when more substitution possibilities of oil-based products to their respective biomass-based substitutes are possible. To analyze the impacts of re-using bio-nylon and 1,3PDO as an input into bioelectricity, a cascade mechanism is applied.

Before drawing conclusions, we would like to mention some of the major caveats of our model. First, we address the issue in a comparative-static manner. We are not able to conclude when the new situation occurs, and we abstract from adaptation problems associated with the introduction of the new technologies. Secondly, the economy adapts to the changes induced by the policy measures by the means available in the model. There are other possible ways to reduce greenhouse gas emissions that are not included in our model, e.g. use of tree planting for pure CO_2 sequestration purposes, or implementing other renewable energy technologies. However, the choice of possible energy developments is in line with the policy expectations for Poland. Thirdly, one should keep in mind that the model is a stylized representation of the economy, and though it is calibrated using the best available data, numerical results from the simulations should be interpreted with sufficient care. Fourthly, we do not deal explicitly with the costs involved with biomass transportation distances. Moreover, we deal here with technologies that are not implemented yet and the real production costs and production quantities may vary from the ones that we obtained based on field studies and information in the literature. Despite these limitations, we would like to highlight some interesting results.

First of all, regardless of the choice of the technology, Poland reaches its national policy goals of achieving 7.5% bioelectricity shares in total electricity production within a 10% emission reduction level and a 25% bioelectricity subsidy. The more stringent goal of 14% can be reached with a 25% emission reduction in combination with a 25% bioelectricity subsidy. This of course, comes at a cost, of around 1.5% of welfare loss to reach the first target and around 4% of welfare loss to reach the second Polish targets.

Secondly, the novel technologies become competitive and are introduced in the production structure. The Refiner process will be able to outcompete the traditional processes used to produce nylon and 1,2EDO. This switch does not induce a higher share of bioelectricity, however. The reason for this is that the refiner process requires large amounts of grass, which will compete with food and biomass for scarce land.

Thirdly, it seems that with the assumed production structure for bio-refinery processes, productive land is first dedicated to biomass for the bio-based chemicals production and than for biomass for the Bioelectricity sector. An increasing demand for grass reduces production potentials of dedicated biomass crops and traditional food crops.

Fourthly, when environmental policy becomes more stringent, and these processes are enhanced with a cascade, the Press process can compete with the Refiner process, and both new technologies will become profitable. The cascade does stimulate the production of bioelectricity, but it induces more of a shift in inputs in the bioelectricity sector (from biomass to the cascaded bio-nylon and 1,3PDO) than an increase in production level of bioelectricity. Combining the cascade with a clean production process for Press and Refiner can stimulate production using these processes, but the effect is limited.

Finally, we can conclude that dedicated biomass crops will remain the main option for bioelectricity production. More advanced systems as analyzed in this paper may, however, contribute to some extent in the transition towards sustainable (energy) production, as they stimulate bio-based production processes that replace oil, once the product turns to waste material, and can be used to produce bioelectricity.

CHAPTER 7

Summary and conclusions

7.1 Introduction

Biomass is one of the potential sources for sustainable energy production. It can contribute to a policy to combat climate change (i) by reducing greenhouse gas emissions via direct substitution of fossil fuels for energy purposes and/or replacing fossil-fuel based material, and (ii) by sequestering carbon in soils and in bio-materials. Moreover, it can contribute to (iii) the security of energy supply that plays an important role in the energy policies of the European Union. Finally, biomass plantations can, under certain circumstances, assist in achieving other environmental policies, e.g. (iv) contribute to the improvement of soil and water quality, (v) improve the landscape and (vi) provide a habitat to species.

Increased demand for energy crops, due to diverse international climate agreements, or to national policies, may induce a pressure on currently productive agricultural land. There is no consensus in the literature over to what extent those energy plantations may affect food production and land use. However, it is important to keep in mind that both food and energy crops require land. Therefore, an economic analysis of the potential for biomass energy, taking into account land availability and productivity of biomass plantations, is needed. Moreover, it is important to investigate whether food production and prices are affected by the increased demand for biomass. A second key aspect that might limit biomass production is its relatively high production cost as compared to fossil fuels, especially for crops from dedicated energy plantations; biological waste materials or by-products of agricultural production are much cheaper. Since there is only a limited amount of residuals and ‘good-quality’ wastes available, the high price of pure energy crops might be an obstacle.

For countries in the European Union, it can be interesting to allocate biomass production in Central and Eastern Europe, where, compared to Western Europe, there is more land available that can be used for this purpose. Moreover, the agricultural sector in Eastern Europe is in the phase of modernization. Together with new technologies, such as multifunctional biomass systems, this can reduce the competition for land and increase the economic potential for biomass.

As argued above and in more detail in Chapter 1, there is a need for a detailed, quantitative economic analysis of multifunctional biomass systems and their impacts on the agricultural and other production sectors in the economy, greenhouse gases (GHGs) emission reductions, land use patterns and international trade.

Therefore, the major research question of this thesis is: *"What are the impacts of energy policies and large-scale multifunctional biomass systems on biomass and bioelectricity production, land use, agriculture and the rest of the economy?"* To answer this research question, four research questions were formulated. Research question 1: "*Which types of multifunctional biomass systems can be applied on a large-scale?*" needs to be addressed first. Different types of 'multifunctional biomass systems' have been discussed in this thesis, depending on the crop or technology characteristics e.g. i) multi-product use, ii) multifunctional biomass plantations, iii) material substitution and iv) cascading. *Multi-product use* is defined as using a crop that can be split into two or more different parts that are used for different applications. One part of the crop can be used as input to energy production, and the other for e.g. material applications or food. *Multifunctionality* of biomass plantations stands for multiple uses of land dedicated to biomass, from which the main purpose is energy production. The term *material substitution* is used when biomass resources substitute fossil-fuel based resources and *cascading* means the subsequent use of biomass for a number of applications, exploiting the full potential of biomass product. The general characteristics of all these systems are discussed in Chapter 1 and followed up in Chapters 4-6 depending on the analyzed biomass system.

Secondly, a proper quantitative methodology has to be determined for analyzing the impact of energy policies on biomass production and on other sectors of the economy with explicit attention to land use and interactions between different markets, as formulated in the research question 2: "*What quantitative methodology, including model type and specification, is capable of analyzing the economics of multifunctional biomass systems?*". After a general discussion on model types in Chapter 1, this is elaborated in Chapters 2 and 3, where applied partial equilibrium and general equilibrium model specifications are used, respectively.

Thirdly, the role of multifunctional biomass systems is important to assess. Based on the literature, expert opinions and the quantitative analysis in this thesis, different types of systems are defined and analyzed in terms of research question 3 "*To what extent can multifunctional biomass systems improve the efficiency of biomass production and reduce the pressure on productive land?*". To shed light on research question 3, Chapters 4-6 deal with the impact of the different multifunctional biomass systems on land use, bioelectricity and agricultural production; in Chapter 4, the focus is on multi-product use, in Chapter 5 on multifunctional biomass plantations and in Chapter 6 on material substitution and cascading. At the same time these chapters assess research question 4: "*What are the impacts of multifunctional biomass systems on the allocation of resources in the economy?*". Besides the focus on biomass and the agricultural sector, also the impact on other sectors of the economy and trade is dealt with in Chapters 4-6.

The case study country is Poland, a European Union country with large potentials for biomass production. Poland is characterized by relatively low prices for land and labor, compared to most Western European countries, and has a large scope for further improvement of the agricultural sector, with potential benefits for biomass plantations.

Section 7.2 discusses the major finding chapter by chapter, while Section 7.3 formulates conclusions in the form of answers to the research questions. Then, Section 7.4 identifies some more general conclusions for policy, and Section 7.5 concludes with the recommendations for further research.

7.2 Summary of the major findings

Chapter 2 deals with the impact of energy policies on biomass and traditional agricultural production with special attention to GHG emissions, and land use in a partial equilibrium framework. The model captures the most important mechanisms that govern the interactions between agriculture and biomass in the presence of a tax on conventional electricity and a tax on carbon. Two policies are tested: (1) an electricity tax, and (2) a carbon tax. Both policies are analyzed in three different settings: (a) without subsidies, (b) with a subsidy on bioelectricity and (c) with a subsidy on biomass production. To be able to make consistent comparisons between these scenarios, an equal yield tax reform is applied by redistributing any remaining additional government income from the environmental policy to the private households in a lump-sum manner.

The results show that the electricity tax in combination with the bioelectricity subsidy can achieve the Polish goal to increase the share of bioelectricity to 7.5% in the year 2010, under the assumptions of the model specification. The carbon tax induces an increase in bioelectricity shares as well, but to a smaller extent. As expected, the bioelectricity shares are the highest when bioelectricity production is subsidized, for all scenarios. All policies are welfare reducing, though it should be noted that the environmental benefits are not taken into account in the utility function, and thus these welfare costs only represent the economic costs of the policy. Looking at the effects of the taxes on food prices and production quantities, one can see distinctive differences. An electricity tax stimulates the reallocation of labor and capital to both the agricultural and biomass sectors, which causes an intensification of production for both sectors and hence their production increases (by around 5% for a tax rate of 10%). The situation looks different in the carbon tax scenario. In general, the emission intensive sectors decrease their production. Since agricultural production emits GHGs as well, this sector becomes smaller (by around 2% for a carbon tax rate of around 25%). The clean biomass and bioelectricity sectors can profit from the new policies in all scenarios.

Prices of agricultural commodities increase, in all scenarios, though in the electricity tax scenario to a lesser extent than in the carbon tax scenario. Generally, this price increase is very limited (0.2% to 2.2%). Land use changes towards more land allocated for biomass crops, but the changes are very limited in both scenarios, for the specification without subsidies and for the specification with bioelectricity subsidies. A relatively large area of land is dedicated to biomass production in both scenarios for the specification with biomass subsidies: around 60 thousand and 50 thousand hectares additionally are dedicated to biomass under the electricity tax and carbon tax scenario, respectively. 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 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.

Chapter 3 analyses the impact of diverse energy policies on sectoral production and prices of different commodities, with special attention to biomass and agricultural sectors, similarly to Chapter 2. Moreover, it also analyzes international trade patterns and land use changes that are triggered via the policy impulses. However, a more elaborated methodology is used to perform the analysis: an applied general equilibrium (AGE) modeling framework. This implies not only that all sectors in the economy are taken into account, but also that the economy is modeled as a fully closed cycle: all financial and physical flows have a source (origin) and a sink (destination). For instance, the partial equilibrium model in Chapter 2 does not contain a full budget balance for the consumers. In the AGE model, in Chapter 3, the scenarios concentrate on a system of tradable emission permits, rather than on taxes. The scenarios include various levels of emission reduction by limiting the number of permits issued, combined with (1) a lump-sum redistribution of permit revenues, (2) a subsidy on biomass, and (3) a subsidy on bioelectricity. All three scenarios are analyzed in unilateral and multilateral settings and assume ex post equality in the provision of public goods via an endogenous lump-sum transfer between households and government.

From a comparison of the results it is clear that subsidizing bioelectricity (Scenario 2) increases its share the quickest, compared to the other scenarios. This scenario is also the least costly in welfare terms, compared to the other two. With a 10% emission reduction implemented through a tradable emission permit system and a 25% subsidy on bioelectricity, the first Polish policy target of 7.5% bioelectricity share in total electricity production can be reached. To reach the same target using a subsidy of 25% on biomass instead of the bioelectricity subsidy, the required emission reduction equals 30%. In the scenario without additional subsidies, to reach the first policy target, around 50% of emissions have to be reduced. For a 10% emission reduction level, there is a limited decrease in food production (in all cases less than 3%) for all scenarios, but the smallest losses occur in the scenario where biomass is subsidized. The prices of agricultural goods increase, but our results show much smaller price increases (max 2%) than some other studies, because the reallocation of labor and capital allows for an intensification of agricultural production. In contrast to most partial equilibrium models in the literature, the partial equilibrium model in Chapter 2 also contains closure of the factor markets via the income definition of the private households, for those factors that are active in analyzed part of the economy; the large part of the budget, however, is fixed. Therefore, the price changes in Chapters 2 and 3 are comparable. The proposed energy policies also influence the land allocation of Poland: the area devoted to forestry and biomass plantations can increase substantially, provided that a subsidy scheme is included. In the multilateral specification, the target shares of bioelectricity are reached faster than in the unilateral specification, as the specialization effect is more pronounced. However, the permit prices are higher, due to the fact that Poland cannot import cheaper dirty goods from the Rest of the World.

Chapter 4 investigates the economic impact of multi-product crops. Multi-product crops are crops that can be used partially for energy production and partially for other purposes, such as food or materials. In this chapter, the focus is to what extent the multi-product crops can decrease the pressure on productive land, and what is their impact on production and prices of agricultural commodities. To facilitate the analysis, the model builds directly on the model developed in Chapter 3, thereby allowing for an explicit comparison of a scenario with and a scenario without multi-product crops. Central to the investigation in this chapter is to what extent those by-products can influence the shares of bioelectricity in total electricity production. It turns out that implementation of multi-product crops in the form of utilizing agricultural by-products as biomass source increases the share of bioelectricity by around 2%-points compared to the situation where those by-products are not used, for each level of emission reduction. Equivalently, around 5%-points less emission reductions are needed to achieve the same share. The results clearly show that utilizing by-product contributes to increase the bioelectricity share, but that there are not enough by-products to reach the energy goals for Poland without using dedicated biomass systems. Using by-products has very limited effects on food production and prices. Under both scenarios there is an increase in the acreage of forestry and biomass plantations. Those changes are more distinct in the multi-product scenario, where there is an incentive to produce forestry goods, due to (i) large EU subsidies for afforestation, and (ii) considerable amounts of possible by-products that can be used in the Bioelectricity sector.

Chapter 5 focuses on multifunctional biomass plantations. Food crops cannot grow on land that is contaminated with heavy metals, due to potential health hazards, but biomass crops can and can even clean up contaminated land through a process called phytoremediation. Therefore, the impacts of energy policies (the combination of emission permit reduction and bioelectricity subsidy, financed in different manners) are analyzed in an extension of the model from Chapter 3 where contaminated land is accounted for. The current area of contaminated land in Poland is rather small, and thus changes in bioelectricity shares in total electricity production are also limited; however phytoremediation can play a role in reducing the pressure on productive land. Clearly, biomass plantations can benefit from the availability of cheap contaminated and degraded land, even when additional costs have to be made to make these land types suitable for production, as long as these additional costs are not too high. In all scenarios, the production of agricultural crops decrease by max 3% and the food prices increase by max 2%, assuming a 20% bioelectricity subsidy level and 10% GHGs emission reduction. Interestingly, the utilization of contaminated and degraded land impacts the trade pattern of biomass. Without utilizing the contaminated land, and when the bioelectricity subsidies are high, Poland will import cheap biomass from the rest of the world to satisfy the large domestic demand; however, when utilizing the currently non-productive land, Poland's supply of biomass can increase substantially and thus biomass can be exported. This may have positive impacts not only for Poland, but for the entire European Union.

Chapter 6 analyses the potential influence of biorefinery and cascading systems on the economy, with a focus on land use and agricultural production. The model from Chapter 3 is extended by i) introducing two novel biorefinery technologies, the Press and the Refiner processes, that produce bio-nylon and 1,3PDO, which are grass-based substitutes for nylon and 1,2EDO, respectively, and ii) cascading mechanisms for grass-based products. With 20% GHG emission reduction, the relative prices change such that the Refiner process is more efficient than the traditional processes used to produce nylon and 1,2EDO. This switch does not induce a higher share of bioelectricity, however, as the Refiner process requires large amounts of grass that compete with food and biomass for the scarce land. When environmental policy becomes more stringent, and these processes are enhanced with a cascade, the Press process can compete with the Refiner process, and both new technologies can become profitable. The cascade does stimulate the production of bioelectricity, but it induces more of a shift in inputs in the Bioelectricity sector (from biomass to the cascaded bio-nylon and 1,3PDO) than an increase in the production level of bioelectricity. Combining the cascade with a clean production process for Press and Refiner can stimulate production using these processes, but the effect is limited. Dedicated biomass plantations remain the main determinant of the possibility to produce clean electricity. The more advanced systems, however, contribute to some extent in the transition towards a sustainable energy production, as they stimulate bio-based production processes that replace oil and can be used to produce bioelectricity.

7.3 General conclusions from the analysis

7.3.1 Conclusions on multifunctional biomass systems

To formulate the general conclusions based on this thesis, the specific research questions that were posed in the Introduction chapter have to be answered. The first question, research questions 1, refers to: "*Which types of multifunctional biomass systems can be applied on a large scale?*"

Several multifunctional systems are analyzed in Chapters 4-6 according to their potentials to increase the share of bioelectricity in total electricity production, and the potentials to reduce the pressure on productive land. The choice of these systems was based on the following criteria: (i) low production costs, (ii) high energy potential, (iii) low land-input demands, (iv) no detrimental environmental effects, and (v) high potential for CO_2 reduction.

Based on the literature review and on expert opinion, the following by-products were chosen: straw of cereals, rape, other agricultural crops, and forestry residuals. These by-products are produced in large quantities in Poland, securing surplus biomass for the Bioelectricity sector.

Moreover, the technologies based on the input of straw and forestry residuals are well known and used on a small scale already.

Since in Poland there are some areas of contaminated and degraded land available, the exploration of the phytoremediation characteristics of willow plantations and forestry was chosen that allow for utilization of the land currently taken out of production (Chapter 5).

In Chapter 6, two new biorefinery technologies were analyzed that have the potential to use grass to produce bio-nylon and 1.3PDO that can substitute currently produced fossil fuels based nylon and 1.2EDO, respectively. Both technologies are in the development phase, though they are very promising. It is, however, not expected that in the near future these technologies can be applied on a large scale.

While it is clear that all these multifunctional biomass systems can be adopted, albeit not all on a large scale, an economic analysis is required to assess the potential that these systems have to contribute to the transition towards a sustainable energy supply. The answers to research questions 3 and 4 shed more light on this issue.

7.3.2 Conclusions for modeling

In order to derive some conclusion for modeling, it is useful to summarize the modeling approaches used in the different chapters. In Chapter 2 a partial equilibrium model is constructed and in Chapters 3-6 an applied general equilibrium model is constructed, starting from a relatively simple (Chapter 3) to a more detailed and complex model (Chapter 6). The model in Chapter 3 describes the Polish economy and the relationships between different sectors, with disaggregated agricultural, biomass and electricity sectors. In Chapter 4, the first of the multifunctional biomass systems, multiproductivity of agricultural, biomass and forestry production, is tested. This requires modeling of multiple outputs to simulate by-products, and creation of latent technologies, i.e. technologies that are not used in the benchmark. An external subsidy system is included as well, to simulate the influence of European Union policies on the Polish economy. Based on the model in Chapter 3, the model is extended further in Chapter 5 to include the contaminated and degraded land that currently is not used for food production due to its heavy metal contamination. Several latent production functions for willow and forestry are added in this chapter. Chapter 6 involves further disaggregation of agricultural, biomass and chemical sectors. Two latent technologies, representing two different biorefinery processes are added. The multi-product output of both Press and Refiner processes is specified. Moreover, a cascading system is modeled, that allows using products, which are produced in the biorefineries, as biomass for bioelectricity production. These cascades can easily be extended to other applications. In all chapters, different policy instruments are tested, with focus on the modeling of tradable emission permit markets and different tax and subsidy options.

Based on these approaches, research question 2 "*What quantitative methodology, incl. model type and specification, is capable of analyzing the economics of multifunctional biomass systems?*" can be answered.

The comparison of the partial equilibrium approach in Chapter 2 and the general equilibrium approach in Chapter 3 reveals that the general equilibrium effects of environmental policies cannot be neglected: there are important interactions between the produced goods markets and the factor markets that imply that a general equilibrium framework leads to a superior analysis. However, these mechanisms can to a large extent also be built into an advanced partial equilibrium framework, as shown in Chapter 2. Therefore, the differences in results between Chapter 2 and 3 are smaller than one might imagine a priori. The use of nested constant-elasticity-of-substitution (CES) functions generates flexible production functions that can capture substitution possibilities between different inputs in a detailed manner, and thus allow a realistic approximation of production technologies. Moreover, this approach can easily be extended to a multiple-output setting by using constant-elasticity-of-transformation (CET) functions.

The extended analyses of different multifunctional biomass systems were carried out in the general equilibrium setting to secure that important secondary effects of the policy impulses and implementation of those systems are properly accounted for. The modeling framework allows for a relatively easy specification of alternative technologies, which are important in the analysis of the multifunctional biomass systems. Different alternative technologies, some of which are not present in the benchmark, can be specified and their productivity can be compared using endogenous prices. Thus, the model allows for an analysis of the conditions under which latent technologies become competitive, for instance in terms of the required level of environmental policy.

An element that requires special modeling attention is the availability of EU subsidies for Polish farmers. These subsidies are fundamentally different from domestic subsidies, as they provide a source of income for an agent in the model, without a corresponding expenditure for another agent. A further complication is that the subsidy rate is fixed, but the total budget needed for the subsidy varies endogenously with the production activities in the Polish economy. This situation is specified through the formulation of a fictitious agent that provides the financial sources for the EU subsidies, for which the utility is not taken into account in the optimization procedure.

Although in the static model the life cycle of products cannot be explicitly modeled, resource cascading can be captured in a crude manner via the modeling of the steady-state situation. The steady-state situation fits well with the underlying assumptions of the comparative-static framework that disregards transition processes from the original equilibrium to the new equilibrium, but rather focuses on the comparison of the two equilibria. The analysis in Chapter 6 shows that the static approximation of the cascade can influence the model results, though the relatively small nature of the cascade under analysis implies that the impacts of the cascade on the results are limited.

7.3.3 Conclusions on the economic potential of multifunctional biomass systems

The next two research questions: "*To what extent can multifunctional biomass systems improve the efficiency of biomass production and reduce the pressure on productive land?*"

(research question 3), and "*What are the impacts of multifunctional biomass systems on the allocation of resources in the economy?*" (research question 4), refer to the economic potential of multifunctional biomass systems.

Depending on the policy goals, different multifunctional biomass systems perform best. For instance, the multi-product crops can substitute fossil fuels as an input in the electricity production, and the use of contaminated and degraded land expands the possibilities for biomass production, and hence secures the biomass supply potential. When energy policy aims at the substitution of fossil fuels based materials, the biorefinery processes perform well. What turns out to be rather difficult is to combine all these goals; none of the multifunctional biomass systems clearly dominates the other systems, and preference for a certain system depends on the weight that is given to the different policy goals The cascading system was proposed to simultaneously: i) substitute the fossil fuels based chemicals, and ii) increase the potential for the biomass input in Bioelectricity sector. This, however, turns to have a limited impact. According to the analysis there is a trade-off between biomass production for the energy purposes and for substituting fossil fuels based materials. This trade-off mechanism is mainly dictated by the competition for the productive land.

Surprisingly, the competition for productive land between the biomass and traditional agricultural crops is not as strong as expected before undertaking this study. All biomass systems studied in this thesis, under the analyzed energy policies, have an impact on quantities and prices of food crops. The impact is, however, rather small, as the current analysis incorporates interlinkages between sector and factor markets that are often overlooked. The prices of agricultural goods increase by a few percent in most cases, in contrast to some earlier studies. The analyzed multi-product options for energy production have a small positive impact on agricultural production; the production quantities of the sectors that produce multiple outputs generally increase, and the prices of goods decrease slightly, compared to the situation where by-products are not available. One has to remember that the analyzed quantities of by-products of agricultural crops and forestry in this thesis are very conservative; if larger quantities of by-products can be extracted, this result can be stronger.

Utilizing the available contaminated and degraded land for biomass and forestry production, has very limited effects on agricultural production. However, it has substantial impacts on the production of biomass and, generally, it slightly reduces the pressure on productive land, since the production of biomass switches to currently non-productive areas. Due to a limited availability of such non-productive areas, it is difficult to further expand biomass production. Introducing the biomass plantations on contaminated and degraded land brings economic and environmental benefits, though as mentioned the impacts are limited.

The cascading systems, in contrast, impose a large pressure on productive land, at the expense of both traditional agriculture and biomass crops. The need for an increased grass production to meet the demands of the biorefineries, reduces the potentials for productive land for other types of land intensive production in the analyzed case studies. Since the agricultural sectors are relatively large compared to the biomass sectors, they can easier accommodate losses of the available productive areas. Biomass production, however, though small in the benchmark, decreases more substantially compared to the situation when the biorefinery and cascading processes are inactive. Moreover, the biorefinery and cascading systems induce an increase in land prices. This, of course, has consequences for the prices of agricultural and, especially, biomass crops, as the competition for scarce land intensifies. Thus, the cascading system can on the one hand contribute to the potential of biomass in the Bioelectricity sector, but on the other hand it increases the demand for land for production of grass at the expense of the traditional energy crops. On balance, total production of biomass-based electricity is roughly the same as in the situation without the cascade. The main environmental benefit reaped by the cascade therefore is its contribution to material substitution.

Overseeing these multifunctional biomass systems, the general conclusion can be drawn that in order to attain the current energy policy targets, dedicated biomass plantations are required. More advanced systems, and refinements of these systems, as discussed above, may contribute to reduce the costs associated with the adoption of the energy policies, or may enhance the associated environmental benefits, but their contribution remains limited. While each dedicated biomass plantation may be small-scale, total production of biomass needs to increase substantially.

Generally, those systems that can improve the productivity of energy, biomass and/or agricultural production, should be implemented first. For instance, exploring the phytoremediation characteristics of biomass plantations and utilizing contaminated land that currently is taken out of production, can benefit land intensive sectors and also the Bioelectricity sector. Hence, the incentive structures should guarantee that this land can be used before expanding the biomass area on currently productive agricultural land. Utilizing by-products of agricultural and forestry production, i.e. utilizing the multi-product characteristics of many crops, also brings benefits to the overall system in terms of not compromising agricultural production and simultaneously providing cheap biomass for energy purposes.

In general, all sectors in the economy adapt once the stringent environmental policies are implemented. As expected, the sectors with zero or relatively low greenhouse gas emissions can maintain their production or even expand, while the dirty sectors decrease their production. Since the Polish agricultural sector is relatively clean, compared to e.g. the industrial sectors, the pressure to reduce the food production is limited. Moreover, the cost for emission permits does not have a very large impact on agricultural commodity prices. The agricultural sector in Poland is in the process of rationalization and, also following to the model results, becomes more efficient in its production processes.

7.4 General conclusions for policy

Poland has ratified the Kyoto protocol, and is expected to easily fulfill the promised GHGs reduction targets. Also with respect to the 2nd Sulphur protocol it decreased its SO_2 intensive production and applied sufficient precautions. Those international targets, however, did not stimulate the bioenergy production in Poland, and they cannot be used as a push towards sustainable energy use. However, since recently, Poland is a member of European Union, and therefore it is obliged to work towards EU environmental regulations that impose lower bounds on the use and production of biomass based fuels and energy. Moreover, Poland imposes its own internal energy targets that stimulate bioelectricity production. However, currently imposed policies are not likely to be sufficient to attain these energy targets. Consequently, the market needs additional incentives to stimulate the production of biomass and bioenergy, and hence it is important to assess the incentive structures that can support the policy goals.

Though this thesis does not aim to compare different policy instruments that can be used to attain the energy targets, and the implementation of specific instruments will depend also on aspects not covered here, including for instance enforcement costs, the modeling framework allows the comparison of different market based instruments.

One of the mechanisms to stimulate cleaner production and stimulate biomass based electricity is through emission permit trading. This instrument has two strong points from a theoretical perspective: tradable emission permits are i) costs-effective and ii) effective. The first characteristic ensures that the targets are reached at minimum costs and the second describes to what extent the government can be sure that the targets are achieved. Though, strictly speaking, cost-effectiveness is not ensured due to the interaction with existing distortionary taxes. It is common to use tradable permits within a general equilibrium setting since they comprise another market that has to be in equilibrium and for which an equilibrium price has to be found. One has to be aware, though, that in reality a market for tradable permits for many small-scale polluters can be difficult and can lead to very high transaction costs. The choice of using this instrument in the model does therefore not imply a policy recommendation. It is chosen because it provides the best reference point and because it fits with the general equilibrium framework.

The reduction of the number of emission permits has to be substantial to stimulate growth of Bioelectricity sector sufficiently to reach the domestic Polish goals. Such a stringent policy induces relatively large welfare losses that can amount to several percent. To reduce the welfare losses and increase the bioelectricity potential simultaneously, the subsidies on biomass and bioelectricity sectors were analyzed. It turns out that both types of subsidies, combined with a relatively low level of emission permit reduction induce an increase in bioelectricity shares at smaller welfare costs. The bioelectricity subsidy instrument turns to be superior to stimulate biomass production, as expected. Interestingly, analyzing the financing mechanisms for the bioelectricity subsidy, the least welfare reducing result was attained from taxing the conventional electricity production and transferring the revenues in a lump-sum manner to the private households. The adoption of an additional reduction of the number of emission permits resulted in larger welfare costs. One has to remember, however, that the environmental benefits are larger when the policy targets emission reduction, though these benefits are not explicitly included in the utility function, and thus welfare costs only comprise the costs of implementing the policies.

Despite reaching national targets, Poland can also contribute to the overall EU targets of increased production of biofuels and biomass based energy. Generally, when Poland reaches its first policy goal of increased bioelectricity shares in total electricity production of 7.5%, it can export its biomass surplus to other countries. However, to reach its second policy goal, without exploring different biomass systems it is difficult to satisfy its own needs for clean bioelectricity and at the same time export Polish biomass. Though generally Poland has a potential to export its biomass, it depends strongly on the level of national policies. Moreover, once stimulating the bioelectricity production via the subsidy mechanisms, Poland can have a choice whether it will be interested in exporting a subsidized product. This discussion, however, goes beyond the focus of this thesis.

Despite the policy instruments implemented to stimulate bioelectricity production and use, the government can decide to stimulate the use of currently non-productive land for biomass production. Moreover, the utilization of the by-products can be also beneficial from both an environmental and welfare point of view.

7.5 Recommendations for further research

Several extensions of the analysis can be envisaged. First, a dynamic model would be able to describe the transition path towards a cleaner economy and indicate the timing of the policy and its impact on the economy, needed to achieve the policy goals. Moreover, with a dynamic specification, the role of phytoremediation of willow plantation can be better assessed, since it could be possible to incorporate that cleaned land becomes available for food production after a certain time frame. For the cascading of resources, a transition path to a steady state situation is not known in the current setting and a dynamic specification would allow an analysis of the introduction phase of the new processes.

Secondly, better quantitative information is needed on the benefits of environmental and energy policies. If the environmental benefits are taken into account in the measure of welfare, the efficient levels of the policies and optimal allocation of resources and production quantities can be determined. Based on this, the proposed policies can be better justified. Similarly, accounting for the additional benefits from implementing the multifunctional biomass systems could improve the evaluation of the welfare impacts on the consumer.

Thirdly, the economy adapts to the changes induced by the policy measures by the means available in the model. There are other options to achieve these policy targets that are not included in our model, such as CO_2 sequestration, the flexible mechanisms mentioned in the Kyoto Protocol, e.g. joint implementation, in order to reduce CO_2 emissions via foreign investment, CO_2 capture and storage technologies and, last but not least, alternative options for clean energy production including the use of wind or solar energy. Though it is arguable to what extent these alternative options can play a major role in the short run, incorporating the full set of available options could certainly improve the results of the model. Moreover, there are limited possibilities to express technological progress that can accelerate reaching the policy targets and can reduce the costs of new technologies.

Fourthly, there is ongoing research to improve existing biomass and bioelectricity technologies and create more possibilities for efficient production of bioelectricity. Continued analysis of these systems is therefore encouraged, especially when they are analyzed in an economic context and compared to existing technologies.

Fifthly, the model does not take into account transportation distances and the associated transportation costs. For instance, transporting biomass requires much larger costs and implies much higher emissions than transporting bioelectricity; the latter can easily be connected to an international grid. For this type of analysis, a spatial model would be very beneficial. A spatial model can also illuminate which regions are most suitable for biomass plantations.

Not withstanding these limitations and caveats, the present analysis sheds light on the economics of multifunctional biomass systems, using an advanced economic framework to investigate the interactions between these systems and the rest of the economy. Given the urgent need for a transition towards sustainable energy use and the high economic stakes involved, these new insights are of utmost importance for scientists and policy makers.

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SAMENVATTING

De economie van multifunctionele biomassasystemen

Menselijke activiteiten leiden tot uitstoot van een aantal vervuilende stoffen, die bijdragen aan milieuproblemen zoals klimaatverandering. In antwoord op deze milieuproblemen is er een stijgende vraag naar schone energie. Biomassa is een van de mogelijke bronnen van een duurzame energievoorziening. Stijgende vraag naar biomassa kan echter leiden tot extra druk op schaarse landbouwgrond. In dit proefschrift wordt een economische analyse uitgevoerd van het potentieel voor energie uit biomassa, met aandacht voor de beschikbaarheid van land en de productiviteit van biomassaplantages. Verder wordt onderzocht in hoeverre voedselproductie en prijzen worden beïnvloed door de stijgende vraag naar biomassa. Multifunctionele biomassasystemen kunnen bijdragen aan efficiëntere productie van biomassa, en kunnen de druk op productief land verminderen.

De onderzoeksvraag van dit proefschrift is: *"Wat zijn de gevolgen van energiebeleid en grootschalige multifunctionele biomassasystemen op de productie van biomassa en bioelectriciteit, landgebruik, landouw en de rest van de economie?"*.

Verschillende typen van 'multifunctionele biomassasystemen' worden in dit proefschrift bediscussieerd, afhankelijk van het gewas of de technologische karakteristieken, zoals i) multi-product gebruik, ii) multifunctionele biomassaplantages, iii) materiaalsubstitutie, en iv) cascades. *Multi-product gebruik* wordt gedefinieerd als het gebruik van een gewas dat gesplitst kan worden in twee of meer verschillende delen die voor verschillende doeleinden gebruikt kunnen worden. Een gedeelte van het gewas kan als input dienen voor de productie van energie, en een ander deel bijvoorbeeld als materiaal of als voedsel. *Multifunctionaliteit* van biomassaplantages behelst het meervoudig gebruik van land waarop biomassa wordt verbouwd, met als primair doel de productie van energie. De term *materiaalsubstitutie* wordt gebruikt wanneer biomassa als substituut dient voor fossiele grondstoffen. *Cascades* zijn het opeenvolgend gebruik van biomassa voor een aantal toepassingen, gebruik makend van het volledig potentieel van het biomassaproduct.

Het toepassingsgebied voor de numerieke analyses is Polen, een lid van de Europese Unie met een groot potentieel voor de productie van biomassa. Polen wordt gekarakteriseerd door relatief lage prijzen van land en arbeid, in vergelijking met de meeste West-Europese landen, en heeft een grote potentie voor verbetering van de landbouwsector, met mogelijke voordelen voor biomassaplantages. In 2001 heeft de Poolse overheid doelstellingen geformuleerd ten aanzien van een stijging van het aandeel van bioelectriciteit in de totale electriciteitsproductie tot 7,5% in 2010 en 14% in 2020.

Hoofdstuk 2 behandelt de gevolgen van energiebeleid voor de productie van biomassa en traditionele landbouwgewassen met speciale aandacht voor de uitstoot van broeikasgassen en landgebruik. Een partieel evenwichtsmodel is gebruikt als basis van de berekeningen. Het model bevat de belangrijkste mechanismen die de interacties tussen landbouw en biomassa bepalen, in aanwezigheid van een heffing op conventionele electriciteit of een heffing op de uitstoot van broeikasgassen (emissieheffing). Beide vormen van beleid worden geanalyseerd in drie varianten: (a) zonder aanvullende subsidies, (b) met een subsidie op bioelectriciteit, en (c) met een subsidie op de productie van biomassa. De resultaten laten zien dat door een heffing op electriciteit, in combinatie met een bioelectriciteitssubsidie, de Poolse doelstelling om het aandeel van bioelectriciteit te laten stijgen tot 7,5% in 2010 kan worden bereikt, onder de veronderstellingen van de modelspecificatie. Een emissieheffing leidt eveneens tot een toename van het aandeel van bioelectriciteit, maar minder sterk. Zoals verwacht zijn deze aandelen in beide scenario's het hoogst als de productie van bioelectriciteit wordt gesubsidieerd. Alle varianten leiden tot een lager niveau van welvaart, waarbij moet worden aangetekend dat de milieubaten van het beleid niet meegenomen worden in de nutsfunctie. Een electriciteitsheffing stimuleert de landbouw en biomassasectoren. Door de emissieheffing daalt de productie van sectoren met een relatief hoge uitstoot van broeikasgassen; aangezien de landbouwsector ook broeikasgassen uitstoot krimpt deze sector ook onder dit beleid. De schone biomassa en bioelectriciteitssectoren kunnen profiteren van het nieuwe beleid in alle scenario's. In alle scenario's stijgen de prijzen van landbouwgewassen, maar minder in het scenario met de electriciteitsheffing dan in het scenario met de emissieheffing. Over het algemeen zijn deze prijsstijgingen zeer beperkt tenzij de productie van biomassa wordt gesubsidieerd. Ten aanzien van de uitstoot van CO_2 is de electriciteitsheffing niet zo effectief als de emissieheffing, zoals verwacht. Voor de uitstoot van N_2O zijn de verschillen tussen beide scenario's verwaarloosbaar. De verschillende subsidievarianten beïnvloeden de uitstoot van beide broeikasgassen substantieel: een subsidie op de productie van bioelectriciteit leidt tot de grootste reductie in uitstoot van CO_2, terwijl een subsidie op biomassa het meest effectief is voor reductie van de uitstoot van N_2O.

In *hoofdstuk 3* wordt een uitgebreidere methodologie gebruikt om de gevolgen van diverse vormen van energiebeleid te analyseren: een algemeen evenwichtsmodel. Het belang van uitbreiden tot een algemeen evenwichtsmodel zit besloten in het meenemen van verschillende terugkoppelmechanismen die de gevolgen van het energiebeleid beïnvloeden en die niet meegenomen kunnen worden in een partieel evenwichtsmodel. In hoofdstuk 3 is het beleid geïmplementeerd via een systeem van verhandelbare emissierechten, in plaats van via heffingen. De scenario's bevatten verschillende niveaus van reductie in uitstoot door middel van het verminderen van het aantal emissierechten dat wordt uitgegeven, in combinatie met (i) een 'lumpsum' terugsluizing van de opbrengst van de rechten, (ii) een subsidie op biomassa, en (iii) een subsidie op bioelectriciteit. Alle drie scenario's zijn geanalyseerd in de context van een unilateraal en een multilateraal energiebeleid. De vergelijking van het partieel evenwichtsmodel in hoofdstuk 2 met het algemeen evenwichtsmodel in hoofdstuk 3 laat zien dat de algemeen evenwichtseffecten niet verwaarloosbaar zijn. De onderliggende terugkoppelmechanismen kunnen echter grotendeels ook in een geavanceerd partieel evenwichtsmodel worden ingebouwd, zoals hoofdstuk 2 laat zien. De verschillen in resultaten tussen hoofdstuk 2 en 3 zijn daarom kleiner dan men *a-priori* zou verwachten.

Met een vermindering van de uitstoot van 10% door middel van verhandelbare emissierechten en een subsidie van 25% op de productie van bioelectriciteit kan de eerste Poolse doelstelling van 7,5% aandeel van bioelectriciteit in de totale electriciteitsproductie worden gehaald. Om dezelfde doelstelling te halen met een subsidie op biomassa in plaats van op bioelectriciteit is de benodigde vermindering van het aantal emissierechten 30%. In het scenario zonder aanvullende subsidies moet de vermindering van het aantal emissierechten ongeveer 50% bedragen. Voor een vermindering van het aantal rechten met 10% is de daling in de productie van traditionele landbouwgoederen beperkt (in alle gevallen minder dan 3%), maar de kleinste daling treedt op als biomassa wordt gesubsidieerd. De prijzen van landbouwgoederen stijgen, maar veel minder (maximaal 2%) dan in sommige andere studies wordt gesuggereerd, omdat de herallocatie van arbeid en kapitaal een intensivering van de landbouwproductie bewerkstelligt. Het voorgestelde energiebeleid beïnvloedt ook het landgebruik in Polen: het areaal dat gebruikt wordt voor bosbouw en biomassaplantages neemt fors toe, onder voorwaarde dat een subsidie wordt verstrekt. In de multilaterale specificatie wordt de doelstelling voor het aandeel van bioelectrictiteit sneller gehaald dan in een unilaterale specificatie, aangezien het specialisatie-effect naar een duurzame energievoorziening sterker is. De prijzen van de verhandelbare emissierechten zijn echter hoger, aangezien Polen sterk vervuilende producten niet meer goedkoop kan importeren.

Hoofdstuk 4 beschrijft een uitbreiding van het model en analyseert de economische gevolgen van 'multi-product'-gewassen. Dit zijn gewassen die deels voor energieproductie kunnen worden gebruikt en deels voor andere doeleinden, zoals voedsel of als grondstof. Het blijkt dat het inzetten van multi-product gewassen in de vorm van het nuttig gebruik van bijproducten uit de landbouw als bron van biomassa het aandeel van bioelectriciteit met ongeveer 2 procentpunt doet toenemen voor elk niveau van emissiereductie. Met andere woorden, ongeveer 5 procentpunt minder emissiereductie is nodig om hetzelfde aandeel bioelectriciteit te bereiken. De resultaten laten duidelijk zien dat het benutten van bijproducten bijdraagt aan de productie van bioelectriciteit, maar dat er onvoldoende bijproducten beschikbaar zijn om de energiedoelstellingen van de Poolse overheid te halen zonder specifieke biomassaplantages. Het benutten van bijproducten heeft een gering effect op de productie van voedsel en relatieve prijzen. Zowel zonder als met multi-product gewassen kan het areaal voor bosbouw en biomassaplantages worden uitgebreid. Deze uitbreiding is groter in het multi-product scenario, waarin een grotere stimulans optreedt om het areaal bosbouw uit te breiden, door (i) grote EU-subsidies voor bebossing en (ii) substantiële hoeveelheden bijproducten die kunnen worden gebruikt voor de productie van bioelectriciteit.

Hoofdstuk 5 richt zich op multifunctionele biomassaplantages. Voedsel kan niet worden verbouwd op grond die vervuild is met zware metalen, vanwege de potentiële gezondheidsrisico's, maar biomassa kan daar wel worden verbouwd. De vervuilde grond kan dan zelfs schoon worden door middel van een proces dat phytoremediatie heet. Daarom wordt in dit hoofdstuk een uitbreiding van het model uit hoofdstuk 3 gepresenteerd waarin vervuilde grond is opgenomen. Het huidig areaal vervuilde grond is niet groot en dus zijn de gevolgen van deze uitbreiding voor het aandeel bioelectriciteit beperkt. Phyotoremediatie kan echter een rol spelen in het verminderen van de druk op het schaarse land. Biomassaplantages kunnen duidelijk profiteren van het beschikbaarheid van goedkope vervuilde grond, zelfs wanneer additionele kosten moeten worden gemaakt om deze grond geschikt te maken voor gebruik. In alle onderzochte scenario's daalt de productie van landbouwgewassen met maximaal 3% en stijgen voedselprijzen met maximaal 2%, uitgaande van een subsidie op bioelectriciteitsproductie van 20% en vermindering van de uitstoot van broeikasgassen met 10%. Het benutten van vervuilde grond heeft ook interessante effecten op de internationale handel in biomassa. Als de vervuilde grond niet gebruikt kan worden, en de subsidies op bioelectriciteit zijn hoog, dan zal Polen goedkope biomassa uit het buitenland importeren om aan de grote binnenlandse vraag te voldoen. Wanneer echter de vervuilde grond kan worden benut dan stijgt de binnenlandse productie van biomassa substantieel en kan Polen biomassa exporteren. Dit heeft positieve gevolgen voor Polen, maar wellicht ook voor de gehele Europese Unie.

Hoofdstuk 6 analyseert de mogelijke invloed van bioraffinage en cascades op de economie. Het model van hoofdstuk 3 is uitgebreid met i) het introduceren van twee vernieuwende bioraffinagetechnieken, te weten "Press" en "Refiner", om bionylon en 1,3PDO op basis van gras te produceren, welke een substituut vormen voor respectievelijk nylon en 1,2EDO (gebruikt in PET flessen), en ii) cascades voor deze nieuwe producten. Bij 20% vermindering van de uitstoot veranderen de relatieve prijzen dusdanig dat het Refiner proces efficiënter is dan het traditionele proces om nylon en 1,2EDO te maken. Deze omslag in het productieproces leidt echter niet tot een hoger aandeel bioelectriciteit, aangezien het Refiner proces grote hoeveelheden gras gebruikt, wat leidt tot extra competitie met voedsel en biomassa voor het schaarse land. Wanneer het milieubeleid stringenter wordt, en deze processen worden uitgebreid met een cascade, kan het Press proces concurreren met het Refiner proces en worden beide technieken winstgevend. De cascade stimuleert de productie van bioelectriciteit, maar leidt met name tot een verandering in de gebruikte inputs voor de productie van bioelectriciteit (van biomassa naar de cascade). Biomassaplantages blijven de belangrijkste bron voor productie van schone electriciteit. De meer geavanceerde systemen kunnen echter tot op zekere hoogte bijdragen aan de transitie naar een schone energievoorziening, aangezien ze de afhankelijkheid van fossiele brandstoffen verminderen.

De verschillende analyses in dit proefschrift overziend blijkt dat afhankelijk van de beleidsdoelstellingen, verschillende multifunctionele biomassasystemen het beste werken.

Multi-product gewassen kunnen bijvoorbeeld fossiele brandstoffen vervangen als input in de productie van electriciteit, en het benutten van vervuilde grond vergroot de mogelijkheden voor productie van biomassa, en daarmee het potentiële aanbod van biomassa. Wanneer energiebeleid zich richt op de vervanging van fossiele brandstoffen als grondstof, dan functioneren de bioraffinageprocessen goed. Het blijkt echter moeilijk te zijn om al deze doelstellingen te combineren; geen van de multifunctionele biomassasystemen is superieur aan de andere systemen, en het toekennen van een voorkeur voor een bepaald systeem hangt af van het gewicht dat wordt gegeven aan de verschillende beleidsdoelen.

In het algemeen geldt dat die systemen die de productiviteit van energie, biomassa en/of landbouwproductie verbeteren, de voorkeur verdienen. De reductie van de uitstoot van broeikasgassen moet substantieel zijn om de Poolse doelstellingen ten aanzien van de groei van de bioelectriciteitssector. Dergelijk stringent beleid brengt welvaartskosten met zich mee die kunnen oplopen tot enkele procenten. Het blijkt dat subsidies op biomassa en bioelectriciteit, gecombineerd met een relatief geringe vermindering van de uitstoot, leiden tot een stijging van het aandeel bioelectriciteit in de totale electriciteitsproductie tegen de laagste welvaartskosten.

Alle sectoren in de economie passen zich aan als het stringente energie- en milieubeleid wordt ingevoerd. Zoals verwacht kunnen de sectoren zonder of met relatief lage uitstoot van broeikasgassen hun productie handhaven of zelfs uitbreiden, terwijl de relatief vervuilende sectoren hun productie zien verminderen. Aangezien de Poolse landbouwsector relatief schoon is, zeker in vergelijk met de industrie, is de druk om de voedselproductie te verminderen beperkt. Bovendien hebben de milieukosten een beperkte invloed op de prijzen van landbouwgewassen. De landbouwsector in Polen zit in een proces van rationalisatie en het productieproces kan hierdoor efficiënter worden, zoals ook uit de modelberekeningen blijkt.

Al deze multifunctionele biomassasystemen overziend kan de algemene conclusie worden getrokken worden dat om de huidige doelstellingen van het Poolse energiebeleid te halen, specifieke biomassaplantages noodzakelijk zijn. Meer geavanceerde systemen, en verfijningen van deze systemen, zoals in dit proefschrift besproken, kunnen bijdragen aan het beperken van de kosten van de invoering van het energiebeleid, of kunnen de bijbehorende milieuvoordelen vergroten, maar hun bijdrage blijft beperkt. Hoewel individuele biomassaplantages kleinschalig kunnen zijn, moet de totale productie van biomassa substantieel toenemen om de doelstellingen te halen.

STRESZCZENIE

Ekonomia wielofunkcyjnych systemów biomasy

Działalność człowieka przyczynia się do wzrostu emisji różnorodnych zanieczyszczeń powietrza stwarzających zagrożenia dla środowiska naturalnego takie jak np. efekt cieplarniany. Reakcją na te zagrożenia jest zwiększony popyt na energię odnawialną. Jednym z potencjalnych źródeł takiej energii jest biomasa. Zwiększony popyt na rośliny energetyczne może wywrzeć nacisk na obecne użytki rolne. Z tego powodu w niniejszej rozprawie doktorskiej zostanie przedstawiona analiza ekonomiczna potencjalnej produkcji elektryczności z biomasy z uwzględnieniem dostępności użytków rolnych oraz produktywności upraw roślin energetycznych (biomasy). Ponadto, w pracy analizie został poddany potencjalny wpływ wzrostu popytu na biomasę na produkcję i ceny żywności. Ważnym aspektem pracy jest analiza wielofunkcyjnych systemów biomasy, które potencjalnie mogą wpłynąć na zwiększenie efektywności produkcji biomasy i bioelektryczności i w efekcie zmniejszenie nacisku na użytki rolne.

Główną tezą pracy jest pytanie: „Jakie są skutki polityki energetycznej i wielofunkcyjnych systemów biomasy na produkcję biomasy i bioelektryczności, użytki rolne, rolnictwo i pozostałe części gospodarki?”.

W pracy przedstawione zostały różne typy wielofunkcyjnych systemów biomasy w zależności od rodzaju biomasy jak i technologii: i) zastosowanie wielo-produktowe, ii) wielofunkcyjne uprawy biomasy, iii) substytucja materiałowa oraz iv) kaskadowanie. *Zastosowanie wielo-produktowe* oznacza, że płód rolny może być rozdzielony na dwie lub więcej części, które mogą być stosowane do różnych celów. *Wielofunkcyjność* upraw biomasy jest związana z różnorodnym zastosowaniem użytków rolnych do produkcji biomasy. *Substytucja materiałowa* występuje, gdy surowce biomasy zastępują nieodnawialne źródła energii, natomiast *kaskadowanie* oznacza wielokrotne, zastosowanie biomasy, co umożliwia wykorzystanie pełnego potencjału surowca.

Studium przypadku zostało przeprowadzone w Polsce, kraju członkowskim Unii Europejskiej (EU) o dużym potencjale produkcji biomasy. W porównaniu do innych członków EU, Polska charakteryzuje się relatywnie niskimi kosztami gruntów ornych i siły roboczej oraz dużym potencjałem rozwojowym dla sektora rolniczego, w tym również dla upraw roślin energetycznych. W 2001 roku, rząd polski ustanowił cele dotyczące zwiększenia udziału bioelektryczności w całkowitej produkcji energii elektrycznej do 7.5 % w 2010 i 14 % w 2020.

Rozdział 2 analizuje wpływ polityki energetycznej na produkcję biomasy i tradycyjną produkcję rolną ze szczególną uwagą poświęconą emisjom gazów cieplarnianych (GHG) oraz użytkom rolnym. Do modelowania powyższych zależności zdefinionowany został model równowagi cząstkowej. Model ten pozwala na analizę najważniejszych mechanizmów sterujących zależnościami pomiędzy tradycyjnym rolnictwem a produkcja roślin energetycznych z uwzględnieniem istnienia dodatkowych obciążeń na konwencjonalną energię elektryczną, oraz opłat za emisje gazów cieplarnianych (*carbon tax*). Obydwa scenariusze polityczne są analizowane w trzech różnych sytuacjach: a) z wyłączeniem dopłat, b) z dopłatami do bioelektryczności, c) z dopłatami do produkcji biomasy. Wyniki przeprowadzonych analiz pokazują, że Polska może osiągnąć postawiony cel zwiększenia udziału bioelektryczności do 7,5 % w 2010 przy zastosowaniu podatku na energię elektryczną w połączeniu z dopłatami do produkcji bioelektryczności, przy odpowiednich założeniach modelu. *Carbon tax* w mniejszym stopniu przyczynia się do wzrostu produkcji bioenergii. Zgodnie z oczekiwaniami, udział bioelektryczności jest najwyższy, kiedy jej produkcja jest subsydiowana, niezależnie od wybranego scenariusza. Wszystkie scenariusze polityczne obniżają stopę dobrobytu, jednak należy dodać, że w funkcji użyteczności nie uwzględniono pozytywnych efektów dla środowiska przyrodniczego. Poszczególne obciążenia na energię elektryczną stymulują obydwa sektory: rolniczy i biomasy. W scenariuszu uwzględniającym *carbon tax*, sektory o podwyższonym poziomie emisji zmniejszą swoją produkcję, np. sektor rolniczy zmniejszy się, głównie z powodu emisji gazów cieplarnianych (GHG). W każdym scenariuszu korzystają sektory produkujące rośliny energetyczne oraz sektor produkujący bioelektryczność. Ceny produktów rolnych wzrosną we wszystkich scenariuszach, przy czym w mniejszym stopniu w scenariuszu zakładającym narzuty na energie elektryczną niż przy *carbon tax*. Ogólnie wzrost cen jest ograniczony, zakładając brak subsydiów na produkcję biomasy. W przypadku emisji dwutlenku węgla (CO_2), zgodnie z przewidywaniem, narzut na energię elektryczną jest mniej efektywny niż *carbon tax*. Te różnice są praktycznie nieznaczące w przypadku emisji podtlenku azotu (N_2O). Na emisję duży wpływ mają schematy dopłat subwencji: dopłata do produkcji bioelektryczności najbardziej obniża emisje CO_2, podczas gdy dopłata do produkcji biomasy najefektywniej przyczynia się do redukcji emisji N_2O.

W *Rozdziale 3* do zanalizowania wpływu różnych scenariuszy polityki środowiskowej, została zastosowana bardziej rozwinięta metodologia; mianowicie model równowagi ogólnej (AGE). W porównaniu z modelem równowagi cząstkowej, rozszerzenie do modelu równowagi ogólnej pozwala na uwzględnienie dodatkowych mechanizmów, które mogą mieć znaczenie przy doborze odpowiedniej polityki ochrony środowiska. W rozdziale 3 model koncentruje się na systemie zbywalnych praw do emisji gazów cieplarnianych a nie na narzutach i podatkach. W skład proponowanych scenariuszy wchodzą różne poziomy redukcji emisji wynikających z mniejszej ilości wydanych zezwoleń w połączeniu z (1) dystrybucją przychodów z podatku ryczałtowego z dochodów ze zbywalnych pozwoleń na emisje, (2) dopłat do produkcji biomasy, oraz (3) subwencjonowaniem energii bioelektrycznej. Wszystkie trzy scenariusze są analizowane przy jednostronnych i wielostronnych umowach pomiędzy Polska a resztą świata. Porównanie modelu cząstkowego z Rozdziału 2 oraz modelu ogólnego z Rozdziału 3 pokazuje, że efekty modelu ogólnego na politykę ochrony środowiska nie powinny być pominięte. Jakkolwiek, mechanizmy te mogą być w dużej mierze uwzględnione w zaawasowanym modelu cząstkowym, jak pokazano w Rozdziale 2. Dlatego też różnice w wynikach Rozdziału 2 i 3 są mniejsze niż możnaby oczekiwać a priori.

Polska może osiągnąć założony 7.5%-owy udział energii bioelektrycznej w całkowitej produkcji energii elektrycznej, przy założeniu 10% redukcji emisji poprzez system zbywalnych praw do emisji i subwencje energii bioelektrycznej w wysokości 25%. W celu osiągnięcia tego samego celu przy zastosowaniu subwencji w wysokości 25% do biomasy w zamian za subwencje do energii bioelektrycznej, redukcję emisji należy zwiększyć do 30%. W scenariuszu bez dodatkowych subwencji, ten sam cel może być osiągnięty przy redukcji emisji o około 50%. W przypadku redukcji emisji o 10%, występuje nieznaczne zmniejszenie- produkcji żywności (we wszystkich przypadkach mniej niż 3%): najmniejszy spadek występuje w scenariuszu z subsydiami dla biomasy. Pomimo rosnących cen produktów rolnych, wyniki naszych badań pokazują niższy wzrost (maks.2%) niż sugerowany przez inne badania, głównie w wyniku przesunięcia w sile roboczej oraz przepływach kapitałowych wpływających na intensyfikację produkcji rolnej. Proponowane scenariusze wpływają ponadto na zmianę w strukturze zagospodarowania terenów w Polsce: areały lasu i upraw roślin energetycznych mogą się znacznie rozszerzyć, przy założeniu istnienia subwencji. Przy wielostronnych umowach, ustanowione cele udziału bioelektryczności mogą być osiągnięte szybciej, jako że efekt specjalizacji w produkcji jest bardziej widoczny., Jednakże wówczas ceny zbywalnych pozwoleń na emisje są wyższe, gdyż Polska nie jest w stanie importować tanich produktów, przy których produkcji emitowane jest wiele zanieczyszczeń.

Rozdział 4 rozszerza model z Rozdziału 3 i analizuje ekonomiczne skutki wielo-produktowych płodów rolnych. Wielo-produktowe płody rolne to płody rolne, które mogą być zużyte częściowo do produkcji energii elektrycznej i częściowo do innych celów takich jak produkcja żywności lub innych produktów (np. ziarno żyta może być użyte w sektorze żywieniowym, natomiast słoma może być przetworzona, na material energetyczny). Okazuje się, że zastosowanie wielo-produktowych płodów rolnych poprzez wykorzystanie produktów ubocznych jak źródło energii podwyższa udział bioelektryczności o 2 punkty procentowe w porównaniu do sytuacji, gdy produkty uboczne nie są wykorzystane. Efekt ten obowiązuje dla każdego poziomu redukcji emisji. Odpowiednio, uzyskanie takiego samego udziału wymaga redukcji emisji o około 5% punktów procentowych. Wyniki jasno dowodzą, iż wykorzystanie produktów ubocznych zwiększa udział bioelektryczności, jednak podaż produktów ubocznych w Polsce jest za niska, aby umożliwić osiągnięcie postawionych celów zwiększenia udziału bioelektryczności. Wykorzystanie produktów ubocznych wywołuje bardzo ograniczone efekty na produkcję żywności i ceny. W obydwu scenariuszach występuje wzrost areału lasów i upraw biomasy. Te zmiany są bardziej wyraźne w scenariuszu wielo-produktowym, w którym produkcja leśna jest wspierana przez (i) znaczne subwencje Unii Europejskiej na zalesianie, (ii) znaczne ilości produktów ubocznych, które mogą być wykorzystane w sektorze energetycznym.

Rozdział 5 koncentruje się na wielofunkcyjnych uprawach biomasy. Z uwagi na potencjalne zagrożenia dla zdrowia, uprawa surowców spożywczych jest niemożliwa na glebach zanieczyszczonych metalami ciężkimi. Te gleby znakomicie nadają się do produkcji biomasy, co więcej biomasa może oczyścić skażoną glebę w procesie fitoremediacji. W niniejszym rozdziale użyto model z Rozdziału 3 wzbogacony o areał gruntów zdegradowanych i zanieczyszczonych. Obecny areał zanieczyszczonych użytków rolnych w Polsce jest relatywnie niewielki, także makroekonomiczne zmiany w udziale produkcji bioelektryczności są także ograniczone. Proces fitoremediacji może jednak odegrać pewną rolę redukując nacisk na gleby produkcyjne. Uprawy biomasy zyskują przy podaży tanich, zanieczyszczonych i zdegradowanych gruntów, nawet gdy wymaga to poniesienia dodatkowych kosztów w przygotowaniu tych gruntów do produkcji. We wszystkich scenariuszach, produkcja rolna obniżyła się o maksymalnie o 3% a ceny produktów spożywczych wzrosły maksymalnie o 2%, przy założeniu 20% subwencji na energie bioelektryczna i 10% redukcji emisji GHGs. Interesujący jest fakt, iż użytkowanie zanieczyszczonych i zdegradowanych gruntów wpływa na strukturę handlu biomasą. Przy wysokich subwencjach bioenergetycznych i bez wykorzystania zanieczyszczonych gruntów Polska będzie importować tańszą biomasę, aby zaspokoić wysoki lokalny popyt. Jednak w przypadku wykorzystania gruntów dotychczas nie-produktywnych, podaż biomasy w Polsce znacznie wzrosnąć i Polska może stać się jej eksporterem. Wtedy korzyści odniesie nie tylko Polska, ale także cała Unia Europejska.

Rozdział 6 analizuje potencjalny wpływ biorafinerii oraz systemów kaskadowych na gospodarkę. Model z Rozdziału 3 jest rozbudowany poprzez uwzględnienie (i) dwóch nowatorskich technologii w dziedzinie biorafinerii, procesów wyciskowych i rafinacyjnych do wytwarzania bio-nylonu i 1,3PDO (propane-diol), które są trawo-pochodnymi substytutami dla nylonu i 1,2EDO (ethane-diol), oraz (ii) mechanizmów kaskadowania dla trawo-pochodnych produktów. Przy 20% redukcji emisji GHG, relatywne zmiany cen są takie, iż proces Rafinacji jest bardziej efektywny niż tradycyjne procesy do produkcji nylonu i 1,2EDO. Zmiana ta nie wywołuje wyższego udziału bioelektryczności, niemniej jednak, jako że proces Rafinacji wymaga dużych ilości trawy, konkuruje on o grunty uprawne z tradycyjnym rolnictwem i roślinami energetycznymi. Gdy zostanie zaostrzona polityka ochrony środowiska, a procesy ten zostaną wzmocnione poprzez kaskadowanie, to proces Wycisku może konkurować z procesem Rafinacji i wtedy obydwie technologie będą przynosić zyski. Kaskadowanie nie powoduje zwiększenia produkcji bioelektryczności, ale wpływa głownie na zmianę wsadów do produkcji bioelektryczności.

Plantacje roślin energetycznych pozostają głównym wyznacznikiem możliwości produkcji bioelektryczności. Bardziej zaawansowane, multifunkcjonalne, systemy biomasy wpływają na zrównoważoną gospodarkę energetyczną, jako iż stymulują one substytucje konwencjonalnych materiałów, materiałami pochodzenia biologicznego.

Porównując różne typy analiz, w niniejszej rozprawie doktorskiej, w zależności od celów polityki środowiskowej różne wielfunkcyjne systemy biomasy osiągają najlepsze wyniki. Dla przykładu, wielo-produktowe płody rolne mogą zastąpić paliwa kopalne jako surowiec do produkcji energii elektrycznej. Natomiast wykorzystanie zanieczyszczonych i zdegradowanych gruntów zwiększa możliwości produkcji biomasy i tym samym gwarantuje potencjał podaży biomasy. W przypadku, gdy polityka energetyczna zakłada zastąpienie surowców z paliw kopalnych wtedy procesy biorafinerii wykazują dobre wyniki. Relatywnie najtrudniejsze jest połączenie różnych celów polityki, jako że nie istnieje dominujący system wielofunkcyjny. Systemy te różnią się w zależności od wagi nadanej poszczególnym celom polityki.

Ogólnie, systemy zwiększające produktywność procesów energetycznych, biomasy i produkcji rolnej powinny być wprowadzane na początek. Redukcja zbywalnych pozwoleń na emisje powinna być dość znaczna tak, aby stymulować wzrost sektora energetycznego umożliwiając Polsce sprostowanie postawionym sobie celom. Tego rodzaju zaostrzona polityka powoduje spadek stopy dobrobytu o kilka procent. Okazuje się że subwencjonowanie biomasy i bioelektryczności w połączeniu z odpowiednio niską redukcją praw do emisji powoduje wzrost udziału bioelektryczności przy zachowaniu mniejszego spadku dobrobytu.

Wszystkie sektory dostosowują się po wprowadzeniu zaostrzonej polityki środowiskowej. Zgodnie z oczekiwaniami, sektory o braku lub niskiej emisji gazów cieplarnianych mogą utrzymać lub nawet rozszerzyć swoją produkcję, podczas gdy tzw. brudne sektory zmniejszą produkcję. W związku z tym, że polski sektor rolny jest stosunkowo czysty, porównując go np. do przemysłu, nacisk na redukcję produkcji żywności jest ograniczony. Ponadto, koszty pozwoleń na emisje nie mają zbyt wielkiego wpływu na ceny produktów rolnych. Sektor rolniczy w Polsce jest obecnie w trakcie procesu racjonalizacji i jak wynika z modelu, staje się coraz bardziej wydajny w swoim procesie produkcyjnym.

Podsumowując, w celu osiągnięcia obecnych celów polityki energetycznej niezbędny jest wzrost areału upraw roślin energetycznych. Bardziej zaawansowane systemy oraz ulepszenia tych systemów, jak w dyskusji powyżej, mogą przyczynić się do redukcji kosztów wprowadzenia strategii energetycznych a także do zwiększenia potencjalnych korzyści środowiskowych. Podczas gdy uprawa poszczególnych roślin energetycznych w Polsce może odbywać się też na małą skalę, całkowita produkcja biomasy powinna zostać radykalnie zwiększona aby osiągnąć postawione sobie cele.

ABOUT THE AUTHOR

Adriana Maria Ignaciuk was born on September 13th, 1974 in Warsaw, Poland. She studied at Warsaw Agricultural University between 1993 and 1998, resulting in an M.Sc. degree in Environmental Engineering. During this period, she was granted a TEMPUS fellowship covering one year full tuition at Wageningen University. In 1998 she received a MATRA fellowship to accommodate her second M.Sc. studies at Wageningen University. In January 2000, she obtained an M.Sc. degree from Wageningen University in Environmental Sciences with a major in Environmental Economics. For her practical training and thesis she worked for 4 months at Council for Scientific and Industrial Research (CSIR) Pretoria, South Africa. After graduation, she began to work as a researcher at the Environmental System Analysis Group of Wageningen University on a project about methodologies to analyze interactions of climate change, acidification and ozone. In May 2001 she was appointed as a Ph.D. researcher at the Environmental Economics and Natural Resources Group of Wageningen University. Her research was conducted within the context of the BioPUSH project, financed by NWO/Novem. In 2005 she successfully completed the doctoral training programme of the Netherlands Network of Economics (NAKE), and of the research school Socio-Economic and Natural Sciences of the Environment (SENSE). During her PhD appointment she was a chair and member of the WIMEK PhD Council and a member of the Wageningen PhD Council.

Training and Supervision Plan

Description	*Credits*[1]
SENSE PhD courses:	
Environmental Research in Context	2
Research Context Activity: Organizing the SENSE PhD Colloquium 2003	4
Integrated Assessment of Global Environmental Change	2
Intertemporal Allocation of Natural Resources and Intergenerational Justice	3
Other PhD courses:	
Quantitative Methods in Economic Research (NAKE[2])	3
Growth and Environment (NAKE)	3
Microeconomics (Tilburg University)	6
Macroeconomics (Tilburg University)	6
Econometrics II	6
Techniques for Writing and Presenting Scientific Papers	1.2
Project and Time Management	1.5
Career Perspectives	1.8
Personal development work:	
Chair of the WIMEK AIO Council	6
Member of ARO Commission at Wageningen University	2
Oral presentations:	**3**
10th Conference on Environmental Economics: Karl-Gustaf Löfgren Symposium, 16-19 June, 2003, Ulvön, Sweden	
European Association of Environmental and Resource Economists, 25-28 June, 2004, Budapest, Hungary	
2nd International Conference on Environmental Concerns, 12-15 October, 2004, Xiamen, China	
6th International Conference of the European Society for Ecological Economics, 14-17 June, 2005, Lisbon, Portugal	
45th Congress of the European Regional Science Association, 23-27 August, 2005, Amsterdam, The Netherlands	
XII Congress of Polish Association of Agricultural and Agribusiness Economists, 21-23 September, 2005, Warsaw, Poland	
Symposium BioBased Economy, 6 December, 2005, Wageningen, The Netherlands	
3rd World Congress of Environmental and Resource Economists, 3-7 July, 2006, Kyoto, Japan	
Total (min 30 credits)	**50.5**

[1] 1 credit point represents 28 hours; [2] NAKE stands for Netherlands Network of Economics

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