Evaluation of Renewable Energy Policies in an Integrated Economic-Energy-Environment Model

d'Artis Kancs* Norbert Wohlgemuth†

January 2008

Abstract

In this paper we further develop the general equilibrium bioenergy model for assessing socio-economic impacts of alternative renewable energy policies and apply it to the bioenergy sector. The policy scenarios are assessed in a comparative static analysis. The numerical simulation results allow us to analyse and compare welfare and distributional impacts of alternative renewable energy policies. Our empirical findings suggest that the bioenergy sector in Poland would benefit most from an indirect tax reduction. According to our simulation results, reducing the fossil energy sectors' subsidies would be the second best policy option.

Keywords: GEM-E3, Renewable energy, CGE modelling.
JEL classification: O13, P28, Q21, Q23, Q28, Q42.

1 Introduction

Renewable energy and particularly bioenergy markets are expected to grow substantially in the next decades as a result of increasing prices of fossil fuels, concerns regarding the security of supply, the aim to diversify fuel supplies, high costs of carbon emissions and subsequent strong political willingness to support bioenergy and other renewable energy sources. In the wake of mounting pressure from international organisations such as the World Bank and the United Nations World Food Programme, European Commission President Barroso has requested a study on whether there is any relationship between the recent skyrocketing food prices around the world and biofuels. "*I have personally asked for a study on all aspects: the impacts on prices,*

*Correspondence Address: London School of Economics, London WC2A 2AE, United Kingdom and Catholic University of Leuven, Leuven B-3000, Belgium. E-mail: kancs@econ.kuleuven.be.

†The authors acknowledges helpful comments from Stef Proost and Denise Van Regemorter as well as seminar participants at the Catholic University of Leuven.

the impact on agriculture, the impact on development, etc. All the aspects." (*José Manuel Barroso* 2008).

Given the pressure of international obligations on the one hand and the sizeable potential of biomass from wood in the Polish primary energy supply (see Figure 1), the present study analyses bioenergy's potential from the two largest green energy sources: the short-rotation forestry and energy field crops. The paper is structured as follows. In section 2 we provide an overview about historical developments and current state of renewable energy sector in Poland. We also briefly review those policies affecting the renewable energy sector's development in Poland. In section 3 we present the theoretical framework, which we implement empirically in section 4, where we also present the empirical implementation of the model. We also refer to the main data sources and detail empirical estimation of model parameters. Section 5 presents the obtained simulation results and discusses potential policy implications. Section 6 concludes.

2 Renewable energy in Poland

In this section we briefly review the Polish energy sector, in general, and the rapidly developing bioenergy sector, in particular. We also outline the underlying institutional framework, which largely determines bioenergy's future in Poland. The section closes by providing an outlook about future opportunities and main challenges of increasing the bioenergy's share in Poland's energy balance.

2.1 The energy sector

Primary energy's production in Poland is dominated by hard coal and lignite, which together accounted for 83% of the total energy's production in 2005 (*Eurostat* 2007). These fuels also account for a large, about 65%, but slowly decreasing share of primary energy use (*EC BREC* 2005). The index of self-sufficiency (the ratio of primary production to primary use) in 2005 was 86% - about twice as high as the EU average. Due to a steadily growing demand for energy in general and for transportation fuels in particular, the share of oil in the total energy consumption is increasingly leading to a higher dependence on imported energy. According to *EC BREC* (2005), the total final energy use is expected to be stable or increase slowly (less than 1 percent per year) in the next 20 years *Hille* (2000).

Energy for heating is one of the dominant energy uses in Poland. Most of the heat demand in urban areas is met by district heating. According to the *EC BREC* (2005) forecasts, heat requirements will decline in the next 20 years as a result of modernisation and efficiency improvements, including end-use efficiency.[1] A number

[1]Since 1989 the district heating plants have been controlled and mainly owned by local government at the municipalities which, in line to the "Energy Act" of 1997, gave local authorities and

of refurbishment plans and restructuring programs have been undertaken in the recent years to remedy the situation with technical and financial problems in order to bring the heating systems up to the EU standards, including improved environmental performance. Heat production in district heating was 412 PJ in 2005, which is below the EU average, when expressed in terms of GDP.[2]

Electricity is another major form of energy in Poland both in terms of production and consumption. The level of electricity generation and consumption in Poland has remained relatively stable in the past ten years. However, the structure of electricity production has changed considerably. Until the nineties, the power generation in Poland has been characterised by large centralised condensing power plants and overcapacity. The gross electricity generation in 2005 amounted to 173.8 TWh (*EC BREC* 2005). The main source – about 97% of electricity – is hard coal and lignite. The remaining 3% is hydro power, biogas and landfill gas, wind energy and some biomass Combined Heat and Power (CHP). The electricity consumption in Poland is about 3800 kWh/capita, much less than the 6-7000 kWh per capita which is typical for EU countries. In contrast to heat demand, the Polish electricity demand is projected to grow, on average 2.2 percent per year (*Polish Ministry of Environment* 2006), which corresponds to a per capita consumption of about 6000 KWh by 2020.

The third major source of energy in Poland is natural gas. Given the gas-grid access and favourable relative energy prices, natural gas can become an important energy source in near future. According to the *Polish Ministry of Environment* (2006), the consumption of natural gas reached 497 PJ in 2005, which is still below the EU average. Most of the natural gas is used in industry and in the residential sector. Less than 5% is used for heat and power production. However, according to the *Polish Ministry of Environment* (2006), natural gas is expected to double its share in the primary energy's demand in the next two decades. Notably, natural gas is assumed to play an important role in meeting the projected increase in demand for electro-energy, and as a clean fuel for the domestic sector. Given that the domestic gas reserves in Poland are rather limited, the expanded use of natural gas will largely depend on gas importing possibilities.

The potential for energy production from waste is another important factor that determines the long-term energy supply in Poland. Currently Poland produces almost 13 measurement ton (Mton) of municipal solid waste (MSW) per year, 97% of which is dumped at over 900 landfills throughout the country. Methane is recovered and used for energy only at 28 landfills. These numbers suggest that there is a significant potential in energy production from waste in Poland.

In line with agreements with the European Union Poland is required to increase the amount of energy produced from land-filled waste. It is expected that about 1.4 Mton of MSW organic fraction will be incinerated by 2010. This corresponds to

municipalities an important role in decision-making of energy sector.

[2] An estimated additional 360-570 PJ was produced in individual boilers in dwellings and other buildings, and 720-870 PJ for process and space heat in industry (EC BREC 2005).

about 14 PJ assuming that 10 GJ/ton can be recovered as energy.

2.2 Bioenergy

According to estimates of the *International Energy Agency* (2004), the Baltic Renewable Energy Centre (*EC BREC* 2005) and the *Polish Ministry of Environment* (2006), the current contribution of renewable energy in Poland is between 3.8% and 5.1% in the total primary energy supply.[3] The *EC BREC* (2005) has estimated that the use of bioenergy was 165 PJ in 2003, equivalent to 95% of total renewable energy supply and about 4% of total primary energy use. According to the *EC BREC* estimates, most of this bioenergy after conversion losses was used for producing 112 PJ of heat and 560 GWh of electricity.

Until recently, the energy from biomass was hardly competitive with fossil energy. However, after Poland's accession to the EU in more and more applications, for example, in waste wood in the wood processing industry or as firewood for domestic heat it is becoming increasingly competitive. This explains the fact that the use of firewood for heating purposes dominates the present use of bioenergy. In particular, a growing number of small and medium-scale district heating systems (roughly 100 producing bioenergy of wood, biogas and straw) have already been implemented since 1995, and further 30-50 are under construction (*Central Statistical Office of Poland* 2007). The majority of these set-ups in the district heating sector are refurbishment projects with coal to biomass fuel conversion and heating network refurbishment, typically supported with grants or soft loans. Only few district heating plants have started biomass co-firing in coal boilers on a trial basis.

According to Figure 1, the short to medium term potential of bioenergy is largely determined by the present land-use and the current generation of biomass and wood waste in agriculture and forestry. According to estimates of *Polish Ministry of Environment* 2006 and *European Commission* (2004), bioenergy will contribute almost 60% to the total renewable energy produced in 2010. The current use of industrial wood byproducts for energy in industry is on the order of 20-25 PJ. However, the real use of firewood is considerably higher since it is also extracted from private forests, plus an unknown level of wood thefts (*Vesterinen* 2004). The forestry residues potential is about 35 PJ with the current harvest rates. The potential of used wood may be similar.

Agriculture produces about 25.5 Mtons of straw, of which 4 to 11 Mtons (60 to 150 PJ) could be used for energy after subtracting for feed, litter and fertilizing needs. In the short to medium term, it may also be relevant to consider short rotation forestry. There is 2.6 Mha of set-aside and fallow land and 0.6 Mha of contaminated agricultural land. Using about 2 Mha of this land for short rotation forestry would

[3] The renewable energy estimates vary significantly, because a sizeable portion of bioenergy, which is used in rural areas, is not included in the formal economy, and therefore is not accounted for in the official statistics.

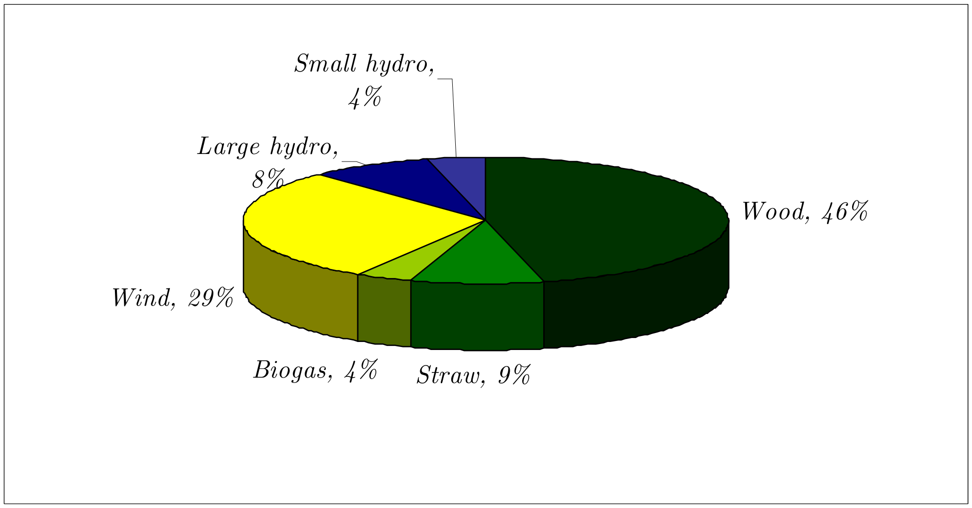

Figure 1: Projected contributions to total renewable energy production in Poland in 2010
Source: European Commission (2007).

result in 180-360 PJ assuming annual yields of 5-10 tons dry substance per ha. Biogas from wet agricultural waste, sewage sludge, and landfill gas could add another 34 PJ. In the 5-10 year time-frame, not including the short rotation forestry or using more of the annual increment in forests, the potential is thus limited to some 250 PJ, of which straw may account for 150 PJ, forestry residues 20-30 PJ, wood waste 20-30 PJ, used wood 20-30 PJ, and biogas 20-30 PJ (*Hille* 2000; *Polish Ministry of Environment* 2006).

Given the sizeable forestry and agricultural land resources, the long-run potential of bioenergy production in Poland is considerable. Forests cover 8.9 Mha, with Pine as the most common species. According to the EC Baltic Renewable Energy Centre estimates (*EC BREC* 2007), the energy stored annually in the 8.9 Mha of forests is on the order of 450 PJ (assuming 6 m^3/ha net growth, 500 kg dry substance per m^3, and 16 GJ/ton). The current harvest rate is about 26 M m^3 per year, which corresponds to about half of the annual increment. Approximately 55-65 PJ may be available as forest residues in the long term and additional volumes could be available as wood waste from the wood industry. The agricultural land area in Poland is about 18.5 Mha or 0.5 ha/capita. Assuming that about 0.25 ha/capita is sufficient for food production, about 9 Mha could potentially be used for other purposes. Allotting this area for energy production and assuming an annual yield of 160 GJ/ha (10 ton/ha dry substance) would result in about 1450 PJ/year of bioenergy. We will use this information about land availability in Poland for the land endowment constraint in the general equilibrium bioenergy model.

2.3 Energy policy

During the nineties, the energy policy in Poland has mainly focused on restructuring, developing the natural gas infrastructure, and improving the energy efficiency. Until recently, the renewable energy has been considered only in the long-term perspective in Poland (*Nilsson et al* 2006). The late 1990s mark the start of political interest in creating conditions for renewable energy development. The "Development Strategy of Renewable Energy Sector" (*Polish Ministry of Environment* 2001) is the key document prospecting the development of renewable energy in Poland. The major policy objective in Poland is to increase the share of renewable energy in primary energy balance to 7.5% in 2010 and to 14% in 2020 (*EC BREC* 2005). The basic elements of Poland's energy policy in general are outlined in the strategy paper "Assumptions of Energy Policy to 2020" (*Polish Ministry of Environment* 2007), which is based on an analysis of the present state and the expected future development of the energy sector.

In the Development Strategy of Renewable Energy Sector bioenergy has been recognised as one of the most promising and most important renewable energy source in achieving this goal. The Development Strategy of Renewable Energy Sector contains two elements with respect to bioenergy. One is the issuing of an "Electricity Feed-In Ordinance" and the other is the obligation on municipalities to prepare local energy plans. The "Electricity Feed-In Ordinance" obliges electricity suppliers to provide an increasing share of electricity from renewable sources in their supply mix, increasing to 7.5% in 2010. However, the quota obligation has not yet been fully enforced and it does not support the fuel-switching in the heating sector. Given that there is no real mechanism to enforce the compliance and that it is not supported by a scheme for certificates trading, this policy has failed to produce stable renewable energy market conditions sought by potential investors. The other policy instrument - local energy plans should include an account of possible ways of utilising local energy sources. However, the experience with local energy plans been mixed at best so far. Many local governments do not have the capacity to prepare good plans and the Development Strategy of Renewable Energy Sector does not specify any deadline for the preparation of plans. Only about 10% of the municipalities have prepared energy plans by the end of 2006.

Although, bioenergy is a major potential renewable energy source in Poland, it does not have an effective and coherent policy support yet. The existing measures, such as grants, soft-loans, and Joint Implementation Projects (JIP) stimulate investments on a rather modest level in renewable energy projects. Therefore, the success development of bioenergy depends, among other factors, on the political will and determination to pursue this option through financial incentives, including, (i) continued investment support, (ii) adjustment of fossil energy taxes and/or, renewable energy production subsidies, and (iii) co-ordinating and expanding research and development efforts.

Based on findings from sections 2.1 - 2.3 the recent developments in the Polish energy sector can be summarised as follows: (i) growing the aggregate energy demand; (ii) favourable natural resource endowments for expanding the bioenergy production; (iii) obligations of international agreements to increase (double) the use of energy from renewable sources; and (iv) absence of an effective bioenergy support mechanism in Poland.

3 Theoretical framework

In this section we present the theoretical framework, which we will use in the empirical analysis. The underlying theoretical framework is based on the general equilibrium bioenergy model developed in *Kancs* (2002). For the purpose of the present study we extend the energy-economic model to the environmental dimension. Introduction of the environment dimension aims at improving the general equilibrium bioenergy model in four directions: (i) integrated analysis of environmental and energy impacts; (ii) representation of a larger set of environmental policy instruments at different levels: standards, taxes, tradable permits; international, national, sectoral; (iii) integrated analysis of different environmental problems: simultaneous analysis of global warming and acid rain policy; and (iv) comparison between a source or a receptor oriented approach: damage valuation versus uniform emission reductions. In this section we informally introduce both main building blocks of the general equilibrium bioenergy model starting with the economic module.[4]

3.1 Economic module

The economic module of the general equilibrium bioenergy model consists of three parts: consumption, production, and market equilibrium conditions. We present these in turn starting with the demand structure.

3.1.1 Demand structure

Following *Kancs* (2002), the representative consumer's consumption problem is decomposed according to a "three-stage budgeting". This particular demand specification allows for sector-specific substitution possibilities between fossil energy goods, renewable energy goods and non-energy goods. In particular, we assume that Polish and imported energy goods are more substitutable than non-energy goods.[5] In the first stage (at the top level), the representative consumer maximises a constant elasticity of substitution production (CES) function of the composite energy good and of all final non-energy commodities (both imported and domestic) given income and composite prices. In the second stage, the representative consumer maximises a CES

[4] For a formal description of the general equilibrium bioenergy model see *Kancs* (2002).

[5] This assumption finds strong support in the data for varieties and prices of energy and non-energy goods (*Reilly* and *Paltsev* 2007).

sub-utility function of all composite energy commodities subject to the expenditure allocated to the total energy consumption from the first stage maximisation. In the last stage, the representative consumer maximises each of the sub-utility functions subject to the expenditure allocated to consumption of the energy (non-energy) commodity from the second-stage maximisation. The Armington assumption (*Armington* 1969) allows for both import and export flows in each sector – a fact, which has been increasingly observed in Poland's energy trade data.[6]

Similar to *Kancs* (2002), the total demand is made up of final consumption, intermediate consumption and capital goods. As for final demand the Armington assumption, which is also set for intermediate demand and capital goods, implies that intermediate input demand in a given sector is a composite of domestic and imported intermediate goods and is given by a CES function. The composite intermediate inputs are treated as a fixed share of total intermediate consumption, they cannot be substituted for. Final energy goods are also a part of intermediate inputs.

3.1.2 Production structure

Production makes use of three primary factors: capital and labour, which are perfectly mobile across sectors, and, for some sectors, of a specific factor (land or natural resources) (see Table 1 for sectoral aggregation). Thus, in this paper we explicitly model land. This extension, which was not accounted for in *Kancs* (2002), allows us to explicitly model the inter-sectoral competition for land and to assess general equilibrium impacts on prices for bioenergy and agricultural/forestry goods. Following *Bovenberg* and *Goulder* (1997) and *Diedrich* and *Petersik* (2001), factor endowments are assumed to be fully employed, which implies wage adjustment. While the latter assumption might not hold for labour, it is a reasonable assumption for other primary factors, such as land and natural resources, which is the main subject of the present study. Moreover, assuming fixed wage rate, this assumption is uncritical for labour too.

As in *Kancs* (2002), production process is represented by a three-level decision making of firms. At the first level each producer chooses between the value added and intermediate inputs according to the Leontief input-output production function. At the second level, each of the Leontief function arguments is defined. For those sectors, which only use the generic factors, the value added is a CES function of capital and labour. For forestry, bioenergy and agricultural activities, which also use a specific factor, the value added is a CES function of this specific factor and of a generic factor of production (which is a composite of labour and capital).

[6]The Armington assumption implies that imperfect substitutes can have different prices in different countries. A major modelling advantage of the Armington assumption is that it permits prices of immobile input factors to differ across regions. If markets are competitive, then differences in input prices lead to differences in output prices, and the Armington assumption provides an intuitive explanation of why consumers do not buy output goods exclusively from the region with the lowest price.

This particular nesting specification of production technology has several important implications for our study. The main advantage of this specification is that it allows for different degrees of substitution between factors of production in different energy sectors and in different input decision stages. In particular, this assumption allows us to assume that the elasticity of substitution between labour and capital is higher in industrial and service sectors than in bioenergy industries. On the other hand, the nesting specification of production technology has two drawbacks for our study: (i) it increases the required model parameters that need to be specified, and (ii) it requires a priori assumptions on input substitutability and complementarily, which cannot straightforwardly be defined among energy goods.

We assume that Polish producers can sell their energy goods and manufacturing services on domestic markets or export abroad. A constant elasticity of transformation (CET) function of output reflects transformation possibilities between domestic sales and sales on export markets. The higher is the elasticity of transformation, the more homogenous are goods sold domestically and goods exported to foreign markets. On the domestic market firms set prices equal to their marginal costs. On export markets they sell at the world market price, which can be increased by an export subsidy, for example, for bioenergy.

Different from *Kancs* (2002), we assume two forms of market competition in the model: perfectly competitive and imperfectly competitive industries (see Table 1 for market forms by sector). This assumption allows us to explicitly account for market imperfections in the Poland's energy sector, which are intensively documented in the literature (see e.g. *EC BREC* 2005). As usual in the monopolistic competition framework, we assume that in each imperfectly competitive sector there is a large number of operating firms. Each firm offers its own and unique variety of the same horizontally differentiated good. The producer price mark-up depends on the price elasticity between different varieties as perceived by firms. Thus, the output price mark-up is a function of the elasticity of substitution between varieties, which corresponds to the opposite of the price elasticity of demand addressed to a variety (there is always a high number of varieties in each sector) and hence to the opposite of the price elasticity of demand as perceived by a firm.

The total cost function of imperfectly competitive firms contains two types of costs: a fixed cost and a variable cost. Fixed costs give rise to increasing returns to scale, they are expressed as a fixed quantity of output. Variable costs incorporate primary factors and intermediate inputs and are proportional to firm output. Average cost equals the sum of constant marginal cost and unitary fixed cost. In sectors with perfect competition fixed cost is equal to zero and the number of firms is equal to one (see Table 1 for sectoral aggregation and the corresponding market forms).

Analogously to consumer behaviour, energy producing firms in Poland export their goods according to the Armington assumption. Given the insignificant share of Polish producers in the export markets, the imperfectly competitive Polish firms are assumed to exert their market power only in the domestic market, where they set output prices as a mark-up over marginal costs. Thus on the foreign market, where they naturally have less market power, Polish firms are considered as price-takers.

3.1.3 Energy market equilibrium

In the short-run, the number of firms is fixed and their profits can vary across the monopolistically competitive energy industries. In the long run, however, the number of identical firms in a sector varies endogenously in the model. If profits are positive, then new firms may decide to enter into the market while negative profits will induce a higher industrial concentration to exploit economies of scale and reduce fixed costs. Given the free market entry and exit, the number of firms adjusts by entering and exiting markets until the zero profit is established in each market. The long-run equilibrium is determined by zero excess demand on all commodity and factor markets.

As usual in CGE models, the domestic income corresponds to the total value added evaluated at net prices plus aggregate taxes minus aggregate subsidies. The model includes an income constraint, which states that total domestic income is allocated among consumption, investment and trade imbalance. As usual, savings are modelled as a fixed share of domestic income. Similarly, sectoral investments are also represented as a fixed share of aggregate investment. To carry out this investment, firms can buy either domestic or imported capital goods according to a CES function.

3.2 Environmental module

The most important methodological innovation of the present study is introduction of environmental module in the general equilibrium bioenergy model of *Kancs* (2002). The central goal of introducing the environment module is to capture the environmental impacts of policy adjustments. More precisely, the environment module allows us to study three important environmental issues: (i) global warming; (ii) problems related to the deposition of acidifying emissions; and (iii) ambient air quality linked to acidifying emissions and tropospheric ozone concentration.

The environmental module introduced in the present study is largely adopted from the GEM-E3 model (*Capros et al* 1997). As in GEM-E3, the environment module contains two submodules: (i) 'energy' submodule, which captures the effects of different policy instruments on the behaviour of the economic agents (e.g. additive (end-of-pipe) and integrated (substitution) mitigation); and (ii) 'environment' submodule, which uses all emission information and translates it into deposition, air-concentration and damage data. This submodule was constructed making use of emission coefficients from the literature.

We consider energy-related emissions of six primary pollutants: carbon dioxide

(CO^2),[7] nitrogen oxides (NO^x), sulfur dioxide (SO^2), volatile organic compounds (VOC) and particulate matter (PM), which are the main source of air pollution. NO^x is almost exclusively generated by combustion process, whereas VOC's are only partly generated by energy using activities. Other important sources of VOC's are the use of solvents in the metal industry and in different chemical products but are not considered here.

3.2.1 Energy adjustments

The 'energy' submodule of the environment module contains three mechanisms of emission reduction: end-of-pipe mitigation (where appropriate technologies are available), substitution between renewable and fossil energy and between energetic and non-energetic inputs, and emission reduction due to a decline in production and consumption. In this section we introduce the three mechanisms of emission reduction in turn starting with the end-of-pipe mitigation.

Emission reduction due to end-of-pipe mitigation is the first channel of energy adjustments. The end-of-pipe mitigation technologies of SO^2, NO^x, VOC and PM are formulated explicitly by bottom-up derived mitigation cost functions. Given that the marginal costs of mitigation are an increasing function of the degree of mitigation, these costs differ between sectors according to the sector-specific mitigation efforts already done.

Substitution between fuels and between energetic and non-energetic inputs is the second channel of energy adjustments. Given that production process is specified in form of nested CES-functions, there is (at least for a substitution elasticity greater than zero) some flexibility on the decision of intermediate use. Input demand is linked to relative prices of these inputs. Hence, if there is an extra cost on energy inputs, there will be a shift in the intermediate demand away from more expensive energy inputs towards less costly inputs. A politically imposed cost on emissions therefore drives substitution towards less emission intensive inputs, e.g. from coal to bioenergy or from energy to materials, labour or capital.

Emission reduction due to a decline in production and consumption is the third source of energy adjustments. In a general equilibrium system that assumes the interdependency of agent decisions, imposing an environmental constraint (through standards, taxes or other instruments) causes additional costs to production (which is linked to the costs of substitution or mitigation installation). An increasing selling price decreases demand of these goods even if this demand is inelastic to price changes (which is usually not the case) because of budget constraints. This lowers production and accordingly the demand for intermediates. Hence, there is an emission reduction due to a demand driven decline in production, which we explicitly account for in the general equilibrium bioenergy model.

Following the GEM-E3, we model firm behaviour such as to increase the relative

[7] CO^2 is responsible for 60% of the radiation causing global warming (*OECD* 2005).

cost of the polluting input (i.e. the price of energy) in the decision process of the firm. The dual formulation of the general equilibrium bioenergy model eases the incorporation of changes in economic behaviour due to emission or energy based environmental policy instruments. The costs of environmental policy requirements are added to the input (and consumption) prices. Intermediate demand is derived from the unit cost function which takes these extra costs into account. Similarly the demand of households for consumption goods is derived from expenditure function, which is the dual of the utility function. Hence, the additional policy constraint is easily reflected in both prices and volumes.

When an environmental tax is imposed, it is paid to the government by the sector causing the pollution. This assumption has several implications for the energy price modelling. First, the price of energy, inclusive the mitigation cost and taxes, is used in the decision by firm demand of production factors (at the energy level and implicitly at the level of aggregates). Thus, it captures the user cost of energy. Second, the price of energy, exclusive taxes and mitigation cost,[8] is used to value the delivery of the energy sectors to non-energy sectors (see Table 1 for energy and non-energy sector classification). Third, a price for the mitigation cost per unit of energy is defined, because the mitigation cost is defined in constant price. In modelling of mitigation activities, installing mitigation technologies is considered as an input for firms and not as an investment. The major advantage of this formulation is its simplicity, especially as the available mitigation cost functions are expressed in terms of annualised cost, and because within this framework, mitigation costs do not increase directly GDP as it would if modelled as investment. For the latter purpose a depreciation and replacement mechanism would have to be introduced. The user's cost of the mitigation equipment would have to be added to the capital income, avoiding however any double counting.

The input demand for mitigation is modelled in two steps. First, the demand for mitigation inputs is allocated to the delivery sectors through fixed coefficients. Second, the total delivery for mitigation is added to the intermediate demand and these inputs are valued as the other intermediate deliveries.

The consumer side of the 'behavioural' submodule is similar to the production side, with one major difference regarding the payment of the environmental taxes to the government. While in the case of firms the environmental tax is paid by the sector causing the pollution, for the households the tax is paid by the sector delivering the product causing pollution to the household. Thus, in the 'behavioural' submodule the environmental tax is treated as an indirect tax paid by households. As above, this has several implications for modelling price of energy goods. First, the price of energy in consumer expenditure allocation decision includes both mitigation cost and tax. We model it is as a user's cost of energy. Second, the price of delivery of energy to the household includes the pollution and energy tax. Third, a price

[8] I.e. it is the same price as in the general equilibrium bioenergy model without the environmental module.

for the mitigation cost is defined in the same way as for the production sectors. The mitigation expenditure of households are modelled as for the production sectors (allocation to activities through fixed coefficient technology and valued though the CES technology). They are not added to the private consumption and do not enter directly in the allocation of total consumption of final goods, only indirectly through the production cost of final goods (i.e. the deliveries by sectors to households).

3.2.2 Environmental costs

The main objective of the 'environment' submodule is computation of emissions, their transportation within Poland and monetary evaluation of damages caused by the emissions and depositions. The environmental cost analysis is conducted on a marginal basis, i.e. it assesses the incremental effects and costs compared to the reference situation.

As in GEM-E3, the 'environment' submodule contains three consecutive stages. First, the computation of emissions of air pollutants from different economic activities using sector-specific emission factors. Second, the determination of pollutants' transformation and transportation from energy producers to final consumers in Poland, i.e. the spatial effect of emissions. Third, the assessment of the value of environmental damages caused by the incremental pollution compared to a reference situation in monetary terms.

The emissions of primary pollutants, CO^2, NO^x, SO^2, VOC and PM, are differentiated by sectors and final goods that use the energy and are linked to the use of energy goods. This link concerns the energetic use of these inputs only. Non-energetic use like refinery and processing is treated separately. For private consumption the key linkages between energy inputs and consumption goods are specified similarly to production side.

The general equilibrium bioenergy model takes into account the spatial effects of emissions through transport coefficients, relating the emissions in Poland to deposition and concentration across different regions in Poland. For secondary pollutant as tropospheric ozone, it implies to consider the relation between the emissions of primary pollutants (NO^x emissions and VOC emissions for ozone) and the level of concentration of the secondary pollutants (ozone).

The environment damage estimates are computed making the distinction between global warming, health damages and other environmental costs. The coefficients for damage per unit of emission, deposition, concentration and per person and their valuation are based on literature estimates (*Loulou et al* 2005).

4 Empirical implementation

In this section we present the empirical implementation of the general equilibrium bioenergy model. We begin by identifying data requirements for the base year. As next we detail data sources which we use in the empirical analysis, where particular attention is devoted to parametrisation of the model. After data description we present the model's base run, which will be used throughout the rest of the paper as a benchmark in the comparative static analysis. Lastly, we present three policy scenarios, impacts of which we will simulate in the following sections.

4.1 Database

The general equilibrium bioenergy model, which we apply in this study, requires a detailed and internally consistent cross-section data for the base year that capture all for the present study relevant linkages between sectors, commodities and economic agents within the Polish economy. Given that only one cross-section of data is used in the empirical analysis, the quality and internal consistency of this data is extremely important for ensuring the reliability of predicted economic and environmental impacts of different renewable energy policies.

In order to compile a consistent data base for the general equilibrium bioenergy model, we draw on the most recent Input-Output tables and National Accounts available. In a first step, GTAP version 6.0 data base *Dimaranan* (2006), which contains 2001 data on input-output, value added, final demand, bilateral trade, tax and subsidy data for 57 sectors, was used to complete the Social Accounting Matrix (SAM) and foreign trade matrix. In a second step, the GTAP input-output data was complemented by two additional data sources. First, the energy production and energy input data from the Polish Emission Centre was used to obtain a more detailed breakdown of energy sectors. Second, the *Eurostat* (2007) production data and the *Central Statistical Office of Poland* (2007) macro-economic data, such as foreign direct investments, government deficit, sectoral labour demand, saving rate of private households and sectoral investment was used to update the GTAP data to 2004.

As a result, the developed SAM for Poland fully tracks the intensities of commodity use in each production and consumption sector for 2004. For the purpose of the present study, the SAM is aggregated into 2 regions (Poland and the rest of the world) and 8 sectors: agriculture and hunting, forestry, coal and peat, crude oil and natural gas, coke and refined petroleum products, electricity, gas, steam and hot water, and rest of the industry (see Table 1 for sectoral classification).

Given the renewable energy focus of our study, the empirical implementation of the general equilibrium bioenergy model requires a detailed statistical information about energy production, consumption of and trade with both renewable and fossil energy goods. An extended literature review indicates that it will be extremely difficult to obtain the true values of the renewable energy production and usage in Poland. Although, several national and international institutions, such as the Main Statistical Office, the Polish Ministry of the Economy and the *EC BREC* (2005) have estimated the share of renewable energy in the total primary energy balance, figures presented by different institutions vary considerably. In the context of the present study, the high divergence between literature estimates of renewable energy's share in the total primary energy balance makes a correct assumption about the actual production and utilisation of renewable energy in Poland hardly impossible.

In the present study we assume that the share of renewable energy in the consumption of primary energy was around 4.5% in 2004. However, in order to account for the extreme variations among different sources, we perform sensitivity analysis assuming that the share of renewable energy is 3% and 6%. The obtained sensitivity analysis results yield different absolute levels in production and consumption, but the production structure is similar to those results presented below.

Table 1: Sectoral classification and industry market form

Sector code	Sectors of the model	Market form
Energy industries with specific factor		
AAEN	Agricultural bioenergy sector	Perfect competition
AFORE	Forestry bio energy sector	Perfect competition
ACOELPE	Coal and peat activity	Monopolistic competition
Energy industries without specific factor		
AOIL	Crude oil and natural gas	Monopolistic competition
AELEC	Electricity gas steam, hot water	Monopolistic competition
Non-energy industries		
AACLT	Agricultural activity	Perfect competition
AFORE	Forestry activity	Perfect competition
AOIND	Other industry and services	Monopolistic competition

Source: GTAP 6.0, own aggregation.

4.2 Parametrisation of the general equilibrium bioenergy model

According to the general equilibrium bioenergy model, technologies of firms and preferences of consumers are represented by constant elasticity of substitution (CES) functions. The CES cost and utility functions contain two types of parameters: elasticities (also called responsiveness parameters) and position parameters (also called share parameters). The former define how input and goods ratios react to changing input and output price ratios. They are drawn from *Kancs* (2002). The latter fix input-output coefficients, given input and output prices. In other words, they shift input and output demand functions to the position implied by the data. They are calibrated within the general equilibrium bioenergy model.

The specific nesting technique of the demand and production structures adopted in the general equilibrium bioenergy model offers several advantages for empirical implementation of the model, such as allowing for sector-specific response on demand and supply side. The downside of the nesting approach is that it requires a considerable amount of behavioural parameters. Therefore, in order to meet the high demand of behavioural parameters a parametrisation technique known as calibration need to be applied.

The general equilibrium bioenergy model is calibrated to the 2004 data for Poland. The initial elasticities of substitution were set according to *Kancs* (2002). Elasticities of substitution between primary factors of production and for the Armington elasticities, energy sectors were differentiated from non-energy sectors. This assumption was subject to an intensive literature survey, which confirm that, the elasticities of substitution are indeed different between energy and non-energy goods. However, the elasticities of substitution are uniform within each commodity group (energy and non-energy). As usual, the calibrated parameters were subject to extensive sensitivity analysis. The sensitivity analysis results are available from the author. In addition to sensitivity tests, we compare the calibrated parameter values with those available in the literature. The closest estimates to our study are those of *Reilly* and *Paltsev* (2007).

Like most CGE models, our general equilibrium bioenergy model is written as a set of simultaneous linear and non-linear equations describing the behaviour of economic 'agents' and determining equilibrium conditions. The general equilibrium bioenergy model is solved in a comparative static mode, which allows us to directly compare the situations before and after implementation of policy instruments. Solving the model for the long-run equilibrium we obtain a set of endogenous variables, including household incomes, prices, supply and demand quantities for factors and commodities and welfare indicators. The model is implemented by the General Algebraic Modelling System (GAMS) and solved using the CONOPT and MINOS solvers (*Brooke et al* 1988).

4.3 Model's base run - BR

Base run (BR) serves as a reference scenario for measuring costs and benefits of alternative renewable energy policy instruments. Given that the base run serves as a benchmark in the comparative static analysis, its definition and assumptions made at this stage is one of the most critical issues for comparability of the simulation results. Unreliable assumptions in the reference scenario will likely lead to biased results, when turning to quantitative assessment of renewable energy policy instruments.

In order to adjust the general equilibrium bioenergy model for future changes in the macroeconomic environment in Poland, several a priori assumptions about exogenous policy and non-policy changes in the general equilibrium bioenergy model need to be made for projecting the 2004 base year situation to 2010.

First, the non-price-induced growth in production is incorporated into the model according to the technical progress. In the base run and in all policy scenarios the energy sectors' output growth rates are set to 2 % per year, which reflect the level of international long run averages.[9] In order to explicitly account for technical progress and increased efficiency in energy use, growth rate of the technical progress for energy inputs are set at slightly lower levels than those for outputs (1.5 %). The technical progress growth rates are assumed to be scenario-uniform, i.e. they do not vary among policy scenarios.

The next set of assumptions, which needs to be made in the general equilibrium bioenergy model, concerns the world market prices for energy and non-energy goods. In our study they are kept stable until 2010, they are not calculated endogenously in the model. However, we explicitly measure the effects of the world market price increase for energy goods in on of the policy scenarios (PWMINCR scenario).

Third, the empirical implementation of the general equilibrium bioenergy model also requires assumptions about changes in aggregated demand of energy goods in the Polish economy. Corresponding to the shift of supply curves, demand curves are shifted by the growth of population, individuals' income and changes in consumer preferences. Given that both the population and labour force growth are exogenous to our model, their long-run development needs to be assumed a priori. Recognising that Poland's population has decreased since re-establishment of the independence in 1990 and that this negative trend is slowing down and seems to be coming to a halt, 1 percent population and labour force growth per annum until 2010 seemed to be the most plausible assumption. The second shift factor on the demand side is that of income and expenditure growth. Since reliable long-term forecasts of economic growth for Poland are not available, the annual growth rate of income/expenditure has been set at 3 percent per annum.[10]

As usual, in order to check for model's robustness with respect to specific assumptions, we perform sensitivity analysis. I.e., we arbitrary change values of the assumed technical progress and growth rates and solve the general equilibrium bioenergy model for the base run equilibrium. The sensitivity analysis results indicate that the general equilibrium bioenergy model is not sensitive with respect to the growth rate of income/expenditure and technical progress. Instead, the sensitivity analysis results suggest that the specified general equilibrium bioenergy model is sensitive with respect to the assumed production and consumption share of bioenergy in total primary energy. These sensitivity analysis results highlight the importance of improving

[9] The imposed technical progress growth rate captures not only purely technical progress, but also the recovery of the Polish energy sector due to the progress in privatisation in the energy sector and restructuring of the Polish economy.

[10] One could presume an accelerated income growth after Poland's integration into the EU. However, since no reliable data is available, this will not be accounted for in our model.

the bioenergy data base in the CEE transition economies.

4.4 Renewable energy policy scenarios

In order to assess and compare alternative renewable energy policies, we construct several policy scenarios, each of which contains a set of policy instruments. In particular, based on suggestions of the expert appraisal on 'Economic and Legal Aspects of the Utilisation of Renewable Energy Sources in Poland' (*EC BREC* 2005) and on national energy authorities' requests, three renewable energy development scenarios have been designed for the purpose of the present study.[11] Each of the three renewable energy policy scenarios presumes implementation of different policy measures: (i) the bioenergy tax reduction scenario assumes indirect activity tax reduction for the bioenergy sector; (ii) the fossil energy subsidy reduction scenario assumes removing subsidies for the fossil energy sectors; and (iii) the PWMINCR scenario assumes a world market price increase for energy goods. In the following we present the three simulation scenarios in turn starting with the tax reduction for bioenergy.

4.4.1 Tax reduction for bioenergy (ATAXCUT scenario)

Adjustments in the energy sectors' tax rate serve as the departure point for policy experiments in our study. Instead of increasing the fossil energy sectors' taxes, the bioenergy tax reduction scenario assumes that the indirect activity tax has been reduced in 10% steps up to 50% for the bioenergy sector (ABEN) which, in other words, means that all fossil energy sectors ACOELPEA, AOIL and AELEC are in the bioenergy tax reduction scenario taxed twice as high as the bioenergy sector compared to the reference scenario (BR). Tax rates for all other sectors are kept at their base run level in the bioenergy tax reduction scenario.

The main economic motivation of the fossil energy tax compared to other policy measures could in Poland be that it limits the cost of government's interventions by allowing the renewable energy's production to sink if production costs are unexpectedly high. However, fossil energy tax does not guarantee a particular level of renewable energy to be achieved. This means that the fossil energy tax rate might need to be adjusted due to changes in external circumstances, like inflation, technical progress and increases in emissions. Therefore, it may be necessary to adjust the tax level after the first round of simulations and to repeat policy simulations in order to achieve the internationally agreed renewable energy commitment in the Accession Treaty with the European Union.

According to *Bovenberg* and *Mooij* (1994) and *Bovenberg* and *Goulder* (1997), implementation of the fossil energy tax touches on many modelling issues, such as

[11] The main criteria for selecting these policy measures we used were the minimisation of required state subsidies and tax relief subject to provision of favourable conditions for development of the renewable energy sector.

the tax base, the variation or uniformity across sectors, the association with trade, employment, revenue, or research and development policies, and the exact form of the tax implementation mechanism, e.g. a fossil energy tax alone or in conjunction with other policy measures. In the context of our study it seems reasonable to assume that the fossil energy tax requires Polish energy producers to pay an ad valorem rate for every output unit. Therefore, in the model it is treated as an indirect activity levy in terms of output value and is collected from the domestic energy producers only. Given that every fossil energy producers face a uniform tax rate on every output unit, changes in the tax rate could indeed result in the least expensive increase of the share of renewable energy throughout the economy, if energy, factor, and product markets are perfectly competitive (*Tietenberg* 2000). In Poland, however, energy markets are far from being perfectly competitive, implying that a fossil energy tax may not necessarily maximise the economic efficiency of energy production. Therefore, in the present study we assume monopolistic competition in the fossil energy sectors.

4.4.2 Abolishment of fossil energy subsidies (ASUBCUT scenario)

Evidently, impacts of a fossil energy tax reduction need to be compared with alternative policy instruments. For this purpose we develop a scenario of reducing energy sector's subsidies, which serves as a policy alternative to the bioenergy tax reduction scenario.

According to previous studies (*Bovenberg* and *Mooij* 1994, *Bovenberg* and *Goulder* 1997), even without raising new taxes, removing subsidies from the fossil energy sectors could create a win-win situation, encouraging in such a way renewable energy's production and avoiding dead-weight losses to the economy. In contrast, a renewable energy sector subsidy would lower relative costs of producing renewable energy by, for example, paying a subsidy per kWh produced, providing investment subsidies or fiscal benefits. Given that the use of fossil energy subsidies for competitive purposes may cause problems due to the WTO agreement on subsidies and countervailing measures, a reduction of the energy Producer Subsidy Equivalent (PSE) serve as a second scenario in the simulation experiments.

The main objective of the fossil energy subsidy reduction scenario is to reduce the relative fossil energy sectors PSE level compared to the bioenergy sectors. In order to achieve this we assume that in the fossil energy subsidy reduction scenario all fossil energy sectors' subsidies have been removed, by keeping the renewable energy sectors' subsidies at the initial level. The subsidy rates for all other manufacturing industries are kept at their base run level in the fossil energy subsidy reduction scenario.

According to the energy taxation studies (*Bovenberg* and *Mooij* 1994, *Bovenberg* and *Goulder* 1997), the main difference between a subsidy and an activity tax is that in the short run a subsidy may allow some firms to continue operating, which would not happen in the case of a tax (those with average variable costs above prices). Moreover, a subsidy requires the revenue to be raised somewhere else in the economy, which can also produce dead-weight losses. The two scenarios – bioenergy tax reduction and fossil energy subsidy reduction – should shed light on these issues in the context of Polish economy.

4.4.3 World market price increase for energy goods (PWMINCR scenario)

The third and last scenario – the world market price increase for energy goods scenario – offers a possibility for assessing impacts associated with fluctuations of world market prices for energy goods. The unpredictable fluctuations of world market prices for energy goods with a strong upward trend since 2002 are illustrated in Figure 2.

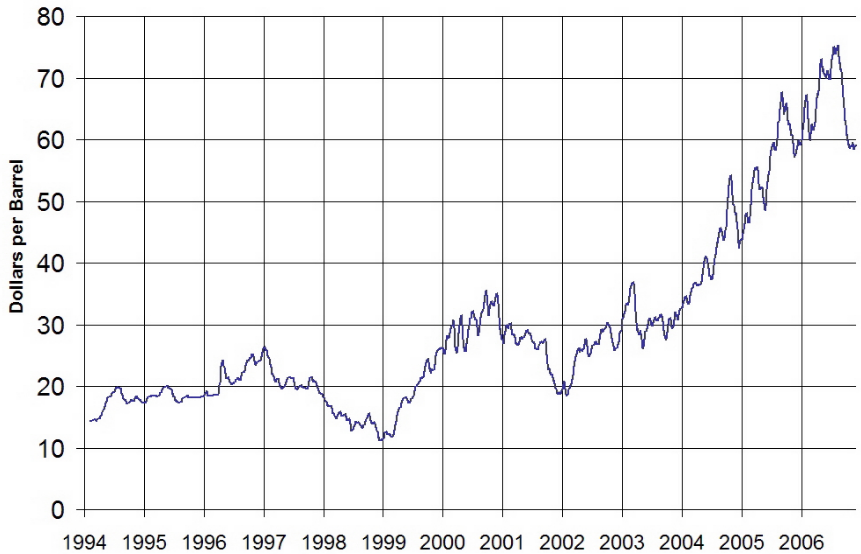

Figure 2: Oil prices on the world market in Dollars per Barrel, 1994 – 2006
Source: NYMEX (2007).

The sizeable price fluctuations for energy goods as reported in Figure 2 might be avoided if, for example, the energy is produced domestically from bioenergy crops. Therefore, in the context of the present study, the main objective of the world market price increase for energy goods scenario is to assess benefits from a long-run access to renewable energy supplies at relatively constant prices. The scenario of world market price increase for energy goods simulates a world market price increase for energy goods in 10% steps up to 50%, which roughly corresponds to annual energy price increase on the world market starting from 2002.

In addition to the base run assumption of technical progress, we also investigate an alternative scenario of world market price increase for energy goods, where the technical progress is faster than in the reference case. More precisely, in the second scenario of world market price increase for energy goods, the technical progress growth rate is assumed to be 4% per annum. Our motivation to associate an increase in the world market price with an increased productivity is given by the following two assumptions: (i) higher output prices create incentives for private investment, which together with increasing returns to scale leads to lower unit costs; (ii) higher output prices give rise to a higher revenue, which is usually associated with a higher investment in research and development.

5 Simulation results

In this section we present results of the general equilibrium bioenergy model's simulations of different renewable energy policy instruments and discuss their implications for the renewable energy policy making in Poland. In order to increase the transparency of the model-based simulation results, we decompose the total policy effects into price, quantity, welfare, and environmental impacts. In doing so we aim to facilitate the understanding and interpretation of differences between the renewable energy policy scenarios. Moreover, decomposition of the aggregate policy impacts not only facilitates the empirical analysis, it also provides a consistency check for the correct addressing of renewable energy policy questions.

5.1 Changes in relative prices

Adjustments in relative prices can be considered as a source of all further adjustments induced in the economy. Therefore, we start the discussion of simulation results by examining policy-induced changes in relative prices. According to the simulation results, the aggregate bioenergy sector's (AAEN in Figure 3) output price decreases by 2.26% compared to the reference scenario (BR), when indirect activity taxes are reduced by 50% for the bioenergy sector (left columns in Figure 3). All other activities' output prices have not been significantly affected by reducing the indirect tax rate for the bioenergy sector.

According to the theoretical framework presented in section 3, the impact of removing output subsidies depends on the sectoral characteristics of industries, on the type of subsidy involved and on the international co-ordination of implementing similar measures. According to our simulation results, removing the fossil energy sectors' subsidies leads to a remarkable increase in the aggregate output price for the coal and peat sector +1.94% compared to the reference scenario (BR) (see middle column of ACOELPEA in Figure 3). Compared to the other two fossil energy sectors, the coal and peat sector (AELEC in Figure 3) has been subsidised much heavier in the base run, 951.5 million PLN.[12] The crude oil and natural gas sector (AOIL in

[12] Polish zloty [Polski zloty], 1 Polish Zloty = 0.262183 Euro (2007.07.30).

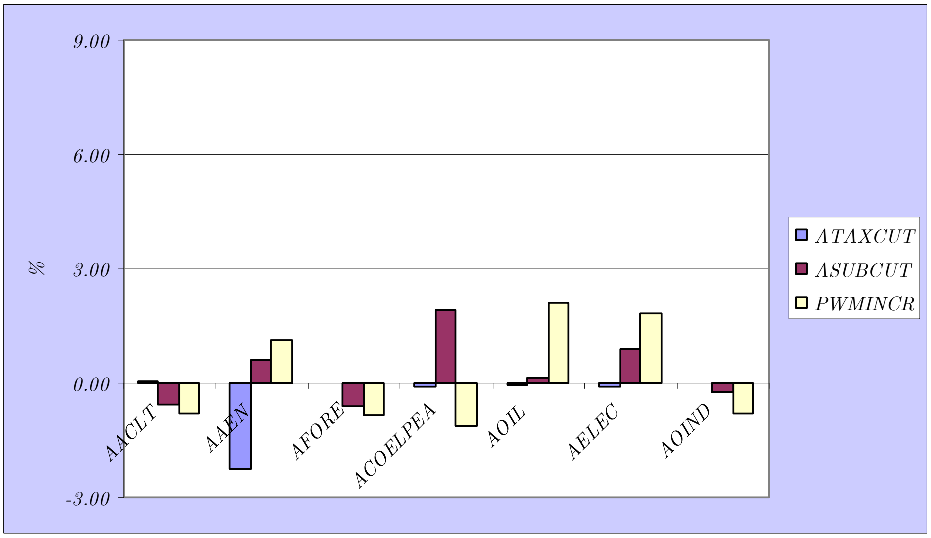

Figure 3: Changes in relative prices compared to the base run in percent

Figure 3) has not been subsidised in the base run at all and the electricity, gas, steam and hot water sector (CELEC) was subsidised only marginally, 79.3 million PLN.

The third scenario – the world market price increase for energy goods – has a sectorally differentiated impacts on the aggregate output prices (right columns in Figure 3). The simulation results reported in Figure 3 suggest the most sizeable aggregate price increase for the crude oil and natural gas sector (AOIL in Figure 3) as well as for the electricity, gas, steam and hot water sector (AELEC in Figure 3), 2.10% and 1.80% respectively. In contrast to our expectations, the aggregate output price of the coal and peat sector (ACOELPEA in Figure 3) has decreased compared to the reference scenario (BR), which requires a more detailed explanation. This general equilibrium effect, when an increase in the world market price leads to a decrease in domestic output price, can be explained according to our theoretical framework by considering each commodity's output price, which has been produced by the coal and peat sector. The output price for agricultural and hunting products (CACLT), and forestry commodities (CFORE) produced by the coal and peat sector has decreased by -0.93%, that of coal and peat commodities (CCOELPEA) by -1.72%, and the output price of other industrial goods and services (COIND), which has been produced by the coal and peat sector, has decreased by -0.88%. Although, output prices of the two remaining activities have increased significantly (+17.84% of crude oil and peat commodities (COIL) and +10.25% of coke and refined petroleum products (CPET)), their share in the total output of coal and peat sector is tiny, 0.23% and 0.01% respectively. Given that CACLT, CFORE, CCOELPEA and COIND goods have considerably larger weights in the electricity, gas, steam and hot water sector's aggregate price index, price increase effects have dominated over those of a price decrease. These adverse price effects are empirically significant and emphasise the importance of an integrated general equilibrium approach to the economy – energy – environment system.

5.2 Aggregate output effects

According to the general equilibrium bioenergy model, changes in the renewable energy policies affect the energy market equilibrium i.e. prices, and due to substitution effects, also quantities produced and consumed in each sector/commodity. Therefore, in order to account for these induced effects, the price-induced substitution effects between alternative sources of energy goods and between energy and non-energy goods and factors are presented next.

According to simulation results reported in Figure 4, the most sizeable increase in the aggregate output of +6.04% might expect the bioenergy sector, if the indirect activity tax would be reduced by 50% (left columns in Figure 4). These output changes are in sharp contrast to the moderate price changes of -2.26% and, therefore, require a more detailed explanation. Given that according to our theoretical framework, the long-run equilibrium is characterised by zero excess demand on all markets and that world market prices are determined exogenously, an increase in total output has to be led back either to an increase in commodity total demand and/or to a decrease in commodity production by other activities. The simulation results reported in Figure 4 suggest significant changes neither in agricultural and hunting products nor in electricity, gas, steam and hot water nor in goods services output levels by other activities. On the demand side, the prices of the two composite goods (CCOELPEA and CELEC) did not decrease significantly either. According to the theoretical framework, the sizeable increase in the aggregate output of bioenergy has to be associated with its negligible weight in Poland's GDP, which is rather marginal compared to fossil energy goods and services. This implies that if the demand for energy goods would increase, then the demand (and hence output) for bioenergy goods would increase over-proportionally compared to fossil energy goods, if the two types og energy goods (renewable and fossil) are substitutable, as in our study.

Removing the fossil energy sector's subsidies gives rise to an increase of aggregate output in two energy sectors, bioenergy (AAEN in Figure 4) and crude oil and natural gas sector (AOIL in Figure 4) (see middle columns in Figure 4). According to our theoretical framework, the markable increase in the aggregate output of bioenergy goods is caused by a decrease in relative output prices (see Figure 3). According to our simulations, the crude oil and natural gas sector would extend its production by 1.68%, because it has not been subsidised in the base run and, hence it has no direct revenue losses if fossil energy subsidies are reduced (see ATAXCUT in Figure 3).

In spite of these, in our view clear-cut simulation results, it is impossible to draw general policy conclusions of socio-economic impacts about a fossil energy subsidy reduction, because the aggregate effects of removing subsidies from the fossil energy

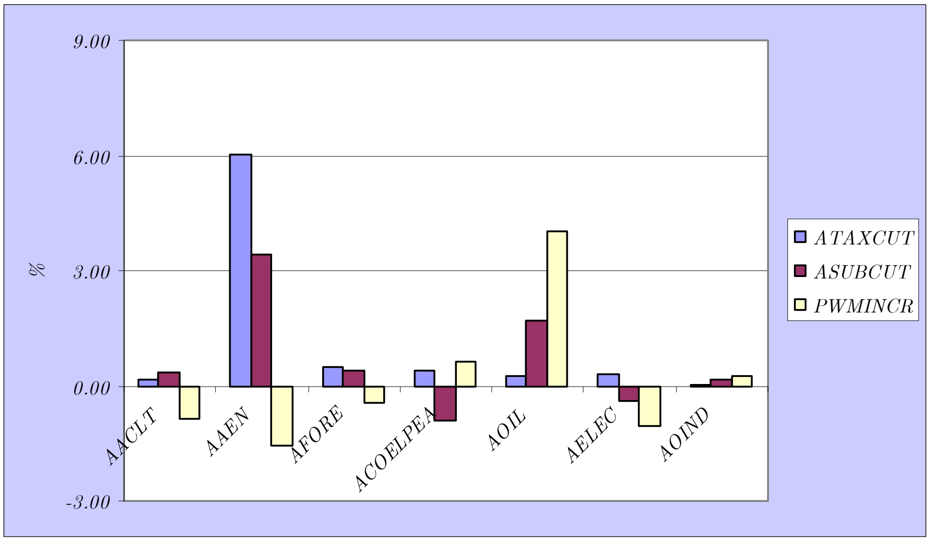

Figure 4: Changes in sectoral output compared to the base run in percent

producers depends heavily on the subsidy type and on the availability of alternative energy sources. Theoretically, it is also possible that removing a subsidy from an energy-intensive industry would subsequently lead to a shift in production from Poland to other countries with lower costs or environmental standards, resulting in a net increase of global fossil energy production and decreasing the share of energy from renewable sources.

According to the simulation results reported in Figure 4, the four energy sectors would adjust asymmetrically (both sign and magnitude), if the world market price for energy goods and services would rise by 50% (see PWMINCR scenario in Figure 4). For example, the crude oil and natural gas sector would extend its production by 4.02%. In contrast, the bioenergy sector, and the electricity, gas, steam and hot water sector would reduce their output shares by 1.56 and 1.05% respectively (see AAEN and AELEC in Figure 4).

According to the general equilibrium bioenergy model, which we apply in this study, these sectorally differentiated supply-side adjustments compared to the base run have to be seen in the context of the commodities' import/export shares. For example, the domestic supply with crude oil and natural gas has been heavily dominated by imports accounting to more than 80% in the reference scenario (BR). If the consumer price for imported goods would rise by 50%, the domestic producers would receive a relative price advantage compared to foreign competitors and expand their supply their shares in both domestic and foreign markets. These results are magnified by the fact that, according to our simulation results, the import share would be considerably smaller for the other three energy goods - CCOELPEA, CPET and CELEC.

When interpreting these simulation results, it has to be kept in mind that price signals can only translate into adjustments in the demand and supply quantities if they indeed reach all economic agents and if those economic agents have the opportunity to respond to them, as it is assumed in our general equilibrium bioenergy model. In a real economy, however, it takes time for economic agents to adjust their behaviour to new price signals, not only because of the capital stock turnover, but also because consumers often do not have full information about energy markets. For example, between 1990 and 2000 energy prices have almost doubled in Poland, whereas the energy intensity has declined only marginally at the beginning of that period (*EC BREC* 2005).

5.3 Welfare impacts

Next, we assess how different policy instruments might affect producer and consumer welfare in Poland. As usual, changes in producer welfare are measured as a difference between the total revenue and total costs. The simulation results reported in Figure 5 reveal that the renewable energy sector might experience the highest welfare gains in the case of producer tax reduction scenario (ATAXCUT) compared to the reference scenario (BR) and to the other two policy scenarios (see left columns in Figure 5).

The simulation results reported in Figure 5 do not suggest any welfare losses for the producers. According to the simulation results reported in Figure 5, three sectors (see AAEN, ACOELPEA and AOIL in Figure 5) would gain in terms of revenue if the fossil energy subsidy would be reduced (see ASUBCUT scenario in Figure 5). According to our theoretical framework, these revenue gains have to be led back either to the composite commodity's price increases and/or to the increases in sectors output level (see above). The simulation results reported in Figure 3 suggest that a world market price increase for energy goods (PWMINCR scenario in Figure 3) would favour, above all, the crude oil and natural gas sectors, whose total revenue would rise by 4.62% compared to the reference scenario (see AOIL in Figure 3). The impact on producer welfare in other sectors is less pronounced if the world market price for energy goods would increase by 50 %.

According to our simulation results, the average reduction of the state budget revenue due to reduced excise duty on bioenergy with a mixture of liquid biofuels amounts to 17.46 million PLN/year.[13] Thus, our simulation results suggest that increasing the share of bioenergy in the total energy supply would also increase the required amount of funding from public sources. However, assuming economies of scale and declining average costs in energy production, a growing renewable energy sector in Poland might allow for a significant decrease of public investment costs in the following years. Moreover, in the presence of declining renewable energy market entry costs, a further development of the renewable energy sector in Poland according to the objectives and targets set by the Polish government would require only a selective

[13] Polish zloty [Polski zloty], 1 Polish Zloty = 0.262183 Euro (2007.07.30).

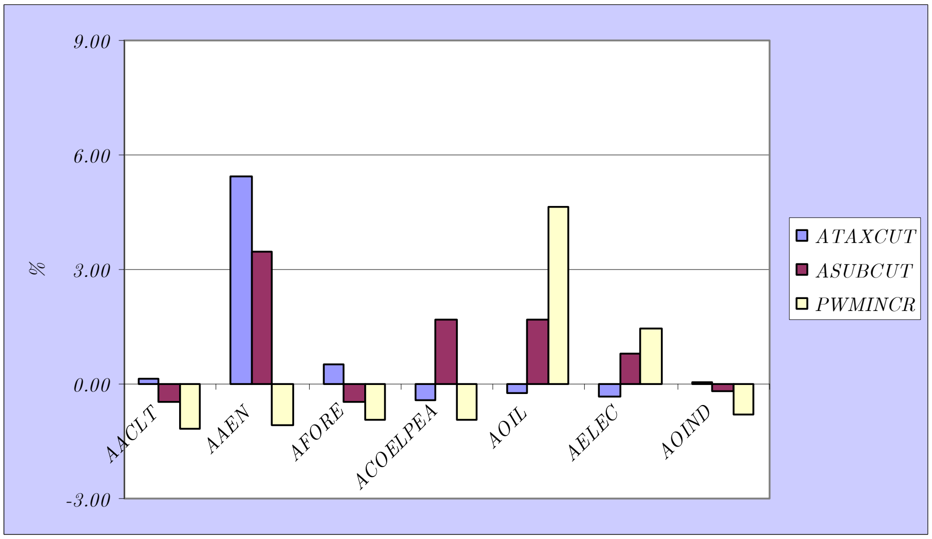

Figure 5: Changes in producer surplus compared to the base run in percent

support to the new technologies coming to the market implying that the government budgetary costs would likely decline.

The simulation results presented above and the following welfare analysis suggest that increasing the share of bioenergy in the total energy supply in 2010 would increase budgetary expenses from public sources. However, the specific budgetary effects, such as changes in government revenue, depend on how this additional money circulates in the economy. In our general equilibrium bioenergy model we assumed that the increased/decreased state revenues are not distributed (flexible government budget balance), which could potentially over/underestimate the aggregate welfare effects. An alternative to this approach could be to assume that the tax revenues collected from the fossil energy sectors are used for correcting market distortions in the Polish economy, e.g. adjusting the taxation of labour, which would benefit society not only by correcting the externality but also by reducing costs of the distorting taxes (the so-called "double dividend"). Indeed, previous studies (e.g. *Bovenberg* and *Mooij* 1994, *Bovenberg* and *Goulder* 1997) report that if the benefits from reducing existing taxes on labour are explicitly accounted for in the model, then the projected economic impacts could be substantially more optimistic than if no compensation or the lump-sum compensation is assumed. A third option would be to invest the surplus in research and development further developing the bioenergy's technology. This would decrease bioenergy production costs and increase competitiveness of the bioenergy sector. These extensions in the modelling framework is a promising avenue for future research.

6 Conclusions

In this study we assess socio-economic impacts of alternative renewable energy policy instruments in Poland. We have highlighted several issues, which might be useful for the renewable energy policy making. According to our simulation results, a fossil energy tax is more efficient than a subsidy. In line with previous studies, we found that a subsidy lowers the average cost of production, while a tax increases the average cost of production giving rise to a deadweight loss in the Polish economy. Our empirical results suggest that the bioenergy sector in Poland might benefit more from an indirect tax reduction than from a removal of fossil energy subsidies. These results underline the advantage of adopting a multi-input and multi-output framework, where producers are not forced to enter/exit the markets but can switch between producing different goods, when relative input and output prices change.

Our empirical results also suggest that sectoral impacts of a uniform policy shock might be asymmetrically distributed between various economic actors and sectors. Given that various energy (and non-energy) sectors have different production costs and price elasticities, they respond differently to equal policy measures. One of the main advantages of the underlying theoretical framework is the ability to capture these induced economy-wide effects. For example, we find that the aggregate non-energy industry and services sector (AOIND) might expand its output as a result of tax increase. Although counter-intuitive, the predicted production increase in the AOIND sector is well explained in the general equilibrium framework, which we adopt in the present study. Moreover, adopting the multiple input and multiple output production technology, we also account for the fact that larger sectors have a greater opportunity for substitution on the output side and can better respond to output price changes.

The downside of our approach is that, like any other economic model, the general equilibrium bioenergy model is based on many assumptions concerning the economic structure (market form, parameters of substitution and transformation, technical change and exogenous variables). Although, it is a necessity and indeed the intention of all models, including the general equilibrium bioenergy model applied in this study, to focus only on the most important economic-environment relationships, one has to bear in mind the assumptions made in the model, when interpreting the numerical simulation results.

References

[1] Armington, P.S. (1969), A theory of demand for products distinguished by place of production, IMF Staff Papers 16, pp. 159–178.

[2] Bovenberg, A.L., and R.A. de Mooij, (1994), "Environmental Levies and Distortionary Taxation", American Economic Review, Vol. 84, No 4 pp. 1085-1089.

[3] Bovenberg, A.L., and L.H. Goulder, (1997), "Costs of Environmentally Motivated Taxes in the Presence of Other Taxes: General Equilibrium Analyses", National Tax Journal, Vol. 50, No. 1 pp. 59-87.

[4] Brooke, A., D. Kendrick, and A. Meeraus (1988), "GAMS: a User's Guide", New York: The Scientific Press.

[5] Capros, P., Georgakopoulos, P., Van Regemorter, D., Proost, S., Schmidt, and Conrad, K. (1997), The GEM-E3 General Equilibrium model for the European Union, Economic and Financial Modelling, pp. 51-160.

[6] Central Statistical Office of Poland (2007), "Aktywnosc ekonomiczna ludnosci Polski", Glówny Urzad Statystyczny w Warszawie, Warsaw.

[7] Diedrich, R., T.W., Petersik, (2001), "Forecasting US renewables in the national energy modelling system", International Journal of Global Energy Issues, Vol. 15, pp. 141-158.

[8] Dimaranan, B. V., Editor (2006), Global Trade, Assistance, and Production: The GTAP 6 Data Base, Center for Global Trade Analysis, Purdue University.

[9] EC Baltic Renewable Energy Centre (2005), Progress report on the EU Renewable Electricity Directive in Poland, EC BREC.

[10] EC Baltic Renewable Energy Centre (2007), Dostosowanie Polskiego prawa do prawa UE w zakresie wykorzystania odnawialnych zródel energii, EC BREC.

[11] European Commission (1997), "Energy for the future: renewable sources of energy", White Paper for a community strategy and action plan.

[12] European Commission (SEC 2004), "The share of renewable energy in the EU, country profiles; Overview of renewable energy sources in the enlarged European Union', COM (2004) 366 final 547.

[13] Eurostat (2007), Statistical yield, production and area data for food crops for years 1995 – 2000 on Nuts-3 region level. , Statistical Office of the European Communities, Luxembourg.

[14] Hille, E. (2000), The Biomass Potential in Poland. Input paper for COOL Europe workshop 3 Polish Foundation for Energy Efficiency, Warsaw.

[15] International Energy Agency (IAE 2004), "Renewable Energy – Market and Policy Trends in IEA Countries' (International Energy Agency).

[16] Kancs, A., (2002), "Integrated Appraisal of Renewable Energy Strategies: A Computable General Equilibrium Analysis", International Journal of Energy Technology and Policy, Vol. 1, No. 2 pp. 59-90.

[17] Loulou, R., J.-Ph. Waaub, G. Zaccour (Eds) (2005), Energy and Environment, Springer, New York.

[18] Ministry of Environment of the Republic of Poland (2006), Informacja nt. wartosci opalowych i wskazników emisji, Krajowego Centrum Inwentaryzacji Emisji.

[19] Ministry of Environment of the Republic of Poland (2007), Projekt Polityki Ekologicznej Pañstwa na lata 2007-2010 z uwzglêdnieniem perspektywy na lata 2011-2014.

[20] Oniszk-Poplawska A., M. Rogulska, and G. Wisniewski (2003), "Renewable energy developments in Poland to 2020", Applied Energy, Vol. 76, pp. 101-110.

[21] Organisation for Economic Co-operation and Development (OECD 2005), "Biomass for Energy: Economic and Policy Issues", OECD, Paris.

[22] Pietruszko, S.M., G. Wisniewski, D. Chwieduk, and R. Wnuk, (1996), "Potential of renewable energies in Poland", Renewable Energy, Vol. 9, No. 1-4 pp. 1124-1127.

[23] Reilly, J., S. Paltsev (2007), "Biomass Energy and Competition for Land," in Economic Analysis of Land Use in Global Climate Change Policy, T. Hertel, S. Rose, R. Tol (eds.), Routledge.

[24] Tietenberg, T.H., (2000), "Environmental Economics and Policy: A Modern Approach", (Addison-Wesley).

[25] Vesterinen, P. (2004), Bioenergy in Poland – Local view about the current status and future prospects. VTT Project Report PRO2/P6036/04.