Modelling renewable energy policies

d'Artis Kancs

Massachusetts Institute of Technology
MA-02139, Cambridge
E-mail: kancs@mit.edu

Abstract: The preparation, implementation, coordination and verification of policy measures is a complex and difficult process. This paper presents the first results of an empirical ex-ante analysis which evaluates the effects of renewable energy policies on the Polish bioenergy sector applying an Applied General Equilibrium model. The empirical results suggest that the Polish bioenergy sector benefits more from an indirect tax reduction than from the removal of fossil energy sector subsidies. Reductions in fossil energy sector output below the reference case (base run) do not impact on all fossil energy sectors equally. The crude oil and natural gas sectors lose less (gain more) compared to other fossil energy sectors by implementing renewable energy policy measures.

Keywords: Renewable energy policies; Applied General Equilibrium; renewable energy; CGE

JEL: D 58, H 25, Q 28

1 Introduction

Renewable energy use is becoming a more and more serious challenge for countries, for which sustainable development also means a better utilisation of raw the materials of energy and an improvement in the state of the environment. The Polish economy is one of the most energy-intensive in the world. Poland has quite large renewable energy resources, although their utilisation in various regions of Poland is differentiated. The share of renewable energy in primary energy use in Poland amounts to 2.5%, whereas in the European Union it amounts to 6%. Estimated figures concerning the utilisation of renewable energy in selected countries of the European Union and in Poland in 1995 are given in Table 1. The integration process with the European Union, as begun in Poland, obliges Poland to undertake actions aimed at developing the energy use from renewable sources [1]. At the same time this provides the chance to take advantage of substantial Community assistance in this field in the pre-accession period.

However, it is envisaged that without accompanying measures Poland will not be in a position to reach the required 14% level. The quantity Poland assumes, as calculated on the basis of different analyses and comparisons, amounts to about 7.5%. This is merely half of the share being stated in the agreement with the European Union. Accompanying measures, which are to be prepared, implemented and verified during the pre-accession period, should allow for doubling the renewable energy share in Poland, and to achieve this value at the level of 14%. To prepare, implement and verify accompanying policy measures, socio-economic benefits, costs, and trade-offs associated with each measure must be identified and their impact on social welfare estimated. This is the main goal of this study.

1.1 Primary energy sources in Poland

The share of renewable energy in the world's energy balance is around 18%. This figure is high due to both the development of new renewable technologies and to the fact that a large part of the world's population does not have access to conventional energy sources (see Figure 1).

The Polish economy relies heavily on domestic coal, which provides 76% of primary energy. Oil and gas contribute 21%, and other sources, including renewable energy, contribute the remaining 3%. In fact, Poland has only very scarce deposits of gas and oil. In addition, the potential for hydropower and wind energy is relatively small. Consequently, power generation and space heating (to a lesser degree) are almost entirely coal-fired. These practices place Poland very high on the list of per capita air polluters, with 8.74 tonnes per capita in 1998 [EIA 2002].

Table 1 Share of renewable energy in selected countries of the European Union in 2000

Country	*Share of renewable energy, %*	*2010 Target, %*	*Increase, %*
Austria	72.7 [2]	78.1	7
Sweden	49.1	60.0	22
Portugal	38.5	45.6	18
Finland	24.7	35.0	42
Spain	19.9	29.9	48
Italy	16.0	25.0	56
France	15.0	21.0	40
Denmark	8.7	29.0	233
Greece	8.6	20.1	134
Germany	4.5	12.5	178
Ireland	3.6	13.2	265
Netherlands	3.5	12.0	243
Poland	**2.5**	**12.0**	**480**
Luxembourg	2.1	5.7	171
UK	1.7	10.0	488
Belgium	1.1	6.0	445
European Union	13.9	22.1	58

Source: RBI 2001

The growing energy demand caused by rapid economic development, limited resources of fossil fuels as well as excessive pollution of the environment have caused major interest in renewable energy sources in Poland. As Tokarczuk [3] states:

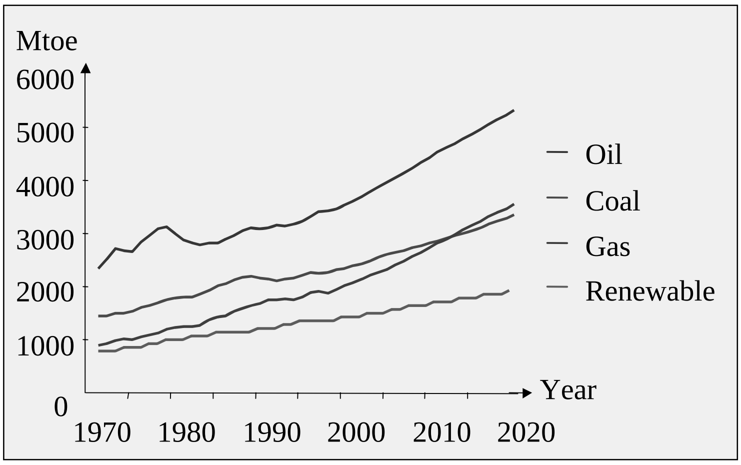
> "I consider the issue of unconventional energy sources as…the chance for rural communities and counties, as well as for households. Utilisation of local energy resources will create new labour places in rural areas, but first of all, it will guarantee both the independence of regional development and the energy security to rural communities."

As a result of a growing environmental awareness in society and a growing interest in renewable energy sources in Poland, the share of renewable energy in total primary energy has increased steadily in recent years [EC BREC 2000].

According to the EC Baltic Renewable Energy Centre [EC BREC 2000], the basic sources of renewable energy in Poland were biomass and hydro in 1999 (see Table 2). Geothermal energy, wind power and solar energy were of lower significance. In 1999 biomass amounted to more than 98% of the energy from renewable source in Poland. Solar, wind and hydro resources are very limited due to Poland's geographic and topographic conditions. Consequently, the only significant potential source of renewable energy that can be developed in the near future is biomass, predominantly wood and straw.

Despite the growing interest of society, the utilisation of energy from renewable sources is facing serious financial problems in Poland mainly due to limited government support for renewable energy systems. The extensive subsidy programs for both food crops and fossil fuels have created a substantial barrier to energy crops. The environmental costs of fossil fuels and row farming are not included, so the benefits of biomass are not valued as they should be. Even funding for research and development has been limited. Another problem relates to high investment costs although operational costs are relatively low. Given the current level of prices for fossil fuels, the renewable energy cost structure is the reason why the payback time of renewable energy projects is long. Another problem is that renewable energy equipment is typically manufactured by small and medium enterprises with low capital, which are often unable to survive in the current bank loan system if their financial resources are frozen. The lack of necessary know-how and experience in the formulation and financing of projects are further problems. [Pietruszko et al 1996, Chwieduk 2000].

Figure 1 World primary energy supply, 1970-2020



Source: Own figure based on EIA 2002

There are many types of plants in Poland, and many ways in which they can be used for energy production. In general there are two approaches: growing plants specifically for energy use, and using the residues from plants that are used for other purposes. The best approaches vary from region to region according to climate, soils, geography, population, and so on.

1.2 Bioenergy's potential in Poland

In Poland biomass is being utilised in direct combustion processes in a solid (wood, straw) and gaseous form (biogas) as well as processed into liquid fuels (oil, alcohol). According to the [EC BREC 2000], the basic sources of biomass for energy production in Poland are energy crops and firewood (estimated figures concerning the utilisation of biomass for energy production by source in 1999 are given in Table 2). Crop residues, animal waste and municipal waste biomass are very limited and their share in total biomass supply will even decrease in the near future (see Figure 2). Energy crops, also called 'power crops', could be grown on farms in potentially very large quantities, just like food crops. Trees and grasses are the best crops for energy, but other, less agriculturally sustainable crops, like corn, tend to be used for energy purposes at present.

Wood for heating purposes has been traditionally used in Poland for many years. In Poland, forest areas occupy 28.8% of the country including state-owned forests with 7.4 million hectares. It is estimated that the forest areas will be developed to 33% in the year 2025. In 1997, 21.6 million m³ of wood was obtained from the state-owned forests, including 2.5 million m³ of firewood. The

Main State Forest Management Board [MSFMB 2002] estimates that a further 2-2.5 million m³ of waste wood remains in the forests due to limited demand. In addition to growing very fast, some trees grow back after being cut down close to the ground, a feature called ‘coppicing.’ Coppicing allows trees to be harvested every three to eight years for 20 or 30 years before replanting. These ‘short-rotation woody crops’ grow as much as 10-15 metres high in the years between harvests. In the cooler, wetter regions of northern Poland, varieties of poplar, maple, black locust, and willow are the best choice. In the warmer southeast, sycamore and sweet gum are best. Currently, experiments are being carried out in Poland with fast-growing trees, e.g. willow (*salix vinimalis*). The current number of wood-fired installations is estimated at over 100,000 units and the total capacity of state-of-the-art wood-fired boilers in homes, the wood processing industry and in the municipalities is estimated at around 600 MW [RBI 2001].

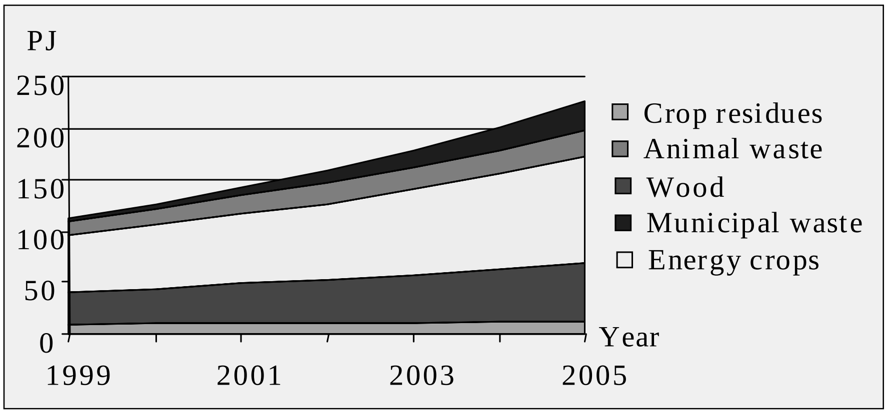
Table 2 Utilisation of renewable energy in Poland in 1999

	Energy utilisation from renewable sources in 1999	
	PJ	*%*
Biomass	101.8	98.0
Water energy	1.90	1.83
Geothermal energy	0.10	0.10
Wind energy	0.01	0.01
Solar energy	0.01	0.01
Total	103.8	100.0

Source: EC BREC 2000

However, as firewood resources will be exhausted, growing special energy crops must be considered. Switchgrass, big bluestem, and other native varieties grow quickly in many parts of Poland, and can be harvested for up to ten years before replanting. Thick-stemmed perennials, like elephant grass, can be grown in hot and wet climates like those of southern Poland. At present, there are already several hundred plantations in Poland with a total area exceeding 1,000 hectares [RBI 2001]. The majority of them are test plantations and only few operate on the basis of commercial production of biomass for energy purposes. Future plantations may be established at infertile and/or contaminated soil, thus offering chances to implement of alternative farm production.

Figure 2 Biomass utilisation by source in Poland, 1999–2005



Source: Own figure based on RBI 2001

A third type of grass includes annuals commonly grown for food, such as corn and sorghum. Since these must be replanted every year, they require much closer management and greater use of fertilisers, pesticides, and energy. While corn currently provides most of the liquid fuel from biomass in Poland, there are more sustainable ways to produce energy from plants. Plants such as soya beans and sunflowers produce oil, which can be used to make fuels. Like corn, though, these crops require intensive management and may not be sustainable in the longer term. A rather different type of oil crop with great promise for the future are microalgae. These tiny aquatic plants have the potential to grow extremely fast in the hot, shallow, saline water.

After plants have been used for other purposes, the leftover wastes are used for energy. The forestry, agricultural, and manufacturing industries generate plant and animal wastes in large quantities. City waste, in the form of garbage and sewage, is also a source for biomass energy [Pietruszko et al 1996, Chwieduk 2000].

Forestry wastes are the largest source of heat and electricity now, since lumber, pulp, and paper mills use them to power their factories. One large source of wood waste are tree tops and branches normally left behind in the forest after timber-harvesting operations. Some of these must be left behind to recycle necessary nutrients to the forest and to provide a habitat for birds and mammals, but some could be collected sustainably. Other sources of wood waste are sawdust and bark from sawmills, shavings produced during the manufacture of furniture, and organic sludge, or ‘liquor’, from pulp and paper mills.

Just as in forestry, most crop residues are left in the field. Some are left there to maintain cover against erosion and to recycle nutrients, but re collected for fuel. Crop residues, particularly surplus straw are also utilised for energy production thus yielding additional profits or generating savings for farms. At the moment, straw is utilised in around ten district heating plants supplying heat to local housing estates in Poland. The total installed capacity of these in 1999 was around 13 MW [RBI 2001]. The surplus straw utilisation is making advances in market conditions, without any significant support from the state, and is usually based on technologies available within Poland. Another conspicuous feature of the current utilisation of solid biomass is the use of non-standard and non-commercial crop residues, such as straw, whose market prices are the lowest. Polish farms produce around 25 million tons of straw (mainly cereal and rape) and hay every year. Some straw is used as bedding material and fodder in animal breeding and as fertiliser, although, since 1990, the amount of surplus straw has been growing, particularly on farms in northern and western Poland, mainly on former state-owned ones, yet the majority of straw available for energy purposes is not utilised. A sizeable portion of surplus straw is burnt in the fields, a fact which poses a serious environmental and health hazard.

Biogas produced from diluted animal manure is another source of renewable energy in Poland. Animal farms produce much ‘wet waste’ in the form of manure. Traditionally, this is used as a fertiliser and sometimes stored at landfills. Both may cause environmental problems relating to pollution of rivers and underground water, odour emission and other health hazards. One of the ecologically acceptable forms of utilisation of animal waste is anaerobic digestion. Around ten farm biogas plants have been erected in Poland since the middle of the 1980s. At the moment, the majority of them are not working for both economic and technical reasons. Prospective investors have been discouraged by high investment costs and the lack of adequately proven technological solutions [Pietruszko et al 1996, Chwieduk 2000].

Besides utilisation in direct combustion processes in a solid (wood, straw) and gaseous form (biogas), biomass is processed into liquid fuels (oil, alcohol). The technical potential of liquid fuels obtained from biomass conversion, such as petrol with ethyl alcohol admixture and a fuel obtained from vegetable and animal fat, is estimated at 12-17 PJ/year. According to current Polish norms, only 5% of ethanol may be added to traditional fuel [RBI 2001]. Ethanol may be produced from raw materials such as cereals, potatoes, sugar beets and molasses. As from 1996, almost the whole Polish production of bio-ethanol (dehydrated ethyl alcohol of vegetable origin) amounting to around 110 million litres has been used as a fuel admixture.

1.3 Objective of the study

Given the growing share of renewable energy in global primary energy utilisation and in particular in Poland, it is becoming more and more important to quantify the economy-wide costs and benefits of the accompanying measures promoting the renewable energy sector.

The Polish CGE model presents an analytical tool for quantifying the economy-wide costs and benefits of accompanying measures promoting the renewable energy sector. The Polish CGE model is not intended to forecast the values of economic variables, but rather to provide useful insights that may help policy makers to undertake more substantial policy actions. The model uses the micro-economic theory and produces results from renewable energy policy experiments and an external price shock to the Polish economy, which can not be falsified.

Growing special energy crops requires the diversification of agricultural land to create short-rotation woody crops (such as poplar and willow) or switch grass for power generation. The usage of land to raise power plant biomass requires the diversification of existing crops, pastures, grazing or forested lands into biomass cultivation and in turn might stimulate the transformation of such land into agricultural production. Simultaneous shifts in production alter agricultural commodity prices. Taking into account these relationships, examination of the biomass alternatives requires an assessment tool, which explicitly considers agricultural production, agricultural product prices, capabilities of land if planted with biomass products, and the allocation of land between forestry and agriculture.

2 Model's description

Computable General Equilibrium (CGE) models can be defined as economy-wide models which depict a simultaneous general equilibrium in all markets of the economy. They provide a comprehensive account of the circular flow payments in the economy. CGE models are widely applied to policy analysis in developed as well as developing countries. The comparative advantage of the CGE models lies in the analysis of policies, when there is a need to consider links between different sectors of production, links between macro and micro levels, and the dis-aggregated impact of changes in policies and exogenous shocks on sectors' structure, household welfare, and income distribution. There are four key features of a Computable General Equilibrium model that makes it a particularly appropriate tool for analysing impacts of various renewable energy policies.

First, CGE models have a micro-economically founded theoretic structure that captures the entire interactions of an economy. A consistent global perspective offers advantages compared to partial equilibrium models, which often miss important inter-market relationships and ignore macroeconomic impacts. Second, general equilibrium models are able to analyse large, discrete, external shocks such as the world market price increase for energy products by 40% from baseline estimates. Econometric based models make questionable inferences when shocks are outside the range of historic variation. The third advantage that CGE models have in the context of policy planning is that they are calibrated to actual input-output data, ensuring that the relative size and importance of various sectors and markets are taken into account when tracing policy impacts throughout the economy. Last, but not least, the focus of a CGE model can be steered on those parts of the economy where the most important adjustments take place. The scaling of markets and sectors in a CGE model founded on data reveals impacts, which are initiated by policy changes' effects.

The Poland CGE model is structured in the neo-classical modelling tradition and provides a simulation laboratory for carrying out controlled experiments, changing policies and other exogenous conditions (such as external price shock), and measuring the impact of these changes. To make it appropriate for renewable energy policy analysis, more advanced features have been added to the existing Poland CGE model, drawing on the resent energy research at IIASA. Most importantly, the existing Poland CGE model has been extended to multiple input and multiple output technologies, allowing in such a way a greater substitution possibilities between energy goods on the production as well as on the consumption side. This feature is particularly important for agricultural and forestry sectors, which can produce both agricultural and forestry products, and energy goods. In additions, the model can treat explicitly biomass' conversion into the energy.

Like most CGE models, the Poland CGE is written as a set of simultaneous linear and non-linear equations defining the behaviour of economic agents. For production and consumption decisions, firms and households behaviour is captured by first-order optimality conditions. The model's equations also include a set of constraints (equilibrium conditions) that have to be satisfied by the system as a whole but which an individual actor does not necessarily consider. The model consists of four major blocks: production, consumption, institutions and equilibrium conditions. There is no objective function. The Poland CGE is solved in a comparative static mode. Each solution provides a full set of economic indicators, including household incomes, prices, supply and demand quantities for factors and commodities, and welfare indicators.

In general, both supply and demand sides of the model in terms of imports and exports adopt the small country's assumption. A second fundamental assumption of the model is that of perfect markets for producers and consumers of goods and services in Poland. Producers and consumers of market goods and services are assumed to behave as price takers on both input and output markets according to which the profit maximisation problem is presented as the decision-making process of a single representative producer for each sector in Poland. This producer of market goods and services chooses input and output quantities at given market prices so that his revenue minus production costs is maximised. In order to be able to study the distributional impacts of government policy changes, the model dis-aggregates the economy into a range of producer goods (activities), consumer goods (commodities) and economic agents (government, households and firms). This section gives an overview of the basic characteristics of the model's structure in general and of each of it's four blocks.

2.1 Production structure

The production block forms the core of the model and is connected though CES (Constant Elasticity of Substitution) and fixed input-output coefficients (LEONTIEF) production functions between each other and to all the other model's blocks (see Figure 3). A combined LEONTIEF, ARMINGTON and nested CES production structure is used for capturing production decisions. The nesting approach minimises the requirements for elasticities that need to be estimated or calibrated. On the other hand it requires a hierarchical assumption on the substitutability and complementarity, which cannot be defined in all cases straightforwardly.

Input substitution is modelled in three successive steps (see Figure 3). Each intermediate input is a composite of comparable domestically produced and imported intermediate goods, which are combined through the ARMINGTON aggregation function (lower right-hand site in Figure 3). The prices of domestic and imported intermediates are used to determine the composite intermediate commodity price. From this price and the price of other intermediate goods used in production process of activity a the entire intermediate goods price $PINTA_a$ is determined.

$$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca}$$

The aggregate intermediate input demand $QINTA_a$ is a LEONTIEF function of all intermediate inputs, which are used in the production process.

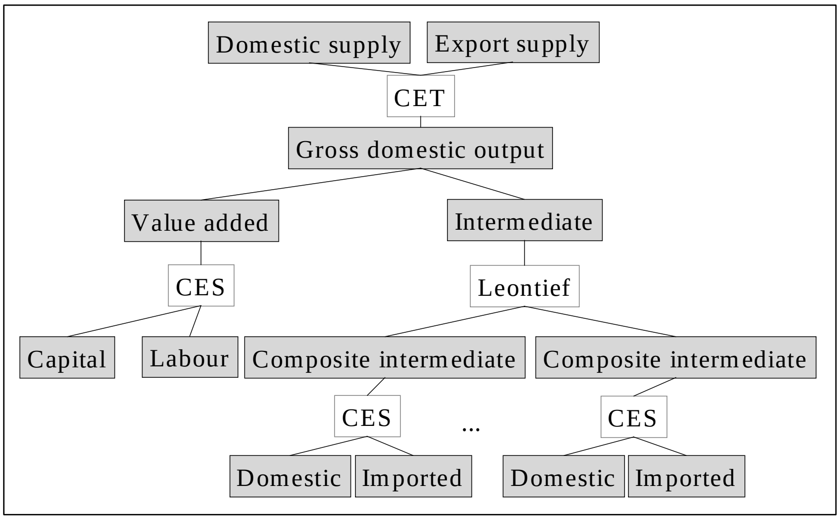
$$QINTA_a = in.ta_a \cdot QA_a$$

On the other nest of the substitution tree (left hand site in Figure 3) the price of primary factors of production is determined (the composite capital-labour price). Primary factors of production include labour and capital. Aggregate value added for activity a QVA_a is a CES function of primary factors.

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot QF_{f\,a}^{-p_a^{va}} \right)^{-\frac{1}{p_a^{va}}}$$

As part of the profit-maximisation decision, each activity uses both primary factors up to the point where the marginal revenue product of each factor is equal to its wage. The quantity supplied by each factor is fixed at the observed level in 1997. An economy-wide wage-variable is free to vary to assure that the sum of demands from all activities equal the quantities supplied and factor markets are cleared. Each activity pays an activity-specific wage that is the product of the economy-wide wage and activity-specific wage (distortion) term. The latter is fixed in the model. In a final step composite primary factor input is combined with intermediate goods input, using fixed coefficients technology based on the 1997 Polish input-output table.

Figure 3 Production structure in Poland CGE



Source: Own figure based on Poland CGE.

At this top level, the aggregate output level of activity a QA_a is specified by the CES production function.

$$QA_a = \alpha_a^a \cdot \left(\delta_a^a \cdot QVA_a^{-p_a^a} + \left(1-\delta_a^a\right) \cdot QINTA_a^{-p_a^a}\right)^{-\frac{1}{p_a^a}}$$

At the next stage, aggregated domestic output is allocated between exports and domestic sales on the assumption that suppliers maximise sales revenue for any given aggregate output level, subject to imperfect transformability between exports and domestic sales, which is expressed by a Constant Elasticity of Transformation (CET) function (see top level in Figure 3).

$$QX_c = \alpha_c^t \cdot \left(\delta_c^t \cdot QE_c^{p_c^t} + \left(1-\delta_c^t\right) \cdot QD_c^{p_c^t}\right)^{\frac{1}{p_c^t}}$$

In the international markets, export demands are assumed to be infinitely elastic at given world market prices. The price perceived by domestic suppliers for exports PE_c is expressed in domestic currency and adjusted for the export taxes.

$$PE_c = pwe_c \cdot \left(1-te_c\right) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c}$$

If the commodity is not exported, total output is passed to the domestic markets, whose price PDD_c is derived from the domestic market supply price for domestically produced and domestically consumed commodity c and composite commodity's price.

$$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c}$$

Each activity produces one or more commodities (multiple output technology) according to fixed yield technology. The level of the activity, yields and commodity prices at the producer level defines the revenue of the activity.

$$PA_a \cdot \left(1-ta_a\right) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a$$

2.2 Demand structure

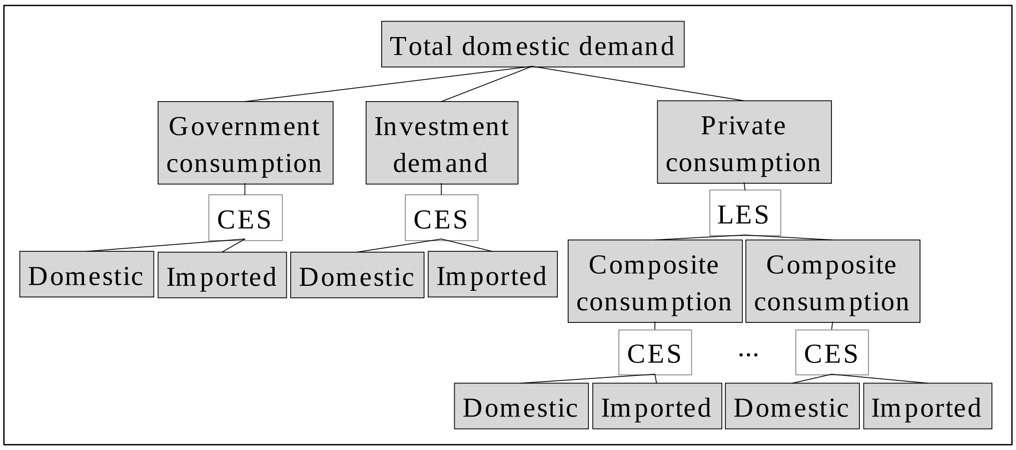
All domestically produced and imported commodities flow through markets. For domestic output, the first stage in the commodities' flows consists of generating aggregated domestic supply from the output of different activities of a given commodity. These outputs are imperfectly substitutable, for example, as a result of differences in timing, quality and location between different activities. Following the techniques introduced by ARMINGTON (1969), the Constant Elasticity of Substitution (CES) function is used for output aggregation from different activities (sectors).

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-p_c^{ac}}\right)^{-\frac{1}{p_c^{ac}-1}}$$

The demand for the output of each activity is derived from the cost minimisation problem of supplying a given quantity of aggregated output subject to this CES function. Activity specific commodity prices $PXAC_{ac}$ serve the role of clearing the implicit market for each dis-aggregated commodity.

$$PXAC_{ac} = PX_c \cdot QX_c \cdot \left(\sum_{a \in A'} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-p_c^{ac}} \right)^{-1} \cdot \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-p_c^{ac}-1}$$

Figure 4 Demand structure in Poland CGE



Source: Own figure based Poland CGE.

Domestic demand is made up of the sum of demands for household consumption, government consumption, investment demand, and intermediate input demand (see upper level in Figure 4).

To the extent that commodity is imported, all domestic market demand for a composite commodity c QQ_c is made up of imports and domestic output, the demands for which are derived on the assumption that domestic demanders minimise costs subject to imperfect substitutability (ARMINGTON assumption). This is also captured by a CES aggregation function.

$$QQ_c = \alpha_c^q \cdot \left(\delta_c^q \cdot QM_c^{-p_c^q} + \left(1 - \delta_c^q\right) \cdot QD_c^{-p_c^q} \right)^{\frac{1}{p_c^q}}$$

International suppliers that are infinitely elastic at given world market prices meet the derived demands for imported commodities. The import prices PM_c paid by domestic demanders also include import tariffs, which are modelled as fixed ad valorem rates.

$$PM_c = pwm_c \cdot \left(1 + tm_c\right) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c}$$

Flexible market prices PQ_c equilibrate demands and supplies of marketed output.

$$PQ_c \cdot \left(1 - tq_c\right) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c$$

Consumption and production meet where sector demand and sector supply are confronted and market equilibrium is established. This equilibrium depends on the sector's domestic price, which in turn is determined by the marginal production costs.

2.3 Institutions

In the model, households, enterprises, the government, and the rest of the world represent institutions. The households receive income YI_i from the factors of production $YIF_{i\,f}$, and transfers from other institutions $TRII_{i\,i'}$. Transfers from the rest of the world to households are fixed in foreign currency.

$$YI_i = \sum_{f \in F} YIF_{i\,f} \cdot \sum_{i' \in INSDNG'} TRII_{i\,i'} + trnsfr_{i\,gov} \cdot \overline{CPI} + trnsfr_{i\,row} \cdot EXR$$

The household use their income to pay direct taxes, save, consume, and make transfers to other institutions. Direct taxes and transfers to other domestic institutions are defined as fixed shares of household income whereas the savings share is flexible for households. The entire net income (after taxes, saving sand transfers to other institutions) is spent on consumption of goods and services.

Household consumption covers commodities, which are purchased at market prices that include taxes, which are valued at activity-specific producer prices. Household consumption $QH_{c\,h}$ is allocated across different commodities according to the demand function derived from the Linear Expenditure System (LES) (see also right-hand site in Figure 4)

$$QH_{c\,h} = \gamma_{c\,h} + \frac{\beta^m_{ch} \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma^m_{c'\,h} - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot \gamma^h_{ac'h} \right)}{PQ_c}$$

Besides households, factor incomes are paid to enterprises. Enterprises also receive transfers from other institutions. Enterprise incomes are allocated to direct enterprise taxes, savings, and transfers to other institutions. Enterprises do not consume commodities. The transfer payments to and from enterprises are modelled in the same way as the payments to and from households (as fixed shares).

The government collect taxes and receive transfer payments from other institutions. In the model all taxes are fixed at ad valorem rates.

$$\begin{aligned} YG = & \sum_{i' \in INSDNG} TINS_i \cdot YI_i + \sum_{f \in F} tf_f \cdot YF_f - \sum_{a \in A} sa_a \cdot PVA_a \cdot QVA_a + \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a \\ & + \sum_{c \in CM} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{c \in CE} te_c \cdot pwe_c \cdot QE_c \cdot EXR + \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c \\ & + \sum_{f \in F} YF_{gov\,f} + trnsfr_{gov\,row} \cdot EXR \end{aligned}$$

The government uses his income to purchase commodities for its consumption and for CPI-indexed transfers to other institutions. Government consumption is fixed in real (quantity) terms whereas government transfers to domestic institutions (households and enterprises) are CPI indexed.

$$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} trnsfr_{i\,gov} \cdot \overline{CPI}$$

Government savings (the difference between government income and spending) is a flexible residual, which ensure that government expenditure equals government revenue (see below).

The aggregate rest of the world (RoW) account is the fourth and last institution covered in the Poland CGE. Transfer payments from the rest of the world and domestic institutions and factors are all fixed in foreign currency. Foreign savings (the current account deficit) is the flexible difference between foreign currency spending and receipts. Foreign trade is subdivided into imports and exports. Final commodities' imports result from the LES. Exports depend on domestic and world market prices and are input for the demand per sector and the production.

2.4 Equilibrium conditions

The model includes three kinds of equilibrium conditions: the government revenue-expenditure balance, the foreign trade balance (balance of payments), and the savings-investment balance. Government revenue-expenditure balance is ensured trough flexible savings, which is the difference between government revenue and government expenditure.

$$YG = EG + GSAV$$

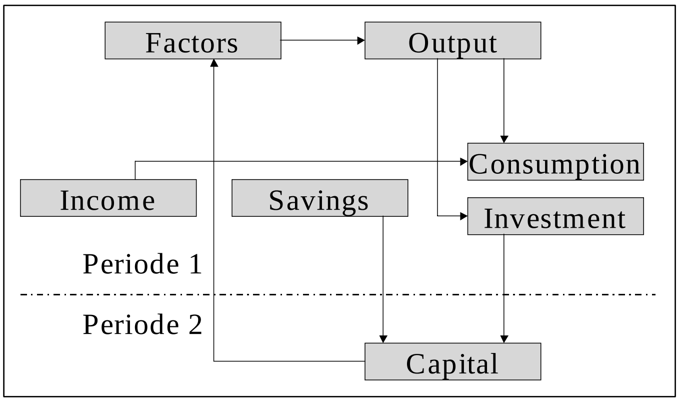
All tax rates are fixed as well as government consumption are fixed at their initial level in the model.

Foreign trade balance, which is expressed in foreign currency, consists of flexible real exchange rate and fixed foreign savings.

$$\sum_{c \in CM} pwm_c \cdot QM_c + \sum_{f \in F} trnsfr_{row\ f} = \sum_{c \in CE} pwe_c + QE_c + \sum_{i \in INSD} trnsfr_{i\ row} + \overline{FSAV}$$

Given that all transfers between the rest of the world and domestic institutions and factors of production are fixed in foreign currency, the trade balance is also fixed. In a ceteris paribus situation, where foreign savings were below the exogenous level, a depreciation of the real exchange rate would correct this situation by simultaneously reducing the spending on imports (an decrease in import quantities at fixed world prices), and increasing earnings from exports (an increase in export quantities at fixed world prices).

Figure 5 Capital flows in savings and investment in the model



Source: Own figure based on Poland CGE.

The savings-investment equilibrium condition is investment driven in the model, which means that real investment quantities are fixed in the model (see Figure 5) In order to generate savings that equal the costs of the investment bundle, the same number of percentage points adjusts the base-year savings rates of selected non-government institutions.

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - TINS_i) \cdot YI_i + GSAV + EXR \cdot \overline{FSAV}$$
$$= \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c$$

Savings decisions are set exogenously for 1997 in the model. However, for the rest of the simulated time span, from 1997 to 2005, changes in savings are derived endogenously in the Poland CGE.

3 Renewable energy policy scenarios

3.1 Base year

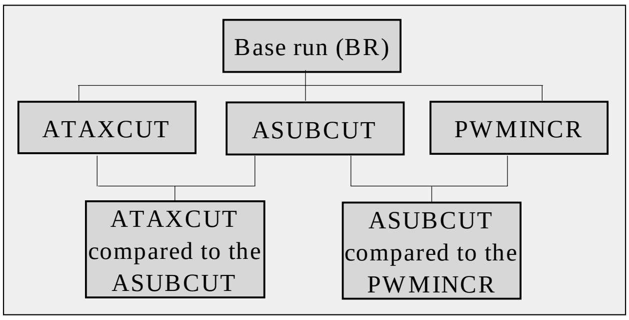
Data that characterise the interrelationships between sectors, commodities and economic agents within the economy are of primary importance in determining socio-economic impacts of renewable energy policies. Many of the impacts of increasing the share of renewable energy indirectly increase the costs of production and consumption. Furthermore, higher energy prices raise production costs, especially in sectors that use energy-intensive processes.

With the exception of substitution and scale elasticities, which are drawn from the literature (see tables A3), model parameters are calibrated (see tables A2) to social accounting data from the 2001 revision of the Global Trade Analysis Project (GTAP) version 5 data base (Dimaranan & McDougall 2002). The GTAP data set includes information on Polish input-output structure, trade flows, final demand patterns, and government intervention, and is benchmarked to 1997. Dimaranan and McDougall have developed a Social Accounting Matrix (SAM) that fully tracks the intensities of commodity use in each of Poland's 57 production and consumption sectors. The Social Accounting Matrix used in the Polish CGE represents a snapshot of the Polish economy. The Dimaranan and McDougall data was completed by two additional data sources. First, energy production and energy input data from the Energy Information Administration (2002) was used to get a more accurate representation of Poland's energy profile. Second, international trade data from the GTAP version 5 data base was used to estimate the foreign trade matrix. Additional macro-economic data such as foreign direct investments, foreign trade balance, government deficit, total labour supply, saving rate of private households and sectoral investment shares are included in 1997 for Poland.

It was extremely difficult to evaluate the volume of renewable energy used in Poland because information is only available through special fact-finding research techniques. Various national institutions, such as the Main Statistical Office, Ministry of the Economy, and the EC Baltic Renewable Energy Centre, have estimated the share of renewable energy in the fuel and energy balance. The figures given by the institutions vary, a fact which is the source of difficulties in the estimating correctly the actual utilisation of renewable energy in Poland. For example, in the statistical yearbook 'Fuel and Energy Economy in 1997-98' (published in Polish by the Main Statistical Office in 1999), the share of the remaining sources (firewood, peat, waste fuels, water energy and other renewable energy carriers) in the consumption of primary energy was around 4.06% in 1997. According to the 'Polish Energy Policy until 2020', renewable fuels had a 5.1% share in the consumption of primary energy in 1997. Furthermore, in the expert appraisal on 'Economic and Legal Aspects of Utilisation of Renewable Sources in Poland' prepared by the EC Baltic Renewable Energy Centre it was estimated that the share of energy from renewable sources was 2.5% (being 104 PJ). The former two figures above 4% seem to be overestimated because combustion of non-renewable sources such as peat was included. One may therefore conclude that the current share of renewable energy in the consumption of primary energy is 2.5% with the total consumption of primary energy in Poland in 1998 being around 4,000 PJ.

Based on the results of the 'Development Strategy of Renewable Energy Sector' [CM 2000] and other expert assessments, three renewable energy sector development scenarios have been designed, which assume the implementation of certain policy measures – ATAXCUT, ASUBCUT and PWMINCR (see Figure 6). The criteria used for the selection of policy measures were the minimisation of required subsidies and tax relief with simultaneous provision of favourable conditions for the development of renewable energy sector. The principles of the three scenarios and a synthesis of the simulation results are presented in the following two sections.

Figure 6 Renewable policy scenarios in the model



Source: Own figure

3.2 Reference scenario (BR – base run)

A base run (BR) serves as a reference point for measuring costs and benefits of alternative renewable energy policy scenarios. Since the base run is the benchmark for the entire quantitative analysis, its definition is one of the most critical issues in the reliability of the modelling results. Unreliable assumptions in the reference scenario could lead to errors in the results by changing renewable energy policies.

Several assumptions about exogenous policy and non-policy parameters of the CGE for Poland CGE are made in projecting the 1997 base run situation to 2005. Non-price-induced growth in production is incorporated into the model according to the technical progress. The technical progress growth rates are assumed to be scenario-uniform. For all scenarios, the energy sectors' output growth rates are set to 2 % per year, which reflects the level of international long-run averages. This expresses not only purely technical progress, but also the recovery of the energy sector due to progress in privatisation and restructuring. Energy input demand is also expected to increase with the expansion of production. To account for technical progress or increased efficiency in energy use, growth rates of technical progress for energy inputs are set at slightly lower levels than for outputs (1.5 %). For labour input in energy, no exogenous increase is assumed by setting the growth rate of technical progress at 0 %.

World market prices for energy products are kept stable until 2005 and are not accounted for explicitly in the model. The Polish CGE aims at measuring explicitly the effects of a world market price increase for energy goods on the energy sectors in the PWMINCR scenario.

Corresponding to the shift of supply curves, demand curves are shifted by the growth of population, individuals' income, and changes in consumer preferences. Poland's population has decreased since independence, but this negative trend is slowing down and seems to have come to a halt. Consequently, zero population growth until 2005 seems to be the most plausible assumption [Piazolo 2000]. The second shift factor on the demand side is that of income or expenditure growth. Since long-term forecasts of economic growth for Poland are not available, the annual growth rate of income/expenditure has been set at 3% [Piazolo 2000]. One could presume an accelerated income growth due to Poland's integration into the EU. However, since it is not expected that Poland will not have accession to the EU until 2005 [Piazolo 2000], this will not be accounted for in the model.

3.3 ATAXCUT scenario

Changes in the energy sectors' tax rates serve as the point of departure for policy experiments. Instead of increasing fossil energy sector taxes, the ATAXCUT scenario assumes that the indirect activity tax (TA) has been reduced by 50% for the bioenergy sector (ABEN), which also means that all fossil energy sectors ACOELPEA, AOIL and AELEC are taxed twice as much as the bioenergy sector compared to the reference scenario (BR). The tax rates for all other sectors in the ATAXCUT scenario are kept at their base level.

$$TASIM\ (ABEN,\ \text{'}ATAXCUT\text{'})=0.5{*}ta0(ABEN)$$

Changes in the fossil energy tax touch on many issues, such as the tax base, the variation or uniformity among sectors, the association with trade, employment, revenue and R&D policies, and the exact form of the mechanism (e.g., a single fossil energy tax or in conjunction with other policy measures). Since each of these factors can influence the effects of changes in the fossil energy taxes, they must be considered in the model. In the Polish CGE, the fossil energy tax requires the Polish energy sectors to pay an ad valorem rate for every output unit. This is treated as an indirect activity levy percent of output value and is collected from the domestic producers.

The main economic advantage of a fossil energy tax compared to other policy measures is that it limits the cost of government interventions by allowing renewable energy to sink if production costs are unexpectedly high. However, fossil energy tax does not guarantee a particular level of renewable energy to be achieved. Therefore, it may be necessary to adjust the tax level after the first round of policy simulations to meet the internationally agreed renewable energy commitment in the *White Book*, where the European Union imposed on Candidate Countries the requirement to adjust their energy use level from renewable sources to that of the Member States at a level of 12% by 2010 [CM 2002]. The fossil energy tax needs also to be adjusted to changes in external circumstances, such as inflation, technical progress, and increases in emissions [van der Zwaan et al 2002]. In the transition economies of Eastern Europe, in particular (such as Poland), fixed tax rates in monetary terms can be significantly eroded by high inflation. Inflation increases abatement costs. Consequently, the tax rate needs to be adjusted for inflation in order to achieve a target renewable energy level [Bovenberg & Goulder 1997, Knox 2002].

In theoretical terms, the fossil energy sectors could be taxed in order to achieve environmental goals such as renewable energy policy targets [Cropper & Oates 1992]. Supposing that every fossil energy producer faces a uniform tax on every output unit (assuming that energy, factor, and product markets are perfectly competitive) would result in the least expensive increase of the share of renewable energy throughout the economy [Bovenberg & Mooij 1994]. In Poland, however, energy markets in particular, deviate from this ideal, so a fossil energy tax may not maximise economic efficiency. Rather, the efficiency of a fossil energy tax should be compared with alternative policy measures. Therefore, the study develops the ASUBCUT scenario, which serves as a renewable energy policy alternative to the ATAXCUT scenario.

3.4 ASUBCUT scenario

According to previous studies, even without adding new taxes, removing the subsidies and trade barriers to the fossil energy sectors would create a win-win situation, encouraging renewable energy production and reducing environmental damage [30–33]. The opposite effect has a renewable energy sector subsidy, which lowers the costs of energy from renewable resources by, for example, paying a subsidy per kWh produced, providing investment subsidies or fiscal benefits.

Criteria other than sustainability and efficiency, such as distributional impacts, are currently likely to influence the design of energy sector subsidies in Poland. The impacts on distribution and competitiveness help explain why, in Poland, some fossil energy taxes are coupled with tax exemptions or indirect activity subsidies. However, since the use of energy subsidies for competitive purposes may cause problems due to the WTO agreement on subsidies and countervailing measures [Stavins 1998], and because energy sectors' subsidies are currently under review in Poland (in some cases reforms have already taken place), changes in Producer Subsidy Equivalents (PSE) serve as the second point of departure for policy experiments.

The objective of the ASUBCUT scenario is to decrease fossil energy sector subsidies compared to the bioenergy sector, which also means a relative increase in the bioenergy sector's PSE level compared to the fossil energy sector's in relative terms. The ASUBCUT scenario assumes that all fossil energy sector subsidies (SA) have been removed, by keeping renewable energy sector's subsidies at the initial level. The subsidy rates for all other sectors in ASUBCUT scenario are kept at their base scenario level.

$$SASIM\,(A,\,\text{'}ASUBCUT\text{'})=0.0*sa0(A)$$

According to economic theory, the main difference in an activity tax is that in the short run, a subsidy may allow some firms to continue operating that would not continue where there was a tax (those with average variable costs above prices). Besides, a subsidy requires that revenue be raised somewhere else in the economy, which can also produce dead-weight losses. It is a difficult policy challenge, and therefore a time-consuming process, to bring energy prices in line with real costs. This is true particularly in transition countries such as Poland, where private customers (households) pay a high cost for low-quality energy services (or a low cost that is heavily subsidised) and in developed countries. The CGE modelling task is to find out which of the policy instruments – an activity tax or an activity subsidy – is a more appropriate measure for supporting the renewable energy sector.

A renewable energy subsidy, like a fossil energy sector tax, does not guarantee the achievement of a particular level of renewable energy. Therefore, it may be necessary to adjust the subsidy level after the first round of policy simulations to meet the internationally agreed renewable energy commitment in the *White Book* of the European Union, which requires that the Candidate Countries adjust their energy use level from renewable sources to that of the Member States at the level of 12% by 2010.

3.5 PWMINCR scenario

In order to assess existing or proposed renewable energy policies, analysts require credible measures for their impacts on social values. Often the direct costs and benefits of a policy measure can be estimated by applying market prices to the quantities of real resources required for its implementation and benefits gained from its impact. Where impacts occur in efficient markets, their social values can usually be readily and appropriately estimated from changes in market prices and quantities (as in ATAXCUT and ASUBCUT scenarios).

However, other costs, environmental degradation, and many benefits such as the long-run access to energy supplies at relatively constant costs, cannot be reasonably estimated directly from market prices. When there are market failures or there is no market at all, then a shadow price is needed – for example, the value of 1% of inter-national fuel price fluctuations evaded. Often, these shadow prices are key factors in determining whether a policy measure has positive or negative net benefits.

There are several ways to obtain the value of a non-market impact. The PWMINCR scenario offers the possibility of conducting one's own valuation study. The objective of the PWMINCR scenario is to assess the benefits from the increased use of bioenergy, by securing long-run access to energy supplies at relatively constant costs for the foreseeable future in Poland. The PWMINCR scenario simulates the world market price increase for energy goods by 40%.

$$PWMSIM\,(CENERG,\text{'}PWMINCR\text{'}){=}1.4{*}pwm0(CENERG)$$

In the PWMINCR scenario, the same technical progress growth rate is assumed as for the base scenario. No information or plausible assumption exists for a third potential shift factor, the change in technology. Hence, the naive assumption of zero changes has been made for PWMINCR scenario. The figures for non-price induced growth of inputs in the PWMINCR scenario are kept at their base scenario level.

4 Simulation results

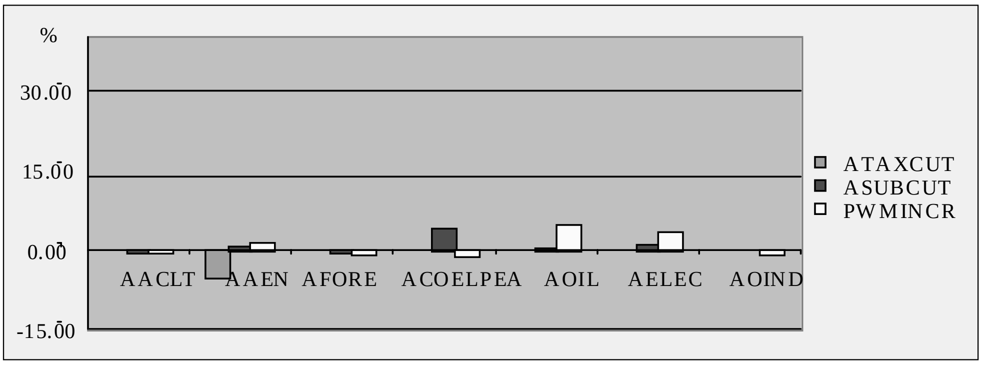
The General Equilibrium Model provides an established micro-economically consistent approach for evaluating the impacts of public policy on resource allocation (efficiency) and the associated changes in income for economic agents ('equity'). It has been, and still is, widely used in analytical work for assessing a broad scope of environmental and energy policy measures, such as tax reforms, where market interactions potentially play an important role. However, for the sake of tractability, analytical approaches are typically rather simple and not sufficiently complex for applied policy analysis. Therefore, a numerical model – the CGE – is used to accommodate the systematic analysis of changes in the renewable energy policy in Poland. In this section the main Computable General Equilibrium model's simulation findings about the renewable energy policies' effects are summarised and their implications to the renewable energy policy design in Poland are indicated.

4.1 Changes in relative prices

It is convenient to start by examining the changes in relative prices because they can be considered as the initial effects of the change in fiscal policy. According to the CGE for Poland, the aggregate bioenergy sector's (AAEN) output price decreases by 5% compared to the reference scenario (BR), if the indirect activity taxes are reduced for the bioenergy sector by 50% (see left-hand columns in Figure 7). All others' activities output prices have not been affected significantly by reducing the indirect bioenergy sector tax.

The extent of the impact of removing output subsidies depends on the specific characteristic of each sector, the type of subsidy involved, and international coordination to implement similar measures. Different initial subsidy rates in the base run lead to different changes in the output prices in implementing policy measures. According to the model's results, removal of fossil energy sector subsidies leads to a remarkable increase in the aggregate output price for the coal and peat sector (ACOELPEA) – 3.8% compared to the reference scenario (BR) (see middle columns in Figure 7). Compared to the other two fossil energy sectors – AELEC and AOIL – the coal and peat sector has been subsidised much more in the base run – 622.8 million PLN. The crude oil and natural gas sector has not been subsidised at all in the base run and the electricity, gas, steam and hot water sector only marginally – 10.4 million PLN.

Figure 7 Changes in relative prices compared to the BR



Source: Own calculations

The third scenario – increase of energy commodity prices on the world markets has varying impacts on aggregate output prices (see right-hand columns in Figure 7). The largest aggregate price increases are calculated for the crude oil and natural gas sector (AOIL) as well as for the electricity, gas, steam and hot water sector (AELEC) – 4.4% and 3.3% respectively. In contrast to expectations, the aggregate output price of the coal and peat sector (ACOELPEA) has decreased compared to the reference scenario (BR), which requires a more detailed explanation. The explanation of this phenomenon, when an increase in world market price leads to a decrease in domestic output price, starts 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 -0.8%, that of coal and peat commodities (CCOELPEA) by -1.27%, and the output price of other industrial goods and services (COIND), which has been produced by the coal and peat sector has decreased by –0.9%. Although, the prices of the output of the two remaining activities has increased significantly – 18% of crude oil and peat commodities (COIL) and 9% of coke and refined petroleum products (CPET), their share in total coal and peat sector output is tiny – 0.016% and 0.003%, respectively. Since CACLT, CFORE, CCOELPEA and COIND have much greater weights in the ACOELPEA activity's price index, their price increase effects dominated the effects of a decrease.

4.2 Aggregate output effects

It is fundamental to perceive correctly that in such an interrelated system as the whole economy (and as represented by the model), any change in fiscal policy modifies all market equilibriums, i.e. prices, and due to substitution possibilities, quantities of producers and consumers in each sector/commodity. Therefore, in assessing the effects of various renewable energy policy measures, estimations of price-induced substitution possibilities between types of energy and between aggregate energy and other inputs are presented next.

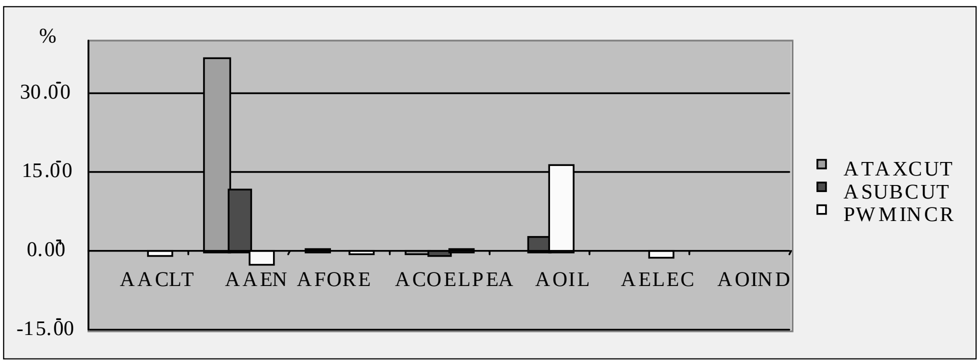
According to the CGE in Poland, the greatest increase in aggregate output – 36%, is that of the bioenergy sector caused by the indirect activity tax reduction by 50% (see left-hand columns in Figure 8). These output changes are out of proportion compared to the moderate price changes of 5% and, therefore, require a more detailed explanation. Since there is no excess demand in the Polish CGE, and world market prices are determined exogenously (see Figure 8), the increase in an activity's total output has to be led back either to an increase in total demand for commodities and/or to a decrease of commodity production by other activities. According to the Polish CGE, there are no significant changes in agricultural and hunting products, and electricity, gas, steam and hot water goods and services output levels by other activities. On the demand site, the prices of composite goods CCOELPEA and CELEC do not significantly decrease either (see Figure 7). The large increase in the bioenergy sector's aggregate output is probably associated with its limited share in the total commodity's output, which is less than 1% in total commodity supply, i.e. if the market's total demand for corresponding commodity increases by 1%, the bioenergy sector's output will grow by 100%, ceteris paribus.

The removal of subsidies for the fossil energy sector increases the aggregate output level of two energy sectors, bioenergy (AAEN) and the crude oil and natural gas sector (AOIL) (see middle columns in Figure 8). The increase of the output of the bioenergy sector is caused by the decrease in relative output prices – 1.8% to 3-4% and -1.1% to +0.3-0.9%. The crude oil and natural gas sector extends production by 2.8%, because it has not been subsidised in the base run and, hence it has no direct income losses.

In spite of these results, it is not possible to draw any general conclusion about the socio-economic effects of removing subsidies for the energy industry. For example, the effect of removing subsidies to coal producers depends heavily on the type of subsidy removed and the availability and economics of alternative energy sources, including renewable energy. There may also be cases where the removal of a subsidy to an energy-intensive industry in Poland could lead to a shift in production to other countries with lower costs or environmental standards, resulting in a net increase in global fossil energy production.

Each of the four energy sectors reacts in a non-uniform manner, if the world market price for energy goods and services rises by 40% (PWMINCR scenario). While the crude oil and natural gas sector extends its production by 16.2%, the bioenergy sector (AAEN), and the electricity, gas, steam and hot water sector (AELEC) reduce their output shares by 2.4 and 1.1% (see right-hand columns in Figure 8). These diverse output-side effects_are closely related to the commodities' import/export share. For example, domestic supply with crude oil and natural gas commodities has been dominated by imports, which count for more than 90% in the reference scenario (BR). As the price for imported commodities rises, domestic producers get a relative price advantage compared to foreign competitors and extend their shares in both domestic and foreign markets. The import share has been considerably smaller for the other three energy products – 1.1, 7.5 and 0.1 of CCOELPEA, CPET and CELEC respectively.

Figure 8 Changes in sectoral output compared to the BR



Source: Own calculations

In interpreting the model's results, it has to be kept in mind that price signals can only influence demand and supply if they actually reach economic agents and if those economic agents have the opportunity to respond to them. In Poland, energy intensity increased by 24% between 1990 and 2000, while energy prices also increased tremendously [6]. Experience shows that 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 accurate knowledge of their energy consumption, or the technical capacity to reduce it.

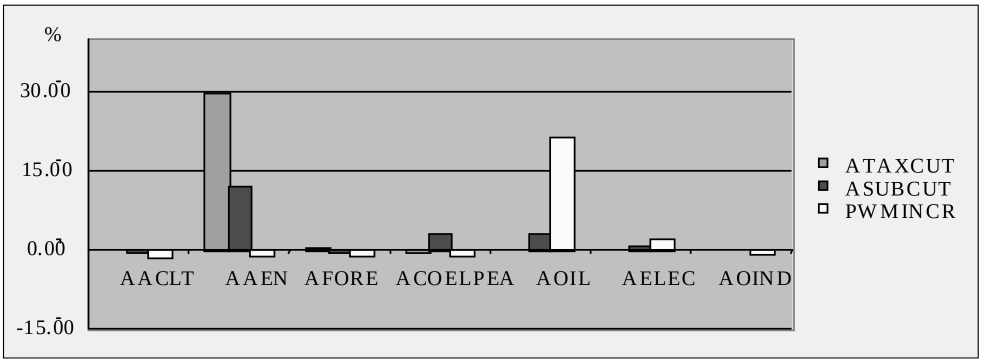
4.3 Welfare effects

The changes in producer welfare are measured as total revenue minus total costs. The model's results reveal that the renewable energy sector has the highest welfare gains in the case of producer tax reduction (ATAXCUT scenario) compared to the reference scenario (BR) and to the other two policy scenarios (see left-hand columns in Figure 9).

There are no significant welfare losses on the producer side . According to the results of the model there are three sectors (AAEN, ACOELPEA and AOIL) whose total revenues increase in the case of the ASUBCUT scenario, 12%, 2.9 and 2.8% respectively. These revenue gains have to be led back either to the composite commodity's price increases and/or to the increases in sector output level (see above).

A price shock on the world energy market (PWMINCR scenario) favours above all the crude oil and natural gas sector, whose total revenue rises by 21% compared to the reference scenario (BR). In all other sectors, except crude oil and natural gas, and electricity, gas, steam and hot water, welfare is boosted insignificantly, if the world market price for energy goods increases by 40%.

Figure 9 Changes in producer surplus compared to the BR



Source: Own calculations

The results of the simulations and analysis showed that the increase of the share of bioenergy in the total energy supply in 2005 would increase the total required amount of funding from public sources. However, the state budget effects of reducing government revenues depend on how this additional or lacking money circulates in the economy. In the bioenergy CGE it is assumed that increased/decreased state revenues are not distributed (flexible government saving balances the state budget), which can lead to the fact that the models' results over/underestimate aggregate welfare effects. An alternative to this approach could be to assume that revenues collected from the fossil energy sectors' tax are used in correcting economic distortions in the economy, e.g. taxation of employment, which would benefit society not only by correcting the externality but also by reducing the costs of the distorting taxes (the so-called 'double dividend'). Previous studies indicate that if the benefits from reducing existing taxes on labour are incorporated into the modelling, the projected economic impacts can be substantially more optimistic than if no compensation or lump-sum revenue compensation is assumed, although the size of the effect depends on model specification.

According to the model's results, the average reduction of income to the state budget due to decreased excise duty on bioenergy with a mixture of liquid biofuels means an additional 12.4 million PLN/year. The results of the simulations and analysis showed that the increase of the share of bioenergy in the total energy supply in 2005 would increase the total required amount of funding from public sources and would require a much larger utilisation of biomass (in cogeneration). The planned development of the renewable energy sector in Poland in the years 1997-2005 would allow a significant decrease in investment costs. An example is the UK, where within nine years (1990-1999) the state support system allowed an average decrease in the costs of energy generated from renewable energy sources at the level of 45%, which in some areas made renewables fully competitive to energy generation from fossil fuels. As such, a further development of the renewable energy sector in Poland according to the objectives and targets set by the Polish government would require only selective support to the new technologies coming onto the market and budgetary costs would decrease.

4.4 Comparing results with other studies

Table 5 gives some details of quantitative empirical studies of environment and renewable energy policies for which sectoral impacts are analysed. These are all at a country or world-region level (e.g., the European Union). Table 5 presents the outcomes of different energy and environmental policies on the sectors' output and welfare. The effects are shown as differences from the reference scenario or the base in the final year of the projection.

The results presented in Table 5 are highly heterogeneous among themselves as well as compared to the bioenergy CGE model's results. There are several reasons explaining these huge differences. First, differences in the referee scenarios lead to differences in the effects of policy measures. Second, even if the reference scenarios were exactly the same, there are other reasons for changes in model results. Model specification and, more importantly, differences in model parameters also play a significant role in comparing the results.

Table 5 Quantitative studies of energy sectors' taxation and removal of subsidies

Region/ country	China	EU-6	EU-11	New Zealand	UK	USA	USA	USA
Author	Garbacci	DRI	Barker	Bertram	CE	CRA	Jorgenson	McKibbin
Year of study	1999	1994	1999	1993	1998	1994	1999	1999
Model type	Static CGE	Macro-economic	Macro-economic	CGE	Macro-economic	Macro-economic	Dynamic CGE	Dynamic CGE
Period	1992-2032	1992-2010	1970-2010	1987-1997	1960-2010	1990-2010	1996-2020	1996-2010
Compen-sation type of tax rev.	All other taxes	Employer taxes	Employer taxes	Corporate tax	Employer taxes	Lump-sum	Income tax	Lump-sum
Sectoral effects								
Agriculture	0%	-7%	+3%	+4%	0%		+4%	-1%
Coal	-19%	-7%	-8%	-24%	0%	-25%	-52%	-40%
Refined oil	-2%	-7%	-17%	-22%	0%	-6%	-4%	-16%
Gas		-7%	-4%	-41%	-4%	-18%	-25%	-14%
Electricity	+3	-7%	-3%	-17%	-1%	-17%	-12%	-6%

Source: Own table based on Burniaux & Truong 2002

The treatment of technical change is crucial in comparing the models' results. The usual means of incorporating technical progress in CGE models is through the use of time trends, as exogenous variables remain constant across sectors and over time. These trends give the date of the solution. Technical progress usually enters the models via two parameters:

1 autonomous energy efficiency (if technical progress produces energy savings, then the value share of energy of total costs will be reduced) and

2 as changes in total factor productivity.

The implication of the results' comparability of this treatment is that technological progress in the models is assumed to be invariant to the policy measures being considered. If in fact the policies lead to improvements in technology, then the real costs may be lower then some of the models presented in Table 5 suggest.

A further source of divergence in the models' results are the assumptions of price-induced substitution possibilities between alternative sources of energy and between aggregate energy and other inputs. All such substitutions become greater as the time for adjustment increases. The problem of comparing the results of the Polish CGE model with those presented in Table 5 is that estimates of substitution elasticities are usually highly sensitive to model specification and the choice of the sample period. There is little agreement on the order of magnitude of some of the substitution elasticities, or even whether they should be positive or negative, e.g., there is debate whether capital and energy are complements or substitutes. If energy and capital are complements, then an increase in the price of energy will reduce production demand for both energy and capital, reducing both investment and growth. It is problematic to compare the models' results straightforwardly, because most CGE models consider very different possibilities of substitution, for example the CGE for Poland used in this study, Global 2100, and Nordhaus's Dice/Rice models assume capital and labour as substitutes, while Green assumes capital and energy as direct substitutes [Burniaux & Truong 2002].

A further basic difference among models and their results is the level of sector aggregation. There are many different products, skills, equipment, and production processes; many important features are missed when they are necessarily lumped into composite variables and functions. Indeed, in practice, different goods have different energy requirements in production, and therefore any changes in consumption and production patterns will affect them differently. Hence those models, which are highly aggregated, (e.g. DRI) miss some potentially major interactions between output and energy use, which is precisely the purpose of the analysis. For example, sector disaggregation allows the modelling of a shift towards less energy-intensive sectors, which might reduce the share of energy in total inputs. In the same way, when a fossil energy sector tax is introduced, it could reduce the estimated costs by allowing substitution effects of energy-intensive goods by less energy-intensive goods.

5 Concluding remarks

5.1 Policy conclusions

Section 4 presented the results of the empirical ex-ante analysis of evaluating the effects of the changes in renewable energy policy in Poland. Producers respond to changes in market prices for energy goods by adjusting their output level and mix, and input demand. Consumers respond to the changes in energy products prices with a reduced demand for some goods and services and increased demand for others.

Whilst the Polish CGE does not advocate that the deployment of bioenergy will be a panacea for environment pollution and rural unemployment, it has highlighted several issues concerning bioenergy support and rural diversification opportunities. Generally, a uniform subsidy can lead to the same increase of renewable energy supply as an equivalent uniform fossil energy tax. In an industry with homogeneous firms, both taxes and subsidies (set at the same levels) yield exactly the same outcome in the short run. According to the Polish CGE, however, a fossil energy tax is more efficient than a subsidy. While the subsidy lowers the average cost of production, the tax increases the average cost of production. The empirical results suggest that the bioenergy sector benefits more from an indirect tax reduction than from the removal of fossil energy sector subsidies. The policy conclusions and recommendations are dominated by the persuasion that for the Polish economy, on the whole, lower and fewer subsidies are recommended. The present situation with high subsidies for food crops and the fossil energy sector aggravates the development of increased production of energy crops. Therefore, the payments for all crops and fossil energy sectors should be lowered especially with a view to the world market and the next round of the WTO negotiations approaching. The author would propose the introduction of an instrument (tax, certificates) which would help to internalise the external costs of the different feedstocks and fuels originated by the production of heat and power. The calculation of the impact of an increasing energy tax shows that low tax rates would already help bioenergy plants to become competitive.

Reductions in the output of fossil energy sectors below the reference case (base run) do not impact on all fossil energy sectors equally. Various energy sectors have different costs and price sensitivities, so that they respond differently to policy measures. Energy-efficiency and combustion device specific technologies, and reductions in demand can affect imputs differently from outputs. In the Polish CGE the taxation effects on fossil energy sectors are mixed. The reasons for that are have been explained above. The aggregate rest-of-the industry and services sector augments their output as a result of policy changes. Aggregate rest-of-the industry and services sector has a high share in national GDP, is much more diversified than small primary industries and energy sectors. According to the multiple output production technology it has a greater opportunity for substitution on the output side.

Furthermore, renewable energy is more labour intensive than conventional energy technologies in delivering the same amount of energy. Greater labour intensities coupled with a comparatively higher multiplier effect in the regional supplier chain constitute a positive justification for supporting bioenergy production. Such benefits would be especially beneficial for remote rural areas, which have experienced a dramatic decrease in employment in the agricultural sector in recent years. Increases in agricultural part-time and casual labour, coupled with the fall in full-time labour, suggests that the agricultural sector is no longer able to carry the cost of full-time employees or to offer incomes commensurate with those available elsewhere. Evidently there is an urgent need for activities which generate supplementary incomes, and if additional income opportunities cannot be found, or at least be supported, there is a constant risk of rural depopulation. Given bioenergy’s propensity for rural locations, the deployment of bioenergy plants may have positive effects upon rural labour markets by, firstly, introducing direct employment and, secondly, by supporting related industries and the employment therein (e.g., the farming community). The agricultural industry has spare labour market capacity and can expand to exploit the emerging market in supplies of biomass for energy usage.

Renewable energy technologies use fewer imported goods and services than conventional energy technologies, so their use provides a great stimulus to both direct and indirect employment in rural industries. Consequently, the use of indigenous energy resources implies that much of the expenditure spent on energy provision is retained locally and is recirculated within the rural economy. Strategically therefore, if policy makers wish to maximise the benefits accruing to the rural areas, renewable energy policy decisions should be based upon a measure's propensity to effect positive economic benefits within the area. Such instruments may be identified according to their respective multiplier impacts, with the result that measures maximising regional inputs and supplier chains should be favoured.

Similarly, by securing a heat and power supply system based on indigenous resources, the exposure to international fuel price fluctuations is minimised, thus reducing the risk of rising costs of production, transport, etc. The increased use of bioenergy, which exhibits both a broad geographical distribution, and diversity of feedstock, could secure long-run access to energy supplies at relatively constant costs for the foreseeable future in Poland.

In summary, bioenergy production may not be the answer for the farming sector in this particular instance. For whilst it is more labour intensive, it results in a greatly reduced profit margin to the farming unit. This in turn implies that, given the current status of subsidy measures, it is unlikely that bioenergy production would be pursued for financial reasons, despite the additional employment that it may create. The policy recommendation of this current study is that without a revision of current agricultural support, it is unlikely that the bioenergy plant will be able to secure a guaranteed supply of feedstock. This is because biomass production is not as profitable as subsidised alternative agricultural practices. Therefore whilst it may generate greater regional benefits in terms of employment and supply linkages, it is unlikely to be the preferred agricultural investment. In response to this, Polish agricultural policy needs to reconsider current artificial price support strategies. If conventional agricultural produce were based upon market prices, then there is every evidence to suggest that bioenergy production may be a financially viable alternative, but until that time, the positive effects of bioenergy on clean environment and rural diversification in Poland will not be realised.

5.2 Limitations and outlook

Clearly the above study of the impact of the renewable energy policies has highlighted several areas which inform strategic decision making. Like most CGE models, the Polish CGE is based on many assumptions concerning economic development (market structure, elasticities of substitution and transformation, technical change, exogenous variables). It is a necessity and indeed the intention of all models including the Polish CGE, to abstract from the much more complex reality. Focusing on those relations which are most important for modelling purposes, the CGE for Poland contributes to a better understanding of the relevant issues and parameters. For the interpretation of the model results, one always has to bear in mind the assumptions made in the model. It would be misleading to base policy decisions on the numerical analysis results without recognising the model's limitations and its assumptions. The major limitations of the Polish CGE are pointed out in this section. This section also provides an outlook for future research, such as imperfect competition, continuous treatment of time, endogenous technical change, adjustment costs in the labour market and in capacity formation, the role of energy conversion costs, uncertainty in the supply of non-renewable resources, etc.

The Polish CGE is solved in a comparative static mode. All results for the policy scenarios in the model refer to one point in time. In reality agricultural land allocation between food and biomass production involves decisions, which operate on different time scales. Most agricultural decisions have time horizons of less than a decade. In comparison, short-rotation woody crops decisions involve one or even more decades. These differences in the time horizons between the production processes require a modelling approach, which considers current agricultural costs and returns versus current costs and future bioenergy returns. Land allocation between food and biomass production along with consideration of harvest age decisions requires a dynamic multi-year framework.

Furthermore, the specification of the market structure is also of considerable importance. The Polish CGE assumes that all markets are competitive. As the previous research indicates, results differ considerably if one deviates from the, often unrealistic, perfect competition assumption. In particular, energy sectors are assumed to behave as price takers on both input and output markets. Clearly, further research should emphasise specifying alternative market structures. The depiction of the agricultural sector also needs to be improved because, even under perfect competition, the ad hoc approach of assuming zero profits irrespective of the quantity marketed, is restrictive.

The same argument holds for modelling disequilibria in factor markets of the economy. Polish statistics show that disequilibria exist in the labour market and in the market for physical capital, and that changes in unemployment or in the utilisation of capacities are often the short-run consequences of sudden changes in the magnitude of a renewable energy policy instrument. It would be necessary to modify the CGE for Poland by allowing explicitly for partial disequilibria in the labour and capital markets by adopting theories on under- or over-utilisation of the primary factors of production.

A further fundamental assumption of the Polish CGE is that of exogenous technical change. CGE calculations for Poland can be regarded as conservative because the yields of the energy crop could easily be increased by 20% in the near future. Additionally the technical progress in the field of combustion equipment is very rapid, resulting in a decrease in investment costs. As the previous studies indicate, the outcome from an renewable energy policy measures in response to a reduction in fossil energy use are very sensitive to the assumption made on the rate of energy efficiency improvement. However, technical progress is considered to be a non-economic, exogenous variable in the Polish CGE. This is not satisfactory because neglect of the induced technological progress may lead to an overestimation of the costs of implementing renewable energy programs. An inadequate representation of policy driven technical change in the current model can also result in an understatement of the advantages of market-based renewable energy policy instruments. In recent years there have been significant new developments in CGE modelling of endogenous technological change [Jaffe & Newell & Stavins 2002, van der Zwaan et al 2002].

A further important aspect to be taken into account for the assessment of the Polish CGE is the validity and reliability of its database. Although Poland’s statistics are far better than those of many other Central and Eastern European countries, the data input into its CGE still has to be interpreted with care. It has to be assumed that most economic data is distorted because of informal economic activities, strategic answering in questionnaires, etc. Inconsistencies due to these problems of inadequacy or aggregation in official statistics are a clear sign of problems in data reliability. Moreover, the very short period of observations without structural breaks in Poland does not allow an econometric estimation of elasticities or other parameters included in the CGE for Poland. Information regarding these parameters for other CEEC is also scarce. Hence, the calibration procedure relies on subjective judgements about the initial elasticities employed in the model. Further research should emphasise estimating behavioural parameters based on time-series data.

The Polish CGE does not attempt to produce definitive forecasts of employment and income impacts, therefore the results should be taken as a tentative first estimate of possible socio-economic effects. Moreover the results cannot be used for scaling purposes, therefore they should in no way be used for an estimation of the employment and income effects arising from the implemention of bioenergy policies across Central Europe. Every bioenergy policy measure should be analysed on an individual basis, as the results are wholly dependent upon the prevailing regional economy, the displaced activities and the direction of project expenditure. Nevertheless, despite all its shortcomings, the Polish CGE can be considered a useful abstraction from reality, provided the results are carefully interpreted. The quantitative results should not be overemphasised, but need to be seen in the context of the model's assumptions. Figures should be interpreted as representing an order of magnitude rather than giving exact numerical information.

Acknowledgement

The financial support received from the Alliance for Global Sustainability is gratefully acknowledged. The author wishes to thank Günter Fischer, Klaus Hubacek, Sylvia Prieler, Laixiang Sun and Harrij van Velthuizen, from the Institute for Applied Systems Analysis (IIASA) for their assistance in conducting the study.

Notes

1 In its *White Book*, the European Union imposed on the Candidate Countries the requirement to adjust their energy use level from renewables to that of the Member States at the level of 12% by 2010 (European Commission 1997).

2 Large differences in the utilisation of renewable energy in European countries are mainly due to the possibility of utilising hydropower in mountainous countries.

3 Polish Minister of Environment Antoni Tokarczuk, 5 September 2000.

Bibliography

Bovenberg, A.L. and De Mooij, R.A. (1994) 'Environmental levies and distortionary taxation', in *American Economic Review,* Vol. 84, pp.1085–1089.

Bovenberg, A.L. and Goulder, L.H. (1997) 'Costs of environmentally motivated taxes in the presence of other taxes: general equilibrium analyses', in *National Tax Journal,* Vol. 50, No. 1, pp.59–87.

Breuss, F. and Steininger, K. (1998) 'Biomass energy use to reduce climate change: a general equilibrium analysis for Austria', in *Journal of Policy Modeling*, Vol. 20, No. 4, pp.513–535.

Burniaux, J. and T. Truong (2002) GTAP-E: An Energy-Environmental Version of the GTAP Model, GTAP Technical Paper No. 16.

Chwieduk, D. (2000) 'Technical and financial aspects of renewable energy applications in Poland', in *Renewable Energy,* Vol. 19, No. 4, pp.521–526.

Council of Ministries (CM) (2000) *Development Strategy of Renewable Energy Sector*, Warsaw.

Cropper, M.L. and W.E. Oates, (1992) 'Environmental economics: a survey', *Journal of Economic Literature,* June, Vol. 30, pp.675-740.

Diedrich, R. and Petersik, T.W. (2001) 'Forecasting US renewables in the national energy modelling system', in *International Journal of Global Energy Issues*, Vol. 15, Nos. 1/2, pp.141–158.

Dimaranan, B. V. and R. A. McDougall (2002). *Global Trade, Assistance, and Production: The GTAP 5 Data Base*, Center for Global Trade Analysis, Purdue University.

EC Baltic Renewable Energy Centre (EC BREC) (200o) *Economic and Legal Aspects of Utilisation of Renewable Sources in Poland*, Warsaw.

Energy Information Administration (EIA) (2002) *International Energy Outlook* 2002, U.S. Department of Energy, Washington DC.

Grubb, M. (2001) *Renewable Energy Strategies for Europe*, Shearwater Books.

Grubb, M. (2002) *Renewable Energy for Europe: Synthesis and Strategies,* Vol 4, May, The Brookings Institution.

Haas, R., Wohlgemuth, N. and Huber, C. (2001) 'Financial incentives to promote renewable energy systems in European electricity markets: a survey', in *International Journal of Global Energy Issues,* Vol. 15, Nos. 1/2, pp.5–24.

Jaffe, A.B., Newell, R.N. Stavins R.N. (2002) Environmental Policy and Technological Change, in *Environment and Resource Economics*, vol. 21.

Knox C. Eng, R. (ed.) (2002) *Renewable Energy 2002*, World Renewable Energy Network, Sovereign Publications Limited, London.

Main State Forest Management Board (MSFMB) (2002) *Order on Detailed Rules and Procedure for the Recognition of Protected Forests and their Management*, Warsaw.

Ministry of the Economy (ME) (2002) *Renewable Energy - Potential Energy Crops for Europe and the Poland,* Warsaw.

Piazolo, D. (2000) 'Poland's membership in the European Union: an analysis with a dynamic Computable General Equilibrium (CGE) model', *LICOS Discussion Paper*.

Pietruszko, S.M., Wisniewski, G., Chwieduk, D. and Wnuk, R. (1996) 'Potential of renewable energies in Poland', in *Renewable Energy,* Vol. 9, Nos. 1-4, pp.1124–1127.

Rabl, A. (2001) 'The importance of external costs for the competitiveness of renewable energies', in *International Journal of Global Energy Issues,* Vol. 15, Nos. 1/2, pp.49–58.

Renewable Energy Equipment Research Group (REERG) (2000) *The 2000-2005 World Outlook for Renewable Energy Equipment*, Icon Group International, Inc.

Reuters Business Insight (RBI) (2001) *Green Energy Outlook*, Reuters, London.

Stavins, R. N. (1988) 'What can we learn from the grand policy experiment?', *Journal of Economic Perspectives*, Vol. 12, No. 3, pp.69-88.

Wohlgemuth, N. (2001) 'The future of renewable energy: from market failure to market penetration', in *International Journal of Global Energy Issues*, Vol. 15, Nos. 1/2, pp.1–4.

Wyman, Charles E. (199) Biomass Ethanol: Technical Progress, Opportunities, and Commercial Challenges, in *Annual Review of Energy and the Environment*, Vol. 24, pp. 189-226

van der Zwaan, B. C. C., R. Gerlagh, G., Klaassen and L. Schrattenholzer (2002) Endogenous technological change in climate change modelling, in *Energy Economics*, Vol. 24, Issue 1 pp. 1-19

Appendix

Table A1 Poland CGE Sectoral Disaggregation

No.	Code	Comprising GTAP V5 Sectors
1	AACLT	Paddy rice; wheat cereal grains n.e.c; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops n.e.c.; bovine cattle, sheep and goats; animal products n.e.c.; rat milk; wool, silk-worm cocoons; fishing
2	AAEN	Bioenergy
3	AFORE	Forestry
4	ACOELPEA	Coal; peat
5	AOIL	Oil; natural gas; gas manufacture, distribution
6	AELEC	Electricity
7	AOIND	bovine cattle, sheep and goad; meat products; vegetable oils and fats; dairy products; processed rice; sugar; food products n.e.c.; beverages and tobacco products; textiles; wearing apparel; leather products; wood products; paper products, publishing; metal products; motor vehicles and parts; transport equipment n.e.c.; electronic equipment; machinery and equipment n.e.c.; manufactures n.e.c.; water; minerals n.e.c.; chemical, rubber, plastic prod; mineral products n.e.c.; ferrous metals; metals n.e.c.construction; trade; transport n.e.c.; water transport; air transport; communication; financial services n.e.c.; insurance; business services n.e.c.; recreational and other services; public admin. And defense, edu; ownership of dwellings

Source: Own calculations based on Poland CGE

Table A2 Poland CGE cross-price and own-price elasticities

	ACOELP	AOIL	AELEC	AFORE	AACLT	AAEN	AOIND
ACOELPEA	-3.75	0.06	-0.15	-0.01	-0.03	-0.03	0.03
AOIL	0.01	-9.88	0.05	0.01	0.02	0.02	0.06
AELEC	-0.07	0.10	-0.84	-0.02	-0.12	-0.12	0.09
AFORE	0.00	0.02	-0.01	-0.36	0.03	0.03	0.06
AACLT	-0.01	0.03	-0.08	0.04	-0.40	0.10	0.18
AAEN	-0.01	0.03	-0.08	0.04	0.10	-0.40	0.18
AOIND	0.00	0.00	0.00	0.03	0.01	0.01	-0.30

Source: Own calculations based on Poland CGE

Table A3 Endogenous variables in Poland CGE

Code	Variables description
$DMPS$	change in domestic institution savings rates
DPI	producer price index for domestic sales
EG	government expenditures
EH_h	consumption spending for household
EXR	exchange rate
$GOVSHIR$	government consumption share
$GSAV$	government savings
$INVSHR$	investment share in nominal absorption
MPS_i	marginal propensity to save
PA_a	activity price
PDD_c	demand price for domestic goods
PDS_c	supply price for domestic sales
PE_c	export price
$PINTA_a$	aggregate intermediate input price for activity a
PM_c	import price
PQ_c	composite commodity price
PVA_a	value-added price
PX_c	aggregate producer price for commodity
$PXAC_{ac}$	producer price of commodity c for activity a
QA_a	quantity of activity
QD_c	quantity sold domestically of domestic output
QE_c	quantity of exports
QF_{fa}	quantity demanded of factor f from activity a
QG_c	government consumption demand
QH_c	quantity consumed of commodity c
$QINTA_a$	quantity of aggregate intermediate input
$QINT_{ca}$	quantity of commodity c as intermediate input to activity a
$QINV_c$	quantity of investment demand for commodity c
QM_c	quantity of imports of commodity
QQ_c	quantity of goods supplied to domestic market
QT_c	quantity of commodity demanded as trade input
QVA_a	quantity of (aggregate) value-added
QX_c	aggregated quantity of domestic output of commodity
$QXAC_{ac}$	quantity of output of commodity c from activity a
$TABS$	total nominal absorption
$TINS_i$	direct tax rate for institution i
$TRII_{ii'}$	transfers from institution i’ to i
WF_f	average price of factor
YF_f	income of factor f
YG	government revenue
YI_i	income of domestic non-government institution i
YIF_{if}	income to domestic institution i from factor f

Table A4 Exogenous variables in Poland CGE

Code	Variables description
$\overline{CPI}$	consumer price index
$\overline{DTINS}$	change in domestic institution tax share
$\overline{FSAV}$	foreign savings
$\overline{GADJ}$	government consumption adjustment factor
$\overline{IADJ}$	investment adjustment factor
$\overline{MPSADJ}$	savings rate scaling factor
$\overline{QFS}_f$	quantity supplied of factor
$\overline{TINSADJ}$	direct tax scaling factor
$\overline{WFDIST}_{fa}$	wage distortion factor for factor f in activity a