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Applied General Equilibrium Analysis of Renewable Energy Policies

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Abstract

In this paper we develop an applied general equilibrium framework 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 assess 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.

JEL classification: O13, P28, Q21, Q23, Q28, Q42.

1 Introduction

The development of the renewable energy sector – particularly energy from wind, water, solar power and biomass - is a central aim of the European energy policy at the beginning of the 21st century. The European Commission's White Paper for a Community Strategy (European Commission 1997) sets out a strategy to double the share of renewable energies in the gross domestic energy consumption in the European Union by 2010 from the present 6% to 12%. The renewable energy policy targets in the new EU member states are less ambitious. For example, Poland has set in its Development Strategy of Renewable Energy Sector a goal to increase the share of renewable energy in the gross domestic energy consumption from 3.8% in 2005 to 7.5 % by 2010 and to 14% by 2020 (Ministry of Environment 2006).

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The development of the renewable energy sector is strategically important for several reasons: (i) renewable energy has an important role to play in reducing Carbon Dioxide (CO^2) emissions, which is a major European Community objective in 21st century; (ii) increasing the share of renewable energy in the total energy balance enhances the security of energy supply by reducing the Community's growing dependence on imported energy sources; (iii) on the background of recent energy price increases renewable energy sources are expected to become economically competitive with conventional energy sources in the medium to long term.

Several of the renewable energy technologies, especially wind energy, hydro power plants and solar thermal applications, are economically viable and competitive. Sectoral competitiveness of other forms of renewable energy, in particular the energy from biomass, depend among other factors on increasing demand and thus on production volume in order to achieve the economies of scale, which are necessary for the sectoral competitiveness. These forms of renewable energy, which are not competitive under present market conditions yet, require appropriate market regulatory instruments, in order to achieve the required economies of scale in the short run and to become competitive in the long run.

The short-run competitiveness of the renewable energy sector can be improved using different forms of government interventions by applying different policy instruments. The selection of an appropriate renewable energy support mechanism with an optimal combination of policy measures, which have to be evaluated, prepared and implemented during the next financial framework 2007 – 2013, need to be performed on the background of renewable energy policy targets of doubling the renewable energy share within next five years in order to achieve the required levels by 2010 and by 2020. The main goal of the current study is to support the policy decision making in the renewable energy sector by assessing the socio-economic impacts of alternative policy instruments.

The paper is structured as follows. In section 2 we provide an overview about historical developments and the state of the renewable energy sector in Poland. We also briefly review the current renewable energy policy in Poland and in the EU. In section 3 we present the theoretical framework, which we apply in the empirical analysis. Section 4 presents the empirical implementation of the model. We also refer to main sources of the data and detail estimation of the 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 bioenergy in particular. Both energy production issues and energy consumption behaviour in Poland are discussed. 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 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 (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

[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 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).

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 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 ambitions of the European Union Poland has plans 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 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 EC Baltic Renewable Energy Centre (2005) and the Polish Ministry of Environment (2006), the current contribution of renewable energy in Poland is between 2.5% 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, recently in some minor 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

[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.

under construction. 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.

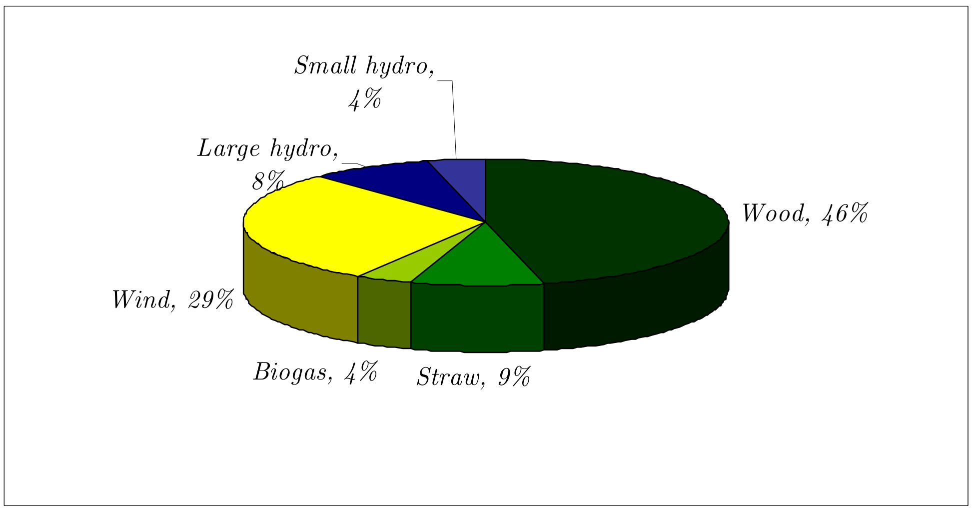

Figure 1: Projected contributions to total renewable energy production in Poland in 2010
Source: European Commission (2007).

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 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. This information about land availability in Poland will represent the endowment constrain of land 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" (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" (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 from 2.4% in 2001 to 7.5% in 2010. The quota obligation has not yet been enforced and it does not support the fuel-switching in the heating sector. Given that there is no real mechanism to enforce 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. 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.

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 use in the empirical analysis. Given that several methodological approaches can be applied for the renewable energy policy analysis, first we identify the criteria for selecting an appropriate theoretical framework. On the basis of these 'selection criteria' we subsequently select the most appropriate methodological approach for our study. Subsequently, we present the main building blocks of the bioenergy model: energy consumption, production and energy market equilibrium.

3.1 Requirements to the analytical framework

The empirical renewable energy literature suggests that several approaches can be used for evaluating renewable energy policies, which range from those simply focus on considering effects of individual policy instruments on employment, investment, and the movement of industry, to far more ambitious methods based upon cost-benefit analysis (Bovenberg and Mooij 1994, Bovenberg and Goulder 1997). One of the key considerations in selecting the appropriate analytical framework for the renewable energy policy analysis is model's ability to consistently reproduce the proposed policy instruments.

Beyond the ability to consistently reproduce the policy instruments, the renewable energy policy impact assessment model must possess several additional characteristics, in order to be useful for renewable energy policy planning purposes. These, second order properties of a renewable energy policy impact assessment model, can briefly be summarised as follows.

First, it is essential that the renewable energy policy impact assessment model is internally consistent, implying that the energy, economy and environment must be treated as one system of interdependent elements (sectors, policies, households, firms etc). Given that any exogenous policy shock (e.g. fossil energy tax) will have reverberations throughout the entire energy-environment system, the renewable energy policy impact assessment model must be capable of capturing and predicting general equilibrium effects of such external shocks. In the context of our study the analytical framework should also be able to deal with interactions between energy policy variables and the feedback characteristics of economy – environment relationships.

Second, the model must be sufficiently detailed for providing information about region and sector-specific policy implications. Thus, a detailed industrial breakdown of energy production and consumption is required. In the context of the present study, the model has to allow for distinguishing at least between the renewable energy industries (agriculture and forestry) and fossil energy sectors (oil, gas, coal).

Finally, the renewable energy policy impact assessment model should have an elaborated treatment of supply and demand for energy, which is differentiated by source. Given that the economy as a whole can behave in ways that cannot be deducted from examining its parts separately, it is very unlikely that any attempt to model the response of energy systems, which does not incorporate energy substitution mechanisms on both supply and demand sides, can ever be more than partially successful. On the demand side the model should have a possibility to substitute for other forms of energy and for other factors of production, e.g., fossil vs. renewable energy. On the supply side the model should allow for a substitution possibility between the energy crop production and the growing of conventional agricultural and forestry plants.

3.2 Choice of the modelling framework

The requirements to the theoretical approach, the most important of which we summarised in the previous section, considerably reduces the freedom of choice with respect to the methodological framework in the context of the current study. Among a few other methods, such as project-level Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), the Computable General Equilibrium (CGE) model is one of the few approaches that meets most of the methodological requirements listed above. The comparative advantage of CGE models compared to other methods lies in the ability to explicitly capture links between different sectors of production, links between macro and micro levels, and to disaggregate the total impact of changes in policies and exogenous shocks along to sectoral structure, household welfare and income distribution. In the context of the present study, the main downside of the CGE framework is that the empirical implementation requires far more data than comparable approaches.

Despite this drawback, considering the advantages a general equilibrium framework offers, in this study we draw on a CGE model, which has recently been developed by Kancs (2002). It is a multi-sectoral general equilibrium model integrating energy, economy and environment in a single system and allowing to carry out comparative static analysis by exogenously adjusting renewable energy policies or other macroeconomic conditions (such as world market prices) and subsequently quantifying the associated welfare and distributional impacts of these exogenous changes.

In order to make the model appropriate specifically for bioenergy policy analysis, more advanced features have been added in this study. Most importantly, the existing model has been extended to imperfect markets, allowing in such a way a more realistic mapping of energy markets in Poland. This feature is particularly important for agricultural and forestry sectors, which can produce both agricultural and forestry products as well as bioenergy goods. Second, for the purpose of the present study we update the model's base year from 1997 to 2004. Finally, we introduce land as a third primary resource and allow agriculture and forestry on the one hand and bioenergy on the other hand to compete for land. This extension 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.

The general equilibrium bioenergy model consists of three major blocks: production, consumption, and equilibrium conditions, which are introduced non-formally in the following sections. For a formal description of the general equilibrium bioenergy model see Kancs (2002).

3.3 The demand structure

Following Kancs (2002), the representative consumer's consumption problem can in our model be 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. 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 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.[4]

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, and cannot be substituted for. Final energy goods are also a part of intermediate inputs.

3.4 The 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 accounted for not 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 be true 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.

As in Kancs (2002), the 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).

[4] 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 it is in the 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 the transformation possibilities between domestic sales and sales on export markets. As higher is the elasticity of transformation, as more homogenous are goods sold domestically and goods exported to foreign markets. On the domestic market, firms set prices equal to the marginal cost. On the export markets they sell at the world market price, which can be increased by an export subsidy, for example, for bioenergy.

Different than in Kancs (2002), we assume two forms of markets in the model: perfectly competitive and imperfectly competitive industries (see Table 1 for sectoral aggregation and the corresponding market forms). 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 Baltic Renewable Energy Centre 2005). As usual in the monopolistic competition framework, we assume that in each imperfectly competitive sector the is a large number of operating firms. Each firm offer 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 and are expressed as a fixed quantity of output. Variable costs incorporate primary factors and intermediate inputs and are proportional to firms' output. The marginal cost is assumed to be constant and the average cost equals the sum of marginal cost and unitary fixed cost. In sectors with perfect competition the 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.

3.5 The energy market equilibrium

In the short-run, the number of firms is fixed and their profits can vary. In the long run, given the free market entry and exit, the number of firms adjusts by entering and exiting markets until the zero profit is established on each market. The long-run equilibrium is characterised by zero excess demand on all goods and factor markets.

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 modelled as a fixed share of aggregate investment. To carry out this investment, firms can buy domestic or imported capital goods according to a CES function.

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 all economic 'agents'. Solving the model for the long-run equilibrium, we obtain a set of economic variables, including household incomes, prices, supply and demand quantities for factors and commodities and welfare indicators. The general equilibrium bioenergy model is solved in a comparative static mode, which allows to directly comparing the situations before and after implementing policy instruments. The model is implemented by the General Algebraic Modelling System (GAMS) and solved using the CONOPT and MINOS solvers (Brooke et al 1988).

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 parameterisation of the model. Lastly, 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.

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 those linkages between sectors, commodities and economic agents within the Polish economy, which are relevant for our study. 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 socio-economic 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 data base version 5.4 Dimaranan (2002), which contains 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 and updated 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 than GTAP currently offers. 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 supply, saving rate of private households and sectoral investment was used to update the GTAP data from 1997 to 2004.

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: Own aggregation based on GTAP data base version 5.4.

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 GTAP data base version 5.4, the Main Statistical Office, the Polish Ministry of the Economy and the EC Baltic Renewable Energy Centre (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.

4.2 Parameterisation 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 adopted nesting approach is that it requires a considerable amount of behavioural parameters. Therefore, in order to meet the high demand of behavioural parameters a parameterisation 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).

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 parameters of 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.[5] 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

[5] 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.

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 independence, while 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.[6]

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 results of sensitivity analysis suggest that the specified general equilibrium bioenergy model is sensitive with respect to the assumed production and usage share of bioenergy goods, which turn out to be one of the most critical assumptions in empirical implementation of our model. Again, these results highlight the importance of reliable data for bioenergy production and usage in CEE transition economies.

5 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 subsequently been designed. 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. The following sections present the three renewable energy policy scenarios.[7]

[6] 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.

[7] 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.

5.1 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 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.

5.2 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.

5.3 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.

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.

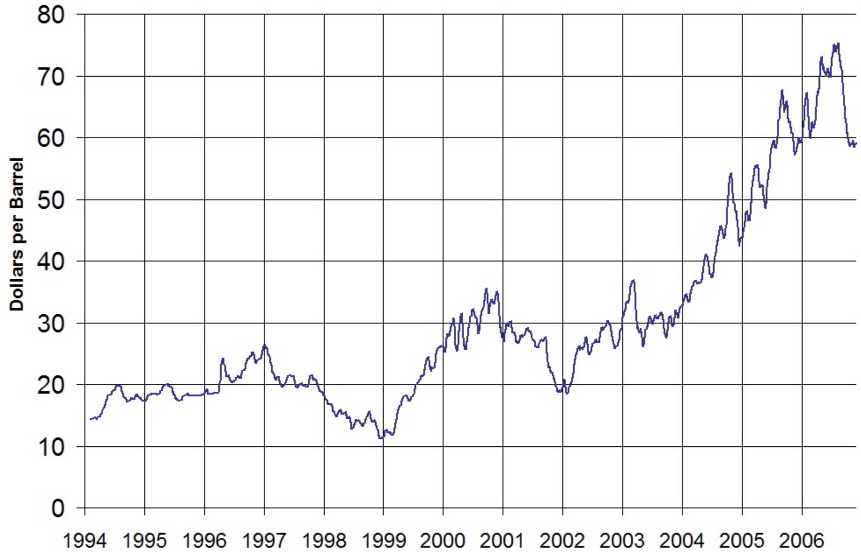

Figure 2: Oil prices on the world market in Dollars per Barrel, 1994 – 2006
Source: NYMEX (2007).

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.

6 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 and welfare effects. In doing so, we hope to facilitate the understanding and interpretation of differences between the renewable energy policy scenarios. Moreover, decomposition of the aggregate welfare impacts not only facilitates the empirical analysis, it also provides a consistency check for the correct addressing of renewable energy policy questions.

6.1 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.

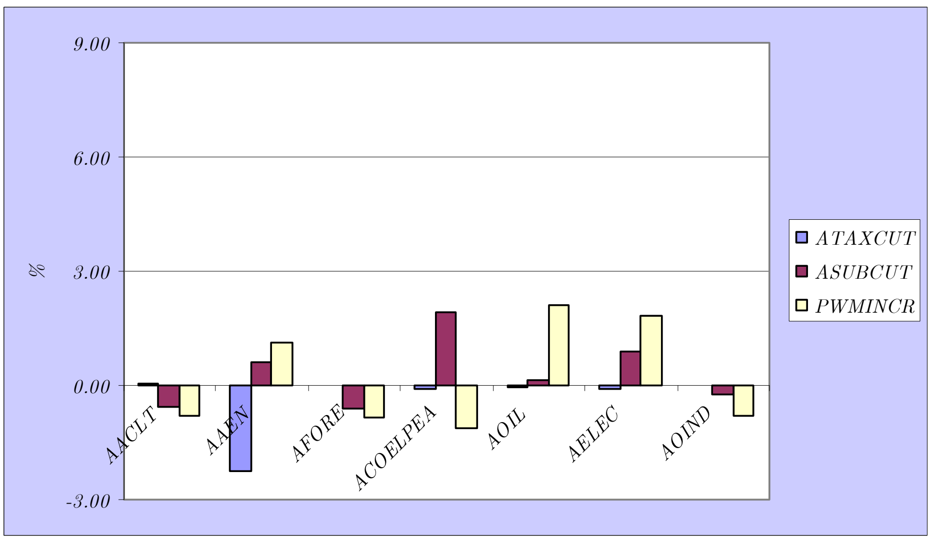

Figure 3: Changes in relative prices compared to the base run in percent

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.[8] The crude oil and natural gas sector (AOIL in

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

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.

6.2 Aggregate output effects

According to the general equilibrium bioenergy model, any changes in the renewable energy policies disturb 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.

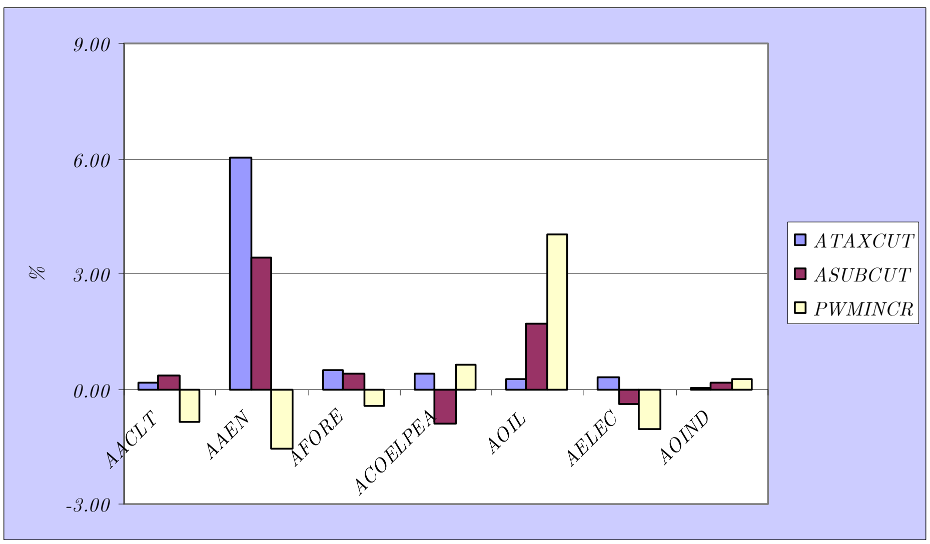

Figure 4: Changes in sectoral output compared to the base run in percent

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 inthe 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 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).

6.3 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 %.

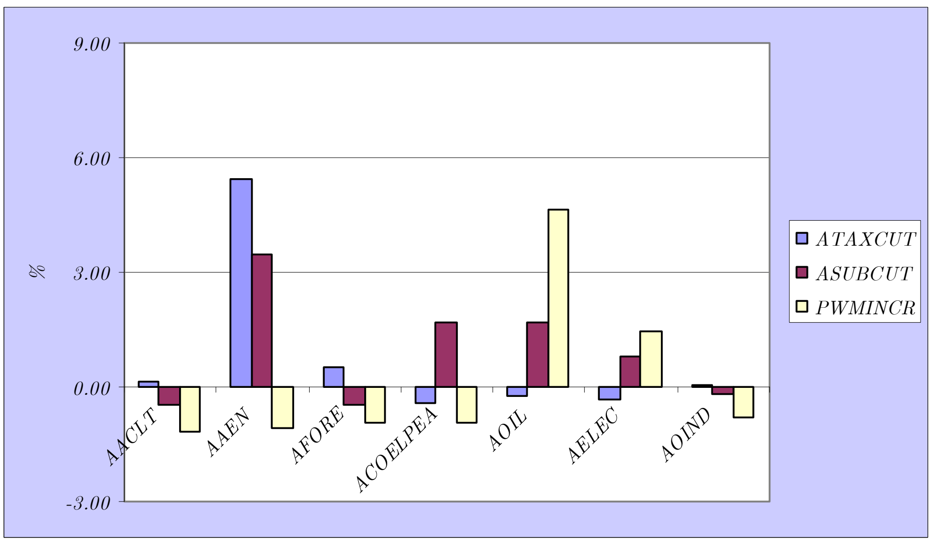

Figure 5: Changes in producer surplus compared to the base run in percent

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.[9] 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 accord-

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

ing to the objectives and targets set by the Polish government would require only a selective 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.

7 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 technology, 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. Our theoretical framework offers the advantage to be able 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 abstract from the much more complex reality of economic-environment relationships, one has to bear in mind the assumptions made in the model, when interpreting the numerical simulation results.

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