JRC Scientific and Technical Reports

Modelling of Energy-Crops in Agricultural Sector Models -

A Review of Existing Methodologies

Peter Witzke, Martin Banse, Horst Gömann, Thomas Heckelei, Thomas Breuer, Stefan Mann, Markus Kempen, Marcel Adenäuer, Andrea Zintl

Ignacio Pérez Domínguez and Marc Müller (editors)

EUR 23355 EN - 2008

JRC EUROPEAN COMMISSION

ipts Institute for Prospective Technological Studies

The mission of the IPTS is to provide customer-driven support to the EU policy-making process by researching science-based responses to policy challenges that have both a socio-economic and a scientific or technological dimension.

European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Address: Edificio Expo. c/ Inca Garcilaso, s/n. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://www.jrc.es
http://www.jrc.ec.europa.eu

JRC42597

EUR 23355 EN
ISBN **978-92-79-08887-2**
ISSN 1018-5593
DOI 10.2791/11341

Luxembourg: Office for Official Publications of the European Communities

Printed in Spain

Table of contents

EXECUTIVE SUMMARY

The present report provides an overview of the different methodologies applied in partial and general equilibrium models used to analyse biofuel policies in Europe, as well as their methodological pros and cons. Whereas partial equilibrium models consist on a very detailed representation of a single sector of the economy, general equilibrium models include a comprehensive view over the whole economy in lesser detail. Within this overview the LEITAP model is included as a general equilibrium model covering biofuel demand and partial equilibrium models are represented by ESIM, FAPRI, AGLINK/COSIMO, RAUMIS, AGMEMOD (agricultural models); POLES and PRIMES (energy sector); and EUFASOM/ENFA (forestry sector). The study is highly relevant for the current modelling work at IPTS, where models such as ESIM and AGLINK play an important role in the Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP) of the AGRILIFE Unit. Additionally, the POLES model is currently part of the model portfolio used by the Competitiveness & Sustainability Unit in several studies analysing possible technological pathways of energy production and demand for bioenergy in Europe, a result of implementing the biofuel directive. This compilation of information is also important since the implicit and explicit treatment of bioenergy, either as a demand shock to the processing of oilseeds or feedstock for bioethanol and biodiesel, or as the introduction of a biofuel-sector into a computational general equilibrium (CGE) is foreseen in the short-term by other economic models used at IPTS.

The selection of presented models was based on their progress towards an explicit treatment of bioenergy, which is a prerequisite for investigating issues like the ‘necessary’ political support to achieve certain market shares. Therefore, the models aim to analyse the impacts of changed economic incentives, perhaps through tax advantages or an increase in the price of crude oil, on the economic development of the biofuel sector. Indeed, modelling biofuels/energy crops requires detailed representations of different options in both agricultural production and in the competition between different uses for food, feed or fuel purposes. This presentation is important for 1st generation biofuel crops, i.e. food crops used for biofuel production using conventional technology, and is implemented in all the models that focus on agri-food sectors. Thus, the impact of enhanced biofuel demand on agri-food markets can be presented and analysed.

However, most of the partial equilibrium models that focus on agriculture, such as AGLINK, FAPRI, ESIM and AGMEMOD, do not include 2nd generation biofuel crops, which are non-food crops using biomass to liquid technology for cellulosic biofuel production. Further analysis taking into account the impact of 2nd generation biofuels needs to be carried out in order to achieve a more profound understanding of the key variables driving biofuel production (e.g. price developments, technical progress and policies). Hoogwijk et al. (2005) and Smeets et al. (2006) indicate that 2nd generation biofuels are more favourable than 1st generation fuels, as they tend to require lower energy inputs for biomass production and increase the efficiency of biomass conversion. Moreover, 2nd generation biofuel crops face a the more ‘relaxed’ competition in final use since they are not in direct competition with food or feed when it comes to final consumption. Here, the competition takes place at the land allocation level, where scarce resources are employed for the production of food, feed or fuel crops. The implementation of 2nd generation biofuel crops in agricultural partial equilibrium models requires methodological extensions in terms of land use change (i.e. willow and switchgrass, which will be grown as perennial crops). The energy and forestry models discussed in this study could help extend existing agri-food models and allow them to contribute to policy debate in this area.

The final parts of the report provide an assessment of relevant practical modelling issues such as data availability, processing demand behaviour, calibration issues, and linkages to non-agricultural modelling systems.

The database situation for energy crops is certainly more complicated than for agricultural raw products, where agencies like FAOSTAT globally monitor production, demand composition and trade flows in view of their direct linkages to food and nutrition. Furthermore, bioenergy's use of biomass has escaped the attention of statistical agencies for a long time, as its impressive development only started a few years ago in industrial countries. Nonetheless, there are private companies which are capable of supplying at least a large part of the missing data for 1st generation biofuels.

The issue regarding processing demand specifications for agricultural raw products is mainly whether they may rely on prices or quantities for biofuel demand being given from other models or model components, or whether non-agricultural biofuel demand itself should be explained, for example, by using crude oil prices. The former option, with biofuel information being fed into the agricultural core model, would certainly correspond to an agricultural focus, but does not achieve stand-alone applicability. A second critical issue is the selection of an appropriate functional form. If processing coefficients are given, demand should be written as a function of processing margins, preferably in a simple but flexible form.

The main relevant calibration problem is to parameterise behavioural functions or optimisation models in such a way that a desired response to changes in economic conditions is reproduced by the models. The dynamic development of the bioenergy sector generally makes it difficult to base this 'desired response' on statistically estimated parameters or elasticities. Consequently, the empirical base of any conceivable calibration exercise is subject to considerable uncertainty and suggests analysing policy options or market outlooks for different assumptions of response parameters. This holds particularly true for 2nd generation biofuels, where future production costs are difficult to estimate, statistical information is largely absent, and the forest sector is highly relevant.

The basic idea underlying model linkages, that is, using the model best suited for the variable in question and then communicating this information with other systems, is especially relevant for the bioenergy issues considered here. Current bioenergy developments at the political and economic level create strong linkages between energy markets (and thereby the general economy) and the agricultural sector. The consistent application of existing modelling systems for energy and agriculture therefore appears to be promising.

ABBREVIATIONS

AGLINK	Worldwide Agribusiness Linkage Program
AGMEMOD	Agricultural Member State Modelling for the EU and Eastern European Countries
BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CAPSIM	Agricultural Policy Simulation Model
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computational General Equilibrium
CGF	Corn Gluten Feed
CGM	Corn Gluten Meal
CHP	Combined Heat and Power
COSIMO	Commodity Simulation Model
COMEXT	The Eurostat Reference Databank on Intra- and Extra- European Trade
DART	The Dynamic Applied Regional Trade
DDGS	Dried Distillers Grains and Solubles
EAA	The Economic Accounts of Agriculture
EC4MACS	European Consortium for Modelling of Air Pollution and Climate Strategies
ENFA	European Non-Food Agriculture Project
ESIM	European Simulation Model
EUFASOM/ENFA	European Non-food Agriculture model
EUFASOM	The European Forest and Agricultural Sector Optimization Model
FAL	Bundesforschungsanstalt für Landwirtschaft
FARMIS	Farm Group Model for German Agriculture
FAO	Food and Agriculture Organization
FAOSTAT	FAO, Statistics Division
FAPRI/CARD	Food and Agricultural Policy Research Institute / Center for Agricultural and Rural Development

FNR	Fachagentur Nachwachsende Rohstoffe e.V.
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies network
GDP	Gross Domestic Production
GHG	Greenhouse Gas
GIS	Geographic Information System
GTAP	Global Trade Analysis Project
HGV	Heavy Goods Vehicles
HRUs	Homogenous Response Units
IIASA	International Institute for Applied Systems Analysis
iMAP	Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis
IMF	International Monetary Fund
LEPII	Laboratoire d'Economie de la Production et de l'Intégration Internationale
MEACAP	Impact of Environmental Agreements on the Common Agricultural Policy
NaRoLA	Nachwachsende Rohstoffe und Landwirtschaft
NEMESIS	New Econometric Model for Environmental and Sustainable development and Implementation Strategies
NUTS	Nomenclature of Units For Territorial Statistics
OECD	Organisation for Economic Co-operation and Development
PMP	Positive Mathematical Programming
POLES	Prospective Outlook on Long-term Energy Systems
PRIMES	Partial Equilibrium Model for the European Energy System
RAINS	Regional Air Pollution Information and Simulation
SEAMLESS	System for Environmental and Agricultural Modelling; Linking European Science and Society
SENSOR	Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions
TIMER	Targets Image Energy Regional Model
TREMOVE	Transport and Emissions Simulation Model
RAUMIS	Regionalised agricultural sector model

1 Introduction

The European Union (EU) is committed to supporting the increased use of bioenergy in different forms. There are various directives urging Member States to promote the use of bioenergy (directives 2001/77/EC, 2003/30/EC, 2003/96/EC); additionally, the EU issued the '*Biomass Action Plan*' (COM (2005)) and the '*European Union Biofuel Strategy*' (COM 2006). According to the *EU biofuels directive* 2003/30/EC, EU Member States should ensure that biofuels and other renewable fuels attain a minimum share of their total consumption of transport fuel. This share should be, measured in terms of energy content, 5.75 % by the end of 2010. In the '*Renewable Energy Roadmap*' (COM 2007a), the European Commission proposed binding minimum targets of 10 % for biofuels in each Member State, though the 2010 target is unlikely to be met. The European Council of March 8-9, 2007, confirmed these reinforced targets. The agricultural impacts of these goals have been investigated in a recent study by the European Commission's Directorate-General for Agriculture and Rural Development (DG Agri) (EU Commission 2007c), which found the 10 % goal to be feasible assuming a contribution of 30 % for 2nd generation biofuel in 2020.

In line with these goals the EU and EU Member States are supporting the development of biofuels with various measures. Among these are tax concessions, investment support and minimum content requirements. On the EU level there is tariff protection for bioethanol, an energy crop premium and the possibility to use set-aside land for non-food purposes. These measures have significantly contributed to the remarkable development of the EU's biofuel sector (see Section 2). The European bioenergy boom is thus strongly determined by political decisions, which is often ignored in the current euphoria surrounding bioenergy.

This report proceeds with a brief overview on the background of biofuels, which summarises existing production technologies and their recent developments. The focus here is on so-called 1st generation technologies. After 2015 many observers expect a greater market share for 2nd generation technologies but this presupposes further technological progress.

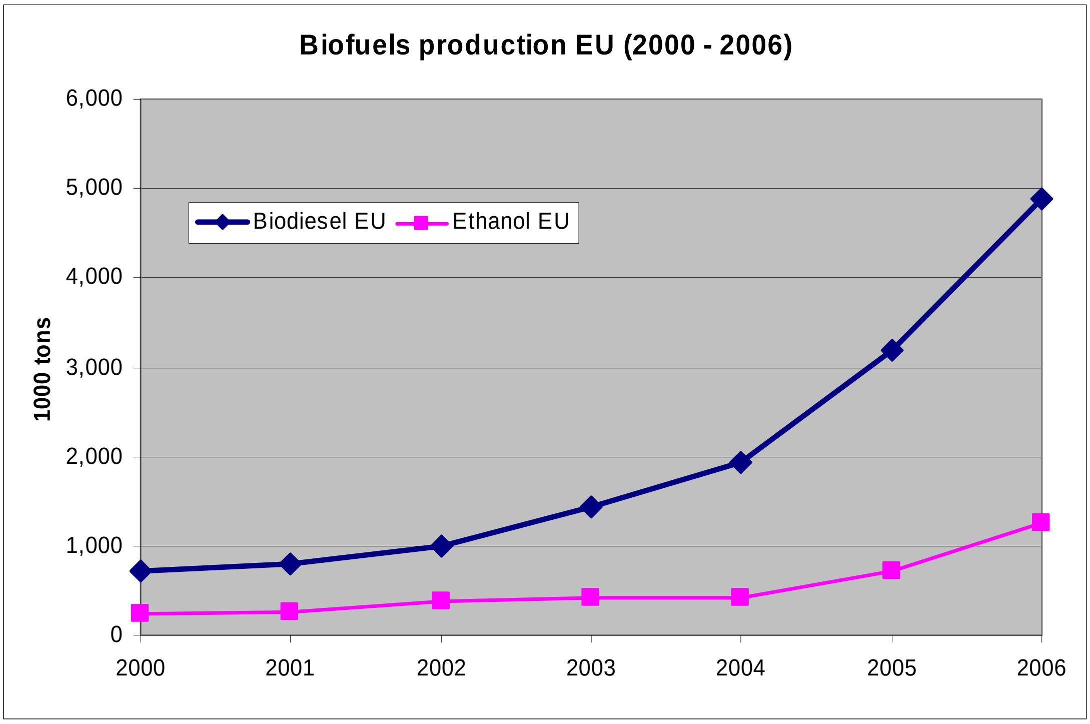
The report continues with a concise review of existing modelling approaches concerning the production of energy crops in agriculture, mainly with a medium-term horizon (up to 2020). However, some of the reviewed modelling systems may also cover a longer time horizon. An assessment of critical modelling issues, including available databases, specification of processing demand, model calibration and model linkages are covered in the later sections.

In terms of the database, it appears that private companies are capable of supplying at least a large part of the missing data for 1st generation biofuels. A key specification issue is whether agricultural modelling may rely on detailed communication with energy related models or whether stand-alone coverage is intended. The main calibration problem is the lack of sufficient observations to permit a statistical estimation of behavioural parameters. Thus, it is recommendable to carry out sensitivity analyses on otherwise obtained parameters.

2 Background information on production technologies for biofuels and their main economic and political determinants

The production of biodiesel and bioethanol for transport purposes in the EU increased strongly between 2000 and 2006 (Figure 1). In this period, biodiesel production surged by over 500 %, and bioethanol production by more than 400 %.

Figure 1: Biofuels production in the European Union (2000 - 2006)



Source: Own illustration, based on EUROBSERVER (2006), internet source: 28.08.07 www.ebio.org/production_data_pd.phd ; http://www.ebb-eu.org/stats.php

Despite this impressive relative increase of production, the market share of biofuels in the EU today barely lies above 1 %.

In general, there are many technical possibilities available to convert biomass to energy. In the case of biofuels, products of importance at the European level are biodiesel and bioethanol, and to a lesser extent vegetable oil.

Figure 2: Production lines of biofuels in Europe

Co-products	Straight vegetable oil	Biodiesel	Bioethanol	BtL	Biogas
Field 1. Biomass	Oilseeds	Oilseeds	Wheat, barley rye, triticale , corn, sugar beet	Straw, miscanthus short rotation coppice	Manure, bio waste, green maize, etc.
2. processing	Oil seed meal (Press cake)	Oil seed meal			Fermentation residuals
3. processing		(soy oil) (palm oil) Glycerin	Dried Distillers Grains plus Solubles (DDGS), Corn, Gluten feed,	Slag (biomass ash, dust and other trash)	Processed biogas
4. Market Gas station	**Diesel** **Modified engines**	**Diesel**	**Gasoline** **E-85 (modified engines)**	**Diesel**	**Electricity Production** **Green-gas -> Gasoline**
Production Costs €/GJ	2005: 14 2015: app. 14	2005: 19 2015: app. 19	2005: 22 (starch) 2005: 24 (sugar) 2015: app. 20 (starch) 2015: app. 22 (sugar)	2005: 30 2015: app. 16	2005: 21 2015: app. 20

Source: FNR 2005

Straight vegetable oil

Vegetable oils can be used directly in modified diesel engines, but the cost of modification is higher than simply using biodiesel or bioethanol. Even though pure vegetable oil is unlikely to be used widely in the private transport sector, it may be attractive for engines with high and constant utilisation (e.g. HGV (Heavy Goods Vehicles), CHP (Combined Heat and Power)). The 1st option for production from seeds is cold crushing in small-scale (regional) plants. In this case, the co-product is 'press cake'. The second, dominant option is a warm crushing process in large-scale central plants. In these plants, oilseeds are heated before crushing and a chemical solvent is added. The co-product is an oil seed meal with a low content of oil.

Biodiesel

Biodiesel can be produced from vegetable oils such as rape seed oil, sunflower seed oil and soybean oil. The technology is both well understood, (it has been in use since the early 1990s) and widely applied. After crushing the oil seeds, the vegetable oil, for example rape seed oil, is processed with 10 % bioethanol. The result is rape methyl ester (biodiesel) and 10 % glycerine. The by-product of the seed extraction grist can also be used as protein rich fodder.

Bioethanol

In general, bioethanol can be produced from every starchy and sugary plant. The main crops used in Europe are wheat, barley, rye, triticale, sugar beets and partly also corn. The processing of starchy crops takes place in five stages (see, for example www.cropenergies.de):

- Milling the substrate (mechanically crushing it in order to release the starch content);
- Heating and adding water and enzymes to convert starch into sugar, which can then be fermented;
- Fermenting the mash with yeast, whereby the sugar is converted into CO_2 and bioethanol;
- Distillation and rectification, which entails concentrating and cleaning the distilled bioethanol from by-products, and then drying (removal of water from) the bioethanol;
- By-products are DDGS (Dried Distillers Grains and Solubles (dry-milling)), or corn gluten feed (wet-milling).

The processing of sugar beets for bioethanol production is equivalent to its processing for sugar production. The by-product of sugar beet pulp is used in various forms (wet, dried, pressed).

3 Review of existing methodologies and modelling results related to biofuels and biomass production

The overview will start at the macro level, where LEITAP[1] is an example of a general equilibrium model that explicitly covers biofuels. We will proceed to partial equilibrium models with a focus on the energy sector, (POLES[2], PRIMES[3]) continue with agricultural partial equilibrium models (ESIM[4], FAPRI[5], AGLINK[6], RAUMIS[7], AGMEMOD[8]) and then examine EUFASOM/ENFA[9], which is an example of a model encompassing both agriculture and forestry.

These models, though a broad selection, do not cover all available agricultural sector models (e.g. CAPRI[10] or CAPSIM[11]). However, all of the selected models have already made some progress towards an explicit treatment of bioenergy, which is required to investigate issues like the 'necessary' support to achieve certain market shares. An implicit treatment of bioenergy simply as a demand shock to the processing of oilseeds, or as feedstocks for bioethanol, may be undertaken with almost any agricultural sector model, thereby analysing the implications of a complete implementation of the EU biofuels directive on agricultural markets. The bioenergy related objective of the models reviewed here is more ambitious; namely, an analysis of the impacts of changed economic incentives, say, through tax advantages or an increase in the price of crude oil, on the economic development of the biofuel sector. To this end, the approaches explored thus far are quite diverse, as this survey shows.

3.1 LEITAP

3.1.1 General information

LEITAP is a global computable general equilibrium model that covers the whole economy, including factor markets, and is often used in World Trade Organisation (WTO) analyses

[1] LEITAP = Demand for food (animals and crops) products model)

[2] POLES = Prospective Outlook on Long-term Energy Systems)

[3] PRIMES = Partial equilibrium model for the European energy system.

[4] ESIM = European Simulation Model

[5] FAPRI = Food and Agricultural Policy Research Institute

[6] AGLINK = Worldwide Agribusiness Linkage Program

[7] RAUMIS = Regionalised agricultural sector model

[8] AGMEMOD = Agricultural Member State Modelling for the EU and Eastern European Countries

[9] EUFASOM / ENFA = European Non-food Agriculture) model

[10] CAPRI = Common Agricultural Policy Regional Impact Analysis Model

[11] CAPSIM = Agricultural Policy Simulation Model

and Common Agricultural Policy (CAP) proposals. It is a modified version of the global general equilibrium model Global Trade Analysis Project (GTAP). The model, and its underlying database, describes production, use and international trade flows of goods and services, as well as primary factor use differentiated by sectors. Assumptions about population growth, technological progress, and the policy framework are the main drivers of the model's results.

3.1.2 Integration of bioenergy

The LEITAP model is currently extended to represent the production, consumption and trade of biofuel products in the Eururalis project Version 2.0 (http://www.eururalis.nl/eururalis.htm). In the current version of the GTAP database, arable crops are: paddy rice, wheat, cereal grains nec[12]., vegetables, fruits and nuts, oilseeds, sugar beet/cane, plant-based fibres, and other crops. The introduction of 1st generation biofuel crops may be modelled as 'standard' arable crops, e.g. oil-seed, cereals and sugar beet/cane. The technology to process these intermediate-to-final products (vegetable oil, and sugar) is already being implemented in the standard model, and the GTAP database also includes the petroleum sector's demand for vegetable oil. However, it should be noted that biodiesel and bioethanol are part of the chemistry sector, so LEITAP has to be adjusted in order to allow for substitution between crude oil and 'crops-oil', as well as 'crops-bioethanol', to produce the final product of the petroleum activity.

For the Eururalis project Version 2.0, (http://www.eururalis.nl/eururalis.htm) the nested Constant Elasticity of Substitution (CES) function of the so-called GTAP-E (see Burniaux and Truong, 2002) has been adjusted and extended to model the substitution between different categories of oil (oil from bio-crops and crude-oil) in the value added nest of different industries.[13]

The base version of GTAP represents intermediate demand in a Leontief structure. It is assumed that the various types of intermediate inputs are demanded in a fixed proportion, whereas substitution relations within the value added nest are depicted by the CES function.

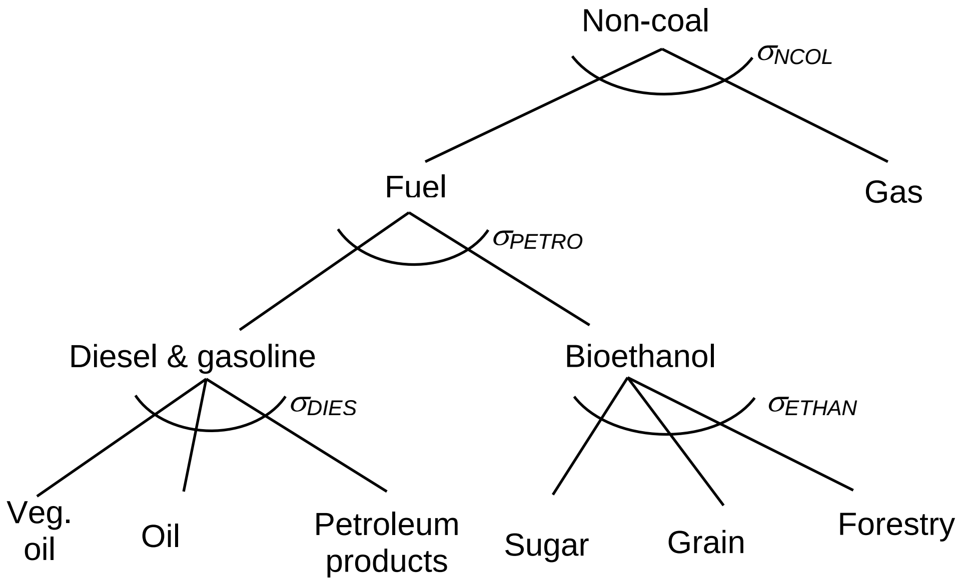
To model biofuel activities the intermediate demand structure is adjusted to a nested CES structure. Compared to the standard presentation of a production technology, the GTAP-E model aggregates all energy-related inputs for the petrol sector, such as crude oil, gas, electricity, coal and petrol products in a nested structure under the value added side as part of an aggregated 'capital-energy' composite. The extended LEITAP model presents fuel production at the 'non-coal level' differently compared to the approach applied under the GTAP-E model. The non-coal aggregate is modelled as follows: 1) it consists of two sub-aggregates, fuel and gas, where 'fuel' combines 'oil' and 'petroleum products' from GTAP-E; 2) fuel is split into gasoline/diesel or into bioethanol; 3) gasoline/diesel can be produced from crude oil, petrol products and vegetable oils, while Bioethanol is made out of grains and/or sugar (see the following figure).

---

[12] Not else classified

[13] Results of that work are available at https://www.gtap.agecon.purdue.edu/resources/download/3428.pdf

Figure 3: Input structure of biofuel production in extended LEITAP



Source: Derived from GTAP-E, Burniaux and Truong (2002).

Under this approach, LEITAP will be able to present an energy sector where industry demand on intermediates strongly depends on the cross-price relation of fossil and biofuel-based energy. Therefore, petroleum industry output prices will be, among others, a function of fossil energy and bioenergy.

In addition, petroleum industry prices for outputs will depend on any subsidies/tax exemptions and, most importantly for current EU policy, on mandatory inclusion rates. Mandatory blending, such as the EU biofuel directive, is modelled by a subsidy given to the petroleum industry to reduce the input prices for biofuel inputs.

For modelling the 2nd generation of biofuels, the current GTAP data set needs to be extended by the introduction of 'new' arable or woody biomass-crops like e.g. switchgrass, short rotation coppice, miscanthus, forestry or by-products of primary agriculture like straw and residuals of food processing. For these new products a new technology/activity at the level of raw product and at the final product level has to be implemented. This approach follows a concept outlined in McDonald, Robinson and Thierfelder (2004). Switchgrass is the 1st example of introducing 2nd generation biofuel crops into the LEITAP model. The data for this adjustment have been derived from the data base published in the F.O. Licht Interactive Data and World Bioethanol and Biofuels Report.

Since switchgrass is a member of the graminae family and is harvested only once a year, its input mix is similar to that of other cereal crops. However, it is a perennial and therefore only requires periodic planting and reduced usage of intermediate inputs. Hence, it will be assumed in a 1st pragmatic approach that the primary input coefficients were the same as those of other cereals and that the intermediate input coefficients were 70 % of those for cereals in each region. All output of biomass production will be purchased as an intermediate input by the petroleum activity.

3.1.3 Applications

Second generation biofuels are not yet operational in LEITAP. However, the version with 1st generation biofuels has been used for Banse et al. (2007) to analyse the impact of EU biofuel policies on world agricultural and food markets. In these scenarios, two different rates of mandatory blending in the individual EU Member States have been analysed: 5.75 % and 11.5 % obligatory blending rates have to be fulfilled in each individual Member State.

Even without the enforced use of biofuel crops through mandatory blending, the share of biofuels in fuel consumption for transportation purposes increases. Results reveal that without mandatory blending, the 5.75 % biofuel share will not be reached in the Member States. With mandatory blending, the EU Member States fulfil the required targets of 5.75 %, albeit at the expense of non-European countries. The share of biofuel use declines in Brazil by 12 % under a mandatory blending rate in the EU of 5.75 % and by almost 25 % with an EU-blending rate of 11.5 %. With enhanced biofuel consumption being a consequence of the EU biofuel directive, prices of agricultural products tend to increase.

3.2 POLES

3.2.1 General Information

POLES is a partial equilibrium model that focuses on the presentation of the energy sector and analyses, e.g. greenhouse gas (GHG) emitting activities. In POLES, the simulation process is dynamic, employing a year-by-year recursive approach that facilitates the description of full developmental pathways from 2005 to 2050. The model enables the production of:

- Detailed long-term (2050) world energy outlooks with demand, supply and price projections by main region;
- CO_2 emission Marginal Abatement Cost curves by region and/or sector, and emission trading systems analyses under different market configurations and trading rules;
- Technology improvement scenarios – with exogenous or endogenous technological change – and analyses of the value of technological progress in the context of CO_2 abatement policies.

As far as induced technological change is concerned, the model provides dynamic cumulative processes through the incorporation of Two Factor Learning Curves, which combine the impacts of ’learning by doing’ and ’learning by searching’ on the technologies’ improvement dynamics. As price induced diffusion mechanisms (such as feed-in tariffs) can also be included in the simulations, the model permits accounting for the key drivers to the future development of new energy technologies. One key aspect of energy technology development analysis of with the POLES model is the presentation of inter-technology competition, with dynamically changing attributes for each technology.

3.2.2 Integration of bioenergy

The POLES model projections are based on the ENERDATA[14] updated international energy databases that keep track of short-term demand and supply trends in the countries covered in the model, price changes on the main energy markets and on the development of energy plant capacities. The database is not publicly available.

In its current geographic disaggregation, the world is divided into 46 countries or regions, with a detailed national model for each Member State of the European Union (25), four industrialised countries (USA, Canada, Japan and Russia) and five major emerging economies (Mexico, Brazil, India, South Korea and China). The other countries/regions of the world are dealt with in a simplified but consistent demand model.

For each region, the model consists of five main modules which describe (1) final energy demand by main sectors; (2) new and renewable energy technologies; (3) hydrogen and carbon capture and sequestration technologies and infrastructures; (4) conventional energy and electricity transformation systems; and (5) fossil fuel supply.

While the simulation of the different energy balances permits the calculation of import demand/export capacities by region, the integration of all modules is ensured in the energy markets module, the main inputs of which are import demand and export capacities of the various regions. Only one world market is considered for the oil market, while three regional markets (America, Europe, Asia) are identified for coal; this is done in order to take into account different cost, market and technical structures. Natural gas production and trade flows are modelled on a bilateral basis. The comparison of import and export capacities and the changes in the reserves/production ratio for each market determines the variation of prices for subsequent periods.

Energy demand is presented for the following aggregated sectors, which facilitates the identification of key energy intensive industries (steel, chemical, non metallic mineral, other industries), main transport sectors (road passenger, road freight, rail passenger, rail freight, air transport) and aggregate representations of services (residential and other services) as well as agriculture. Energy consumption is calculated in each sector for both substitutable fuels and electricity, while also taking into account the specific energy consumption of the individual sectors covered in POLES. Each demand equation combines both income and price elasticity, as well as technological and consumption trends.

The dynamics of the POLES model is based on a recursive (year-by-year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy prices. Version 5.0 of POLES also includes the development of Very Low Energy/Emission end-use technologies (VLE) which helps capture the improvement of energy performance in the sectors, buildings and road vehicles, respectively. In the transport sector, the competition between six types of vehicles is described, while still allowing for the potential introduction of hydrogen and/or electricity in road transport. Here, biofuels enter the model as a mixed blend according to the relative costs of conventional petroleum products.

[14] ENERDATA is affiliated with the French Committee of the World Energy Council and is a member of the French Association of Energy Economists.

The introduction of biofuel use and the adaptation of new technologies are both modelled in a technology diffusion module. This approach was applied in POLES version 5.0 to present the so-called renewable energy module models' 'phasing-in' of a new technology, e.g. biomass gasification, photovoltaic or biofuels for transportation. Here, POLES recognises the difference between technical and economical potentials, as well as the time constants that characterise the diffusion process.

3.2.3 Model applications

POLES has been developed and maintained by the Laboratoire d'Economie de la Production et de l'Intégration Internationale (LEPII) in Grenoble, France, see LEPII (2005 and 2006). The POLES model is a world simulation model for the energy sector, with endogenous international energy prices and lagged adjustments of supply and demand by world region. Developed under various EU research programmes (JOULE, FP5, FP6), the model has been fully operational since 1997 and has been used for policy analyses by the European Commission's Directorate-General for Research (DG Research), the European Commission's Directorate-General for Environment and Sustainable Development (DG Environment) the European Commission's Directorate-General for Transport and Energy (DG TREN), as well as by the French Ministry of Ecology and Ministry of Industry, see EU-Commission (2003). Currently, IPTS (C&S Unit) and LEPII have a joint collaboration for the further maintenance and application of POLES.

3.3 PRIMES

3.3.1 General information

PRIMES is a modelling system for energy markets which is similar, in terms of structure and approach, to POLES. However, PRIMES is more detailed and focuses more on European countries. In fact, early developers of POLES are still at the 'E3M lab' that hosts PRIMES. The model itself describes a non-forward looking market equilibrium over time, including dynamic relationships through learning curves and a vintage approach for technology description, i.e. technologies depend on the time they were built and on their age. PRIMES was developed at the National Technical University of Athens (starting in 1993-94) and is maintained at the 'E3M lab', (http://www.e3mlab.ntua.gr/) where its documentation (E3Mlab – ICCS/NTUA (2005)) is offered for download.

The long run horizon of PRIMES is supported by a detailed description of technology choices in energy demand and energy production. The model explicitly considers the existing stock of equipment, its normal decommissioning and the possibility for premature replacement. At any given point in time, the consumers or producer selects the technology of the energy equipment based on economic criteria which is potentially influenced by policy (taxes, subsidies, regulation, tariffs, etc.) and given technological options (including endogenous learning and progressive maturity on new technologies). Producers also decide on the use of existing capacity and on capacity expansion. Inertia exists in the penetration of new technologies, an adaptive expectations mechanism and consumer habits, respectively. Markets clear at different levels, similar to the procedure followed in POLES, depending on the type of energy (electricity: national, with EU-wide electricity grid; natural gas: multinational; refinery sector: national, etc.).

3.3.2 Integration of bioenergy

The biomass component of PRIMES dates from 2006, is not yet documented in detail and is currently under revision. As a consequence, the following is a quite preliminary assessment based on Kouvaritakis, N. (2007). In the biomass module, all biomass is classified into five categories: energy crops, agricultural residues, forestry, aquatic biomass and wastes. Energy crops are further distinguished into hay (for straw use), sugar, oil and wood crops. Processing cereals (and green maize) into bioethanol is currently included in the 'hay platform', as the fermentation process is similar to the fermentation of straw. Agricultural residues are split into corresponding categories (hay, sugar, oil and wood crops). The biomass system includes twenty primary resources, about thirty transformation processes that produce a total of twelve final biomass energy products (solid biomass for direct combustion, pellets, charcoal, mass burn waste, refuse derived fuel, pure vegetable oil, bioethanol, biodiesel, bioethanol, bio-DME (Dimethyl ether), biogas and biohydrogen). The biomass database includes technical parameters and costs information, as well as production potentials and prices of both final and secondary commodities from the EU and countries outside the EU. The database is not publicly available.

The economic structure of this component is similar to the general PRIMES model, particularly regarding the cost-minimising behaviour and the role of an upward sloping supply function that represents the increasing unit costs associated with the exploitation of biomass production's potential. The main endogenous variables are the prices of biomass related products which are passed on into the general PRIMES model. Most other variables are exogenous to the biomass component (technical potential, demand for biomass related products like bioethanol, policy variables) and are determined by interacting with the core PRIMES model until market equilibrium is reached.

Overall, it is clear that PRIMES is remarkably detailed in its description of the processing demand sectors, including future technological options. It appears that the description is rather simple for the supply of energy crops, where each energy crop is described by independent supply functions with some capacity constraint. Still PRIMES falls short of a full description of the production potential in agriculture with substitution between various crops, for example. Instead, the production potential is apparently derived from (very few) historical observations on biofuels. Furthermore, the agricultural by-products are priced with exogenous prices which may not have received much attention so far, as PRIMES is clearly a general energy model.

3.3.3 Model applications and results

There are numerous applications of the general PRIMES system on behalf of DG TREN, but so far none using the new biomass component. However, even the non-extended version of PRIMES has been applied to bioenergy issues, for example in the EU Commission, (2007a) where the 20 % share for all renewable energies has been investigated in a joint application with GreenX (for a description, see Energy Economics Group (2004)), which, similar to PRIMES, is a process based modelling system. Without particular support for bioenergy, the 2005 PRIMES baseline expects that the share of renewables would be far lower than the desired 20 % even by the year 2030.

3.4 ESIM

3.4.1 Overview

ESIM is a recursive, dynamic, partial equilibrium multi-country model of agricultural production and consumption, and also carries out some 1st stage processing activities. ESIM is a partial model, as only a part of the economy - the agricultural sector - is modelled, i.e. macroeconomic variables (like income or exchange rates) are exogenous. As a world model, it includes all countries, though in greatly varying degrees of disaggregation. Some countries are explicitly modelled and others are combined in an aggregate: the so-called rest of the world (ROW). So far, each of the new EU10 Member States (the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Malta and Cyprus) as well as Bulgaria, Romania, Turkey, and the US, were modelled as individual regions. The EU15 is presented as individual EU15 Member States, except for Belgium and Luxembourg, which are represented as one region. ESIM is a price- and policy-driven model with rich cross commodity relations and the possibility of modelling price and trade policy instruments. As ESIM is mainly designed to simulate the development of agricultural markets in the EU and accession candidates, policies are only modelled for these countries, i.e. for the US (United States) and the ROW, production and consumption takes place at world market prices.

3.4.2 Integration of energy crops

The implementation of biofuels in several partial equilibrium models, for example the European Simulation Model (ESIM), focuses mainly on an impact assessment of different biofuel policies on agricultural markets.

Data

Food and Agriculture Organization (FAO) data on the production of rape cake and rape oil include both cake and oil production from energy and food rapeseed. This is also the case for sunflower seed. Within EU-project n° AGRI -2006-G4-01, data for rape oil and cake production were separated into the production of energy oilseed and oilseed for food production based on plausible assumptions, as statistical data are unavailable.

In ESIM, product prices (also those of non-tradable products) are identical across all EU15 Member States as reproduced in Banse, Grethe and Nolte (2005). Price information is generally obtained from the Directorate General Eurostat (Eurostat). For energy crops (raw commodities, oilseeds, cereals and sugar), producer and market prices are identical to those applicable when these products are used for other purposes. Palm oil and bioethanol prices are obtained from the FAPRI outlook database. To calibrate the ESIM model in view of 1st generation biofuel crops, the database has been adjusted using data published in the F.O. Licht Interactive Data and World Bioethanol and Biofuels Report.

Extraction coefficients for processing oilseeds to biofuels are taken from the ESIM version published in Banse, Grethe and Nolte (2005). Extraction coefficients for processing cereals and sugar are taken from the publication titled Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (2005).

Processing demand for biofuel crops

Under project n° AGRI -2006-G4-01 processing demand equations have been introduced for oilseeds processed to biodiesel and for cereals and sugar processed to bioethanol. In the case of sunflower seed and rapeseed, processing activities in the former ESIM version published in Banse, Grethe and Nolte (2005) are simply extended. However, processing industries' demand for biofuel crops is affected by changes in crude oil prices (pco) which enter the model as an exogenous variable. Processing demand is a function of the prices of the respective processing inputs and outputs:

Equation (1) $$PDEM_{cc,oilseed} = cr\_int_{cc,oilseed} \bullet \prod_{ospro} PD_{ospro}^{elast\_cr_{oilseed,\,ospro}} \bullet PD_{oilseed}^{elast\_cr_{oilseed,oilseed}} \cdot pco^{elast\_coil}$$

where:

cr_int: crushing demand intercept in region cc
elast_cr: price elasticity of crushing demand w.r. to prices
PDEM: processing demand for oilseed in region cc
PD: wholesale price in region cc
pco: crude oil price
cc: Index for countries
ospro: Index for processing outputs.

The endogenous variables are wholesale prices of the processing input (the respective oilseed) and processing outputs (meals and cakes, contained in the subset 'ospro'). The constant term (cr_int), which serves as a shifter for the calibration, as well as the elasticities of processing demand with respect to input, output prices (elast_cr) and fossil oil (elast_coil), are exogenous parameters, the former being calibrated according to base data. The demand function for oilseeds is restricted to being homogenous with degree zero in all input and output prices. The processing elasticities of oilseeds as biofuel crops are taken from Banse, Grethe and Nolte (2005), and the processing elasticities for cereals and sugar as inputs for biofuels are similar to those for oilseeds. In the current version, all inputs for biofuel production (wheat, corn, oilseeds) are considered homogenous with other uses such as food and/or feed. The functions for the input demand of bioethanol processing are similar to those for biodiesel production.

Processing supply is defined as processing demand multiplied by the respective extraction rate, which are derived from the Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL, 2005):

Equation (2) $$Supply_{cc,ospro} = \sum_{oilseed} PDEM_{cc,oilseed} \cdot oilsd\_c_{cc,ospro,oilseed}$$

where:

oilsd_c: extraction rate.

This way of modelling biofuel production ensures that biofuel production changes endogenously due to the development of input such as oilseeds, cereals and sugar, and output prices for biodiesel and bioethanol and fossil prices. However, policies such as the

EU biofuel directive are modelled as exogenous shifts on the demand side, which may change the relative prices of input and output in the biofuel sector since fossil prices remain constant.

Supply of biofuel crops

Supply activities for biofuel crops in the extended ESIM version are modelled similar to agricultural raw products as published in Banse, Grethe and Nolte (2005). For European countries, crop supply functions are separated into two parts: capacity (area), and intensity (yield). As for crops modelled in Banse, Grethe and Nolte (2005), the supply of newly introduced crops (palm oil) in other countries is a direct function of own and cross domestic prices and technical progress. Palm oil is only produced in the ROW and the supply of palm oil is modelled without consideration of by-products such as palm kernel oil, palm kernel meal, tree stems and bark.

3.4.3 Applications

Key applications with the revised ESIM have been carried out in the context of the SCENAR 2020 study done on behalf of DG Agri (Nowicki et al. 2007) and a recent impact analysis regarding a minimum 10 % share for biofuel use carried out by DG Agri staff itself (EU Commission 2007c). The major findings of this study were:

- Main findings: Under a 10 % minimum obligation, about 59 mm t of cereals or about 18 % of domestic use would be used as 1st and including straw also, as 2nd generation feed stock.

- Domestic use of cereals would significantly increase, while exports would decrease over time. Cereal prices would appear to stabilise and reach 150 EUR/t.

- Cereal prices are likely to moderately increase (3% to 6%) compared to 2006 prices under the reinforced biofuels target.

- Second generation biofuel production would reach about a third of the domestic biofuel production, largely by incorporating the straw and wood based cellulosic material into production. Of this wood based material, imports of some 1.75 mm t could be expected.

- In 2020 about 17.5 mm ha (15 % of arable land) in the EU27 would be used for biofuel production. The main source of adding production potential is assumed to be the obligatory set aside.

3.5 FAPRI model

3.5.1 General Information

The models applied at FAPRI/CARD are partial equilibrium models. The FAPRI framework covers the US crops model, as well as the international cotton, dairy, livestock, oilseeds, rice, and sugar models. These models are non-spatial, multi-market models that represent several countries/regions and include a rest-of-the world aggregate. The models are independent, but they also have linkages between each other. As an example, the grains model interacts with the dairy and livestock models to provide information on feed demand in the countries, and also with oilseeds and rice models to supply information on the relative profitability and area harvested for the competing crops. Production is divided into yield and area equations, while consumption is divided into feed and non-feed demand. Agricultural and trade policies in each country are included in the model to the extent that they affect the supply and demand decisions of the economic agents. Examples of these include taxes on exports and imports, tariffs, tariff rate quotas, export subsidies, intervention prices, and set-aside rates. Macroeconomic variables such as Gross Domestic Production (GDP), population, and exchange rates are exogenous variables that drive the models' projections.

3.5.2 Integration of bioenergy

The international bioethanol model is a non-spatial, multi-market world model consisting of a number of countries/regions, including a rest-of-world aggregate to close the model. The model specifies bioethanol production, use, and trade between countries/regions. Country coverage consists of the US, Brazil, EU15, China, Japan, and the rest-of-world aggregate. Further, the model incorporates linkages to agriculture and energy markets, namely US crops, world sugar, and gasoline markets.

The general structure of the country model is made up of behavioural equations for production, consumption, ending stocks, and net trade. Complete country models are established for the US, Brazil, and the EU15, while only net trade equations are set up for China, Japan, and the rest of the world because of limited data availability.

The model is solved for a representative world bioethanol price (Brazilian anhydrous bioethanol price) by equating excess supply and excess demand across countries. Using price transmission equations, the domestic price of bioethanol for each country is linked with the representative world price through exchange rates and other price policy wedges. All prices in the model are expressed in real terms. Through linkages to US crops and world sugar models, the FAPRI model estimates prices for all US crops, including the corn farm price and its by-products, e.g. high fructose corn syrup. Furthermore, the world raw sugar price is also calculated by equating excess supply to excess demand in the world sugar market.

US Bioethanol Model

Total US bioethanol demand is divided into fuel bioethanol demand and a residual demand that consists of non-fuel alcohol use (industrial and for beverages). Fuel bioethanol demand is derived from the cost function for refiners blending gasoline with additives (including bioethanol), including the US prices of bioethanol and crude oil, as well as the gasoline supply and policy measures affecting refiner's bioethanol demand.

Final gasoline demand is a function of unleaded gasoline prices, bioethanol prices, the tax rebate on bioethanol, as well as population and income growth. With this function, consumers respond positively to a decrease in the price of the composite fuel, which is a function of the prices of gasoline and bioethanol. The bioethanol component of the demand for the composite aggregate fuel increases as the bioethanol price falls relative to the price of gasoline, which captures the substitution between the types of gasoline at the gas station pump. In US gasoline production, fuel bioethanol is mainly used as an additive to gasoline. In the current version of the model, bioethanol is presented as a complementary good to pure gasoline.

Bioethanol Supply

To model the domestic bioethanol production in the US, the FAPRI authors use a restricted profit function for bioethanol plants. Both wet and dry mm plants mainly use natural gas as an input in the process. Profit maximisation under capacity constraints yields a profit function that can be expressed as a function of the return per bushel of corn net of energy costs. To account for the different processes of bioethanol production, the relative marginal revenues from the by-products from each process are weighted by the share of production by each mm type.

The model is calibrated on the most recent available data (2005) and generates a 10-year baseline to 2015. The model combines econometric and consensus estimates of supply and demand responses to their respective arguments (prices, price of related products, income, etc.).

In general, data for bioethanol supply and utilisation were obtained from the F.O. Licht Online Database, the FAO's FAOSTAT Online, the Production, Supply and Distribution View (PS&D) of the US Department of Agriculture (USDA), and DG TREN. Macroeconomic data such as real GDP, GDP deflator, population, and exchange rate were gathered from various sources, including the International Monetary Fund (IMF) and Global Insight

3.5.3 Model Applications

The FAPRI biofuel model has been used to simulate the impact of trade policies in the area of biofuel trade, especially the removal of US import tariffs on bioethanol, as well as the removal of the federal tax credit for refiners blending bioethanol, see Elobeid and Tokgoz (2006a).

The main findings of this paper can be summarised as follows:

- The removal of trade distortions induces a 23.2 % increase in the price of world bioethanol relative to the baseline.
- The US domestic bioethanol price decreases by 14.1 %, which results in a 7.5 % decline in production and a 3.2 % increase in consumption.
- There is a strong increase in US net bioethanol imports by 192.8 %.
- In Brazil, production increases by 8.8 % on average due to the increase in bioethanol world prices, with a corresponding decline in Brazil's bioethanol consumption.
- The removal of trade distortions and the removal of domestic subsidies to US refiners blending bioethanol induces a 22.5 % increase in the world bioethanol price.

Other applications of the FAPRI biofuel model have been presented during the OECD Outlook Conference in Banff, Canada, see Elobeid and Tokgoz (2006b).

3.6 AGLINK/COSIMO

3.6.1 General information

AGLINK is a dynamic partial equilibrium model for agricultural product markets developed and applied by the OECD Secretariat and Member Countries. Together with the Commodity Simulation Model (COSIMO) model developed by the FAO based on the AGLINK modelling methods, AGLINK covers the global markets by representing all OECD countries (two of which are exogenous, and with EU members aggregated into a common market) and 36 countries and regions outside the OECD. Designed for temperate-zone products, the model covers the markets for some 15 commodities, including cereals, oilseeds, oilseed processed products, meat, and dairy products. Special emphasis is given to domestic and trade policies which are represented in detail. The model is regularly used to create medium-term projections (baseline) for supply, demand, trade and prices, as well as for the forward-looking analysis of policy changes and other factors. Normally run as a separate model next to AGLINK/COSIMO, the AGLINK Sugar Model specifically covers the regional and international markets for sugar cane, sugar beets and raw and white sugar. Using similar modelling methods and having a similar focus on agricultural policies, the sugar model has a different regional disaggregation. AGLINK/COSIMO and the AGLINK Sugar Model have been combined for the purpose of analysing biofuel markets.

3.6.2 Integration of bioenergy

To analyse bioenergy markets, the combined AGLINK/Cosimo/Sugar model has been modified in two important ways:

- The feedback from changes in international crude oil prices to domestic production has been ensured by taking into account an energy cost element in the supply equations, mainly for crop products.
- Where relevant, the country modules have been extended to endogenously represent bioethanol and biodiesel production, their cost calculation, the shares of different feedstocks in their production, total feedstock use and by-product production. By-products considered include distilled dried grains with solubles (DDGS) from the dry milling process, corn gluten feed (CGF) and corn gluten meal (CGM) from the wet milling process, which in practice substitute for feed grains and oil meals in animal feeds and are modelled as such. In addition, glycerine as a by-product of biodiesel production is considered in value terms. While the Brazilian sugar module already covered bioethanol production, extended modules have been developed for the US, Canada, the EU15 and Poland.

The representation of biofuels in the model is based on the methods already applied for a similar, but more restricted, analysis of biofuel developments in the OECD Agricultural Outlook 2002-2007 (OECD, 2002) and described in detail in von Lampe (2006). The analysis considers the production of both bioethanol and biodiesel. Depending on the country, bioethanol is produced from wheat, coarse grains and/or sugar, with different conversion rates across feedstock types. The production of bioethanol and biodiesel is modelled in a double-log form depending on time, the cost ratio between biofuel and petroleum-based fuel and an exogenous adjustment factor to take into account politically determined growth. The cost ratio is calculated from ‘net production costs’ and crude oil prices. Net production costs are defined as the sum of feedstock costs (directly linked to market prices for grains, sugar and vegetable oils), energy costs (assumed to be a function of crude oil prices) and other costs (assumed to be exogenous), minus the value of by-products used in the livestock industry (linked to market prices for the respective feed substitutes grains and oilseed meal), less subsidies (e.g. by means of tax concessions). These costs may differ across processes using alternative feedstocks.

Based on this representation for biofuel production, the shares of different feedstocks producing a certain biofuel are determined assuming constant elasticities of substitution and driven by relative net production costs. This applies to bioethanol production where several feedstocks are used, whereas biodiesel is produced from the aggregate vegetable oil. Given that the shares of a CES function not always add up to exact unity when net costs change, a second set of scaling equations is applied.

As indicated in the OECD document, parameters are largely taken from Smeets et al. (2005). As information about biofuel production processes generally are available only from one country, many of the parameters applied in the analysis are equal across countries. The AGLINK representation of biofuel production is fairly ad hoc due to the lack of empirical data. Production capacities are assumed to respond inversely to a three-year average of the ratio of net production costs (taking into account total production costs, by-product values and eventual taxes) to gasoline and diesel pump prices, scaled to the same energy content. Short-term adjustments are possible in the capacity use rate that directly responds to the cost-fuel price ratio of the same year. It should also be noted that, for the current version of the AGLINK model, trade in biofuels is not taken into account. In particular, growth in biofuel consumption is assumed to be linked to an equivalent growth in biofuel production within the same country or region.

3.6.3 Model applications

In von Lampe (2006) results of the following set of scenarios are published with the extended AGLINK model:

- A *constant biofuels scenario* includes an exogenous assumption for biofuel production, crop demand for biofuels, and by-product generation at their 2004 level throughout the projection period. This scenario can be read as a no-change scenario with respect to biofuels and is used as the base scenario to compare the results of the following scenarios.
- A second scenario includes growth of biofuel quantities in line with officially stated goals and given baseline prices for agricultural commodities. This scenario is read as a *policy target scenario* with respect to biofuels. However, the envisaged biofuel targets are not fully met due to the feedback to commodity markets.
- A third scenario assumes crude oil prices at a constant level of USD[15] 60 per barrel from 2005 onwards. Compared to the policy-target scenario, the higher oil prices in this *high oil price scenario* affect agricultural commodity markets in two ways. First, agricultural production costs increase with higher energy costs, leading to higher feedstock prices and making the production of biofuels more expensive. Second, domestic prices for petrol-based fuels rise and trigger increased demand for biofuels. Both effects are explicitly analysed separately.
- Crude oil prices are explicitly taken into account only in the context of Brazilian bioethanol production, but for the purpose of the Outlook projection, the same

[15] USD = United States Dollar

development of crude oil prices is assumed for the baseline projections, with a decline to USD 34 towards the end of the projection period (2014) after peaking at approximately USD 46 in 2005.

The AGLINK model is used for the OECD-FAO Agricultural Outlook. For the most recent outlook OCED-FAO (2007), the calculations for biofuel show that the increased demand for biofuels in the EU also translates into strongly increased demand for feedstock products. The use of wheat in the production of biofuels is expected to increase by twelve and reach some 18 million tonnes by 2016. Growth in the use of oilseeds (largely rapeseed) and maize is less dramatic, but would still reach 21 mm t and 5.2 mm t by 2016, respectively.

3.7 RAUMIS

3.7.1 General information

The Regional Agricultural and Environmental Information System (RAUMIS), developed by Henrichsmeyer et al. (1996), is a mathematical programming model covering German agriculture in line with sectoral data on the Economic Accounts for Agriculture. The model is used for medium and long-term agricultural and environmental policy impact analyses. Production is currently represented by 31 plant and 16 livestock activities that use approximately 40 inputs and produce 50 agricultural products. The model comprises indicators such as fertiliser surplus (nitrogen, phosphorus and potassium), pesticide expenditures, a biodiversity index, and greenhouse gas emissions.

Regional differentiation is based on the Nomenclature of Units For Territorial Statistics (NUTS III) level regions (‘Landkreise’ in Germany) and comprises 326 model regions. For every model region, an activity-based matrix is set up with the Economic Accounts of Agriculture (EAA) as a framework of consistency. The sectoral production quantities are allocated to the model regions and different production activities using agricultural data on land use, livestock (farm survey data) and yield surveys on NUTS III level. The allocation of input is partly based on trend- and yield-dependent input requirement functions. A technology module determines machinery and re-investment costs as well as labour requirements that hinge upon the applied technologies and farm structure (Henrichsmeyer et al. 1996, Kap. II.6).

Adjustments caused by changes in general conditions, e.g. agricultural and environmental policies, are determined in RAUMIS using a positive non-linear mathematical programming approach (Howitt, 1995; Cypris, 2000). RAUMIS includes a set of technical, political and economic constraints, e.g. land availability and set-aside obligations. In outlook and impact analyses of alternative policies and framework conditions, a comparative static approach is applied that proceeds in two stages. In the 1st stage, optimal variable input coefficients per hectare or animal are determined. In the 2nd stage, profit maximising cropping patterns and animal herds are determined simultaneously with a cost minimising feed and fertiliser mix. Hence, activity levels and agricultural income on the regional and aggregate level are endogenous variables. The specification of non-endogenous variables is based on trend extrapolations of yields, input coefficients and capacities, as well as exogenous information, e.g. prices and price indices from other models such as CAPRI and AGMEMOD, or expectations of market experts, e.g. from the German Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) and the German Bundesforschungsanstalt für Landwirtschaft (FAL).

3.7.2 Integration of energy crops

Renewable raw materials for biofuel production are provided by traditional crops, e.g. rape seed for biodiesel, and cereals and sugar beet for bioethanol. In practice, there is no activity differentiation with regard to the use of the produce as feed, food or raw material for biofuel production. Hence, activities for biofuel production have not been explicitly modelled in the agricultural supply model RAUMIS except for the activity ‘Rape seed on set aside area’ as a renewable energy crop; the differences between that and regular rape seed activity are lower producer prices and no restrictions for the set aside area.

In Germany, the Amendment of the Renewable Energy Sources Act – (EEG) in 2004 has established an attractive support for using renewable resources for energy production, which has fuelled a rapid expansion of biomass crops. Energy maize has proven to be the most competitive crop among the available traditional and non-traditional biomass crops for power generation in biogas plants. Against this background, the new activity ‘energy maize’ was implemented into RAUMIS (Gömann, Kreins & Breuer, 2007a). The specification is based on the functional relationships that determine input use, e.g. seed, fertiliser, plant protection and machinery from the comparable activity ‘fodder (silage) maize’. The integration of activities that were not observed in the base year requires the appropriate modelling of the adjustment behaviour. Since no information on Positive Mathematical Programming terms (PMP-terms) is available from ex-post analyses and base year calibrations, PMP-terms from comparable activities are used to simulate expected activity levels. In this regard, energy maize is assumed to behave as a cash crop similar to cereal, oilseeds and pulses, and competes for scarce agricultural land. In addition, it is assumed that similar, not-explicitly-formulated cropping conditions exist for energy maize, e.g. crop rotation, soil conditions, etc. In order to test the sensitivity of this approach, PMP-terms from each cereal crop were applied separately for energy maize. In general, the PMP-Terms for cereal crops are comparatively low when the regional acreage share is high, which reflects low implicit (non-observed) marginal costs of increasing the level of the activity. Hence, the simulation results regarding the acreage potential of energy maize were strongly influenced by the regional acreage share of the particular cereal crop. For this reason, a weighted average of the PMP-terms of the regionally-dominant crops was applied in the scenario analysis, with the respective activity levels as weights.

The support of biomass production for power generation mainly occurs through a guaranteed price for electricity generated from biomass (see Amendment of the German Renewable Energy Act in Annex 1) such that the demand for biomass is assumed to be totally elastic, and biogas plants will be built in Germany accordingly. The producer price for energy maize is exogenously determined in relation to the prices of other traditional crops that are taken from agricultural outlooks (e.g. FAPRI/USDA/OECD) or from the results of market models such as AGMEMOD.

Optimal plant production intensities are endogenously determined based on output-input price relations prior to the optimisation of the production structure, i.e. activity levels. Crop yields are held constant during the second stage optimisation where activity levels are endogenous variables. In this regard, the primary production of energy maize, which is the outcome of RAUMIS, also depends on the determined regional crop yield intensities and the optimal activity level.

3.7.3 Model applications and results

The RAUMIS model has been applied with the above specification to estimate the regional economic potential of biomass production (‘energy maize’) in Germany under various scenarios (Gömann, Kreins & Breuer, 2007a, 2007b), i.e. a moderate increase of agricultural prices as projected in FAPRI/USDA/OECD agricultural outlooks from 2006, and a substantial price increase mainly fuelled by a worldwide expansion of bioethanol production. This effect has been incorporated into the 2007 agricultural outlooks of both the USDA and FAPRI.

In the scenario ‘moderate price increase’ RAUMIS calculated an energy crop area of approximately 1.6-1.8 mm hectares in Germany. The biogas processing chain is not integrated into RAUMIS. However, technical coefficients are available from FAL experts (Weiland, 2006). The total power generated from the calculated energy maize production could substitute up to 6-7 % of the total German electric power generation.

In the scenario with a strong increase of biofuel production worldwide (world wheat prices of about 200 USD/t) RAUMIS estimates an energy maize area of about 1.0 mm hectares. A 12 % price increase of the producer price for energy maize (to be paid by biogas plant operators) would even yield an energy maize area of about 1.4 mm hectares, which reflects the price elasticity of supply in RAUMIS.

3.8 AGMEMOD

3.8.1 General information

AGMEMOD is a system of econometrically-estimated partial equilibrium models of the EU Member States, and as such represents and projects relevant agricultural activities of these regions in detail. Besides the animal product sectors, the current commodity coverage for grains consists of soft wheat, durum wheat, barley, maize, rye, triticale, oats, etc., and also of the oilseeds rapeseed, soy beans and sunflower. The model comprehends interactions between the agricultural and food sectors and countries, as well as the resulting feedback effects. AGMEMOD takes into account tariff quotas, restrictions of subsidised exports, production quota intervention prices, direct payments, decoupling of direct payments and set-aside obligations (AGMEMOD Partnership Members, 2007). The model's database contains balance sheets for all commodities (Eurostat sources *AgrIS* (Agricultural Information System) and *NewCronos*).

The current base year is 2000, with 2003 undergoing preparation. The base period for econometric estimation is from 1973 to 2000. The model includes the EU27 Member States (without Luxembourg, Malta and Cyprus), i.e. industrialised and transformation countries. In stand-alone mode, the individual country models could provide projections over a ten year time horizon up to 2015 for the main agricultural commodity markets and could analyse the impacts of policy reforms for each country, as well as for the EU15, in aggregate. Excel spreadsheets were used to allow easy access to the model’s results.

3.8.1.1 Methodology

AGMEMOD is an econometric, dynamic multi-product partial equilibrium model wherein a bottom-up approach is used. Based on a common country model template, country-level models with country-specific characteristics were developed to reflect the specific situation of their agriculture and to be subsequently combined in a composite EU model. This approach captures the inherent heterogeneity of the agricultural systems that exist across the EU, while still maintaining analytical consistency across the country models by adhering as closely as possible to the template. Maintaining analytical consistency across the country models is essential for the aggregation and also facilitates the comparison of a policy's impact across different Member States.

AGMEMOD determines the land allocation of the three crops' sub-models (grains, oilseeds, root crops) in a two-step process. In the 1st stage, producers allocate their land area to the following crop groups: grains, oilseeds and root crops. The total area harvested, e.g. grain, is usually modelled as a function of the adjusted expected average return for the various grains, the cereal set-aside rate and compensation payments. The real expected gross return variable is a function of the moving average of the past real market prices and a trend's productivity growth (trend yield). In the 2nd, the shares of the land areas which have been allocated to grains, oilseeds and root crops will be distributed to a certain culture belonging to that particular crop group. The share allocation is determined by comparing the expected real gross returns for the five types.

AGMEMOD does not distinguish between intra- and extra-EU trade at the Member State level. This implies that the EU net export variable is used as the closure variable at the EU level. Hence, the dynamic multi-market multi-country EU15 model facilitates the generation of market projections and alternative scenario simulations for both the entire EU15 and its individual Member States under the assumption of exogenous world prices. This organisation of the composite EU15 model also permits the analysis of agricultural policy changes for a given subset of countries (or commodities) modelled, while considering the rest of the EU (or commodities) as exogenous. The model depicts import and export flows and net-trade of the EU.

Exogenous variables are policy variables (e.g. intervention prices, direct payments, trade quotas) factor endowments, GDP, population, exchange rates, inflation, and technical coefficients (e.g. fat content). When solving individual country models as stand-alone models, EU key prices and other variables relative to other countries are exogenously determined. The price projections have, in general, been taken from the FAPRI 2006 US and World Agricultural Outlook. Endogenous variables are prices and quantities on national product markets, as well as derived variables, e.g. agricultural sector income, emission indicators and productivity. When the individual country models are combined and run within a composite EU15 setting, some variables that were exogenously determined in stand-alone mode needed to become endogenous variables. Examples of such variables are self-sufficiency rates and prices for the key markets.

3.8.2 Integration of energy crops

Biofuels are integrated into AGMEMOD by decomposing, e.g. the rape oil demand and adding a biofuel demand component to the food and industrial use. A precise estimation of the demand for biofuels based on the available exogenous variables is not feasible. Thus, a normative approach has been applied to implement biofuels into AGMEMOD. While the biodiesel amount is expressed in equivalent amounts of vegetable oil, (for the moment, only rape oil is considered as a source in the main European countries) the demanded bioethanol is expressed in equivalents of used cereal.

Several parameters of the functions that depict the oilseeds sector had to be adjusted or recalibrated in order to allow for the modified demand situation after the establishment of bioenergy targets by the Commission and some Member States. Since the integration of bioenergy into AGMEMOD is part of the ongoing project 'Impact of Environment Agreements on the CAP (MEACAP (Impact of Environmental Agreements on the CAP))' detailed documentation of the modelling approach is not yet available.

In principle, the introduction of demand shifters to account for bioenergy does not require a restructuring of AGMEMOD. Hence, prices and quantities on national product markets and derived variables, e.g. agricultural sector income, emission indicators and productivity, remain endogenous variables. Information from global models on world market prices, which are exogenous in AGMEMOD, are used to represent the influence of the rest of the world commodity markets on those of the EU. Policy measures such as premiums, etc. are also exogenous.

3.8.3 Model applications and results

Using the further-developed model, scenarios and projections were simulated, e.g. the fulfilment of the EU-Target: substitution of (minimum) 5.75 % of transport fuel by biofuel by 2010 (demand issue). First model results have been presented to the Commission (Ledebur, Elmahdi, Wagner 2007) within the EU-Project MEACAP (http://www.ieep.eu/projectminisites/meacap/index.php) but have not yet been documented.

3.9 EUFASOM / ENFA

3.9.1 General information

The European Forest and Agricultural Sector Optimization Model (EUFASOM) is a partial equilibrium model of the European Agricultural and Forestry sector (Schneider & Schwab, 2006) and is based on the US-version of the same model (FASOM, http://www.treesearch.fs.fed.us/pubs/2876). The traditional agricultural and forest sector is represented across the EU through representative production technologies for 15 major traditional crops (including rape and cotton, but not miscanthus, for example), 10 energy crops, 20 tree species, and 10 livestock categories. The model has been developed to analyse changing policies, technologies, resources, and markets, for instance a raise of the carbon tax, or the introduction of new agricultural and forest technologies which have not been used on a large-scale outside experimental plots.

The model is regionalised according to the question investigated. EU countries and 27 non-EU international regions are explicitly represented geographically. Within each political region in the EU, the model can be further resolved with respect to farming and natural conditions, i.e. different farm sizes and farm types. Natural conditions are based on more than 1 000 Homogenous Response Units (HRUs) and can be grouped according to soil textures and stone content, altitude levels, and slopes. For farming and natural conditions, only the shares of area within basic political regions are modelled. The model runs in 5-year steps from 2005 to a selected terminal period. The time steps and the time horizon can be adjusted (shortened or extended) to different specifications. Regarding production technology, options for tillage, irrigation, fertilisation, erosion control, etc. are implemented.

3.9.1.1 Methodology

EUFASOM is a mathematical programming model containing millions of individual variables and equations representing a welfare-maximising objective function and technological, resource, and market restrictions. EUFASOM's objective function maximises total agricultural and forestry sector surplus subject to a set of constraining equations, which define a feasible convex region for all variables. Feasible variable levels for all depicted activities range from zero to an upper boundary, which is determined by resource limits, supply and demand balances or trade balances. Calibrating the model involves restrictions that force the solution to form a convex combination of historically-observed or expert-estimated states.

Solving EUFASOM involves the task of finding the 'optimal' level for all endogenous variables subject to compliance with all constraining equations. By means of EUFASOM's objective function, optimal levels of all endogenous variables are those levels which maximise agricultural and forest sector surplus, which is computed as the sum of total consumer surplus, producer surplus, and governmental net payments minus the total cost of production, transportation, and processing. Basic economic theory demonstrates that maximisation of the sum of consumers' plus producers' surplus yields the competitive market equilibrium. Thus, the optimal variable levels can be interpreted as equilibrium levels for agricultural and forest activities under given economic, political, and technological conditions. Exogenous drivers are interest rate, technical progress, population growth, GDP growth, and policies.

3.9.2 Integration of energy crops

The project 'European Non-Food Agriculture (ENFA)', funded within the EU 6th FP FASOM (Contract N°: SSPE-CT-2005-006581), intends to find the competitive economic potential of non-food options grown alongside traditional agriculture and forestry and other non-food agriculture, and to simulate environmental impact data. Various non-food production lines will be introduced into EUFASOM (planned for late 2007) which produce, from primary activities such as maize, sugar beet, potatoes, rape, sunflower, manure, miscanthus, switchgrass, red canary grass, willow, poplar, eucalyptus, etc., various non-food products, e.g. energy, biofuels, biogas, pellets, electricity, heat, biomaterial, and fibres. The model will be regionalised to NUTS II political regions that will be linked to a Geographic Information System (GIS)-based suitability map for biomass cropping, which takes soil types, altitude levels and slopes into account. Modelling at the farm-type level is also envisaged.

Subject to European data availability, optimisation (welfare maximisation is the objective of EUFASOM) is done through simultaneous simulations of different perspectives and activities in the supply and demand levels across all regions and products such that total welfare is maximised. Key components, parameters and constraints involved in the model include different technologies and their impacts (e.g. energy and GHG (Greenhouse Gas) balances, emissions), natural resource endowments, trade opportunities, governmental policies and other regional interactions which apply both in the input/supply and output/demand sides. Investment costs, land, land qualities, labour, fuel consumption, fertiliser consumption and cropping regime are some of the components taken into account in the former, while end use options such as heat, power, material goods and environmental gains in the form of emission savings are regarded in the latter. In the market module, non-food industrial/agricultural products will face industrial demand curves as most non-food outputs require significant industrial processing, but for heat from combined heat/power plants, some non-food final demand functions may also be needed. Market demand functions are estimated for forest and agricultural goods.

Exogenous inputs to EUFASOM are GDP, world prices of fossil fuels, tax, subsidy, environmental policies, interest rates, risk premiums, etc., technical and economic characteristics of future energy technologies including capacity constraints, and parameters for consumption. Key endogenous variables are prices and quantities for agricultural and forest products for both traditional and renewable products, bioenergy supply functions, rural employment effects, and environmental impacts (GHG emissions, biodiversity, erosion, nutrient balances).

3.9.3 Model applications and results

Within the ongoing development process, EUFASOM modules have been applied, e.g. regarding the model response of willow-based combined heat and power to energy and carbon prices for Sweden.

A global and aggregated version of EUFASOM called 'GLOBAL FASOM' (Global Non-food Agriculture) has been used to investigate the impacts of increasing minimum shares for bioenergy in transport energy use (Havlik, Schneider 2007). First results indicate that a bioenergy share of more than 10 % would have significant price effects (wheat prices in Western Europe would double to a 20 % share), even if bioenergy is produced quite efficiently based on woody crops and bioethanol.

4 Assessment: Database problems

The database situation is certainly more complicated than for agricultural raw products where agencies like FAOSTAT (FAO, Statistics Division) globally monitor production and demand composition and trade flows in view of their direct linkage to food and nutrition. Furthermore, bioenergy's use of biomass has escaped the attention of statistical agencies for a long time, as its impressive development in industrial countries only set in a few years ago. Nonetheless, there are private companies capable of supplying a large part of the missing data for 1st generation biofuels.

4.1 Market data

For modelling purposes, a critical question is where to find market data on biofuels and related feedstocks and by-products. Table 1 summarises the market data available from various organisations.

Table 1 Summary on data sources related to biofuels

Institution	Contact	Access	Costs
OILWORLD	ISTA Mielke GmbH Langenberg 25 21077 Hamburg Germany + 49 (0)40 / 7610500 www.oilworld.biz	with costs	- Weekly report: 20-40€ - Monthly report: 40€ - Annual: print 150€, digital 400€ - Monthly subscription for 6 months: 200-300€
Data available	**Palm, Sunflower, Soya, Rape:** World supply, crushing, trade quantities for oilseeds, oils and meals in key countries, monthly, quarterly and annual. Bilateral trade flows. Weekly and monthly prices **Biodiesel:** EU27: estimated production capacities.		

Institution	Contact	Access	Costs
EUROSTAT	http://epp.eurostat.ec.europa.eu	free	
Data available	**Crop products and derived products:** Areas and production, balance sheets with items processing, industrial use, feed, food, trade, etc. Prices (unit values) for agricultural products (seeds) are part of the Economic Accounts Data (EEA) whereas the price statistics are less well developed for oils and cakes. **Energy**: Supply, transformation, consumption for solid fuels, oil, gas, nuclear, electricity, renewables (heat, biomass, geothermal, wastes). However, biofuel information often only starts in 2005.		
FO Licht	F.O. Licht Zuckerwirtschaftlicher Verlag und Marktforschung GmbH Am Mühlengraben 22 23909 Ratzeburg Germany http://www.agra-net.com/portal/puboptions.jsp?Option=menu&pubId=ag072	with costs[16]	F.O.Licht Interactive Data: 1946.- EURO F.O. Licht World Bioethanol and Biofuels Report and Online: 1660.- EURO
Data available	Detailed trade, import, export, production and consumption statistics for biodiesel, bioethanol, by-products and agricultural products.		
FAPRI Data base	Food and Agricultural Policy Research Institute Iowa State University 578 Heady Hall Ames, Iowa 50011-1070 Phone: (515) 294-1183 E-mail: fapri@iastate.edu	free upon request	
Data available	European level: Barley, corn, rye, wheat use for Bioethanol production (Estimation as of 2006).		

[16] An inquiry for a particular recent dataset including trade matrix and production data for biofuels and byproducts has been directed to FO Licht but is not yet settled in the details.

Institution	Contact	Access	Costs
	Rapeseed, Soybean, Sunflower oil use for Biodiesel production (Estimation as of 2007). Historical data do not identify feedstock use for biofuel.		
FAOSTAT	Food and Agriculture Organisation of the United Nations http://faostat.fao.org/	free or with cost	USD 1 500 (for bulk download) USD 15 000 (with trade matrix)
Data available	On national level: Production data for crops and oilseeds. Market balances do not distinguish industrial use and processing and do not exist for oils and cakes (given in primary product equivalents). Trade data are detailed and also cover cakes and oils.		
USDA - FAS	US Department of Agriculture Foreign Agricultural Service 1400 Independence Ave., S.W. Washington, DC 20250.	free	
Data available	Consumption, production, area and yield of crops and oilseeds on national level + trade balances. Differentiation between industrial and energy use of crops or oilseeds is not made.		
EBIO	European Bioethanol Fuel Association 106, rue Joseph II B-1000 Brussels www.ebio.org	free	
Data available	Bioethanol 2004 - 2006: production data, production capacity, installed production capacity under construction (on Member State level).		
EBB	European Biodiesel Board Ave. de Tervuren 363 1150 Brussels, Belgium Tel: +32 (0)2 763 2477 Fax: +32 (0)2 763 0457 www.ebb-eu.org	free	
Data available	Biodiesel: 2002 - 2006: production data on European Member State level		

In the following subsections, the usefulness of these potential data sources for various bioenergy related variables is assessed.

4.1.1 Biofuels

Production data are available from various sources. For the EU, European level interest groups such as the European Bioethanol Fuel Association and the European Biodiesel Board even offer such information for free. Eurostat apparently does not yet distinguish between biodiesel and bioethanol in its energy statistics.

If trade information and price data are also required, F.O. Licht, author of the World Bioethanol and Biofuel Report and provider of Licht Interactive Data, will be a natural contact point, in particular if international data are also desired (as they would be for use in CAPRI). EU Trade is covered by COMEXT, the Eurostat Reference Databank on Intra- and Extra- European Trade, but this does not help for trade among non-EU members.

For extensions of ESIM, inputs for biofuel products such as wheat, corn, sugar and oilseed oil are assumed to be homogenous with other uses, e.g. sugar for human consumption. Prices for biofuels have been taken from F.O. Licht publications.

4.1.2 Feedstocks

Feedstocks for biofuels are included in many agricultural statistics. However, it appears that none of these identify the composition of feedstocks if there are several available within a country. This information should be collected from national interest groups where it is usually available, e.g. in Germany at the Fachagentur Nachwachsende Rohstoffe e.V. (FNR). Thus, most modelling teams apply simple assumptions, for example that the composition of feedstocks for biodiesel production equals the composition of overall production of oilseeds in a given region. Alternatively, researchers use rough estimates, in particular for the country-specific feedstocks of bioethanol (Lampe 2006, p. 35).

4.1.3 By-products

These are quite well covered by the F.O. Licht World Bioethanol and Biofuel Report and Licht Interactive Data. In terms of prices for oilseeds, cakes and oils, OIL WORLD (http://www.oilworld.biz) is a natural starting point.

5 Assessment: Specifications for processing demand equations

Based on the above review and against the general applied modelling background, a few critical issues have been assessed in this study. In terms of processing demand specifications for agricultural raw products, the choice is mainly whether these may rely on prices or quantities for biofuel demand being given from other models or model components, or whether non-agricultural biofuel demand itself should be explained, for example by using crude oil prices. A second critical issue is the selection of an appropriate functional form. If processing coefficients are given, demand should be written as a function of processing margins, preferably in a simple but flexible form.

5.1 Behavioural models

As a background for the specification of demand equations for processing biofuels, consider the following maximisation problem for the oilseed crushing industry. The industry processes a number of raw products $\mathbf{prc_i}$ (rape seed, sunflower seed, soya seed), valued at prices $\mathbf{w_i}$, to produce certain outputs $\mathbf{y}_i$, (oil for food and cakes) which are valued at prices $\mathbf{p_i}$ indicating the vector of output prices for products derived from raw material **i**. In addition to the raw product prices there are other inputs (labour, capital, electricity etc.) with an input price vector **v**.

Equation (3) $\max\limits_{\mathbf{prc}}\left\{\sum_i \left(R_i\left(\mathbf{p}_i, prc_i\right) - w_i\, prc_i\right) - C\left(\mathbf{prc}, \mathbf{v}\right)\right\}$

where:

R: Revenue function

C: Cost function

prc: Raw product quantity

w: Prices for raw products

p: Prices for processed products

v: Input prices

i: Index for raw products.

The solution to this problem is the set of processing demand equations:

Equation (4) $prc_i = d_i\left(\mathbf{p}, \mathbf{w}, \mathbf{v}\right)$

where:

d: Demand function.

In general, processing demand will depend on all prices. Simplification is possible if the cost function C(.) is non-joint in inputs, i.e. if other inputs valued at **v** are allocable to processing activities **i** and if there are no economies of scope. The maximisation problem in this case yields a processing demand dependant only on the 'own' prices:

Equation (5) $prc_i = d_i(\mathbf{p_i}, w_i, \mathbf{v})$.

However, this assumption is questionable in the case of oilseeds, as certain enterprises may process several oilseeds in the same plants. In this case, processing rape seed may also depend on the price of sunflower seed, for example.

In the case of fixed processing coefficients γ_{ij} providing the output quantity $\mathbf{y_j}$ obtainable from a ton of processed raw material $\mathbf{prc}_i$, the revenue function R(.) simplifies to a linear form, which permits expressing the maximisation problem in terms of margins:

Equation (6) $$\max_{\mathbf{prc}}\left\{\sum_i\left(\sum_j p_j\gamma_{ij} - w_i\right)prc_i - C(\mathbf{prc}, \mathbf{v})\right\} = \max_{\mathbf{prc}}\left\{\sum_i mar_i\, prc_i - C(\mathbf{prc}, \mathbf{v})\right\}$$

where:

γ: Output coefficient of by-product j (pulp, cakes, glycerine, gluten feed, etc.)

mar: Gross margin of prc

j: Index for by-products.

The solution to this problem is a set of processing-demand equations depending on margins:

Equation (7) $prc_i = d_i(\mathbf{mar}, \mathbf{v})$.

This is essentially the specification in the current version of the CAPRI (and CAPSIM) model for processing oilseeds where a normalised quadratic form has been assumed for the solution of the profit maximisation problem, giving rise to linear behavioural equations (see http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri-documentation.pdf, equation 108):

Equation (8) $prc_i = a_i + \sum_j b_{ij}\dfrac{mar_j}{v_0}$

where:

v0: general price index used as a numeraire and as a proxy for labour, capital, electricity and other costs

a,b: Parameters of the demand function.

The assumption of fixed processing coefficients $\gamma_{i,j}$ is used in most reviewed modelling analyses (e.g. LEITAP, ESIM, FAPRI) and also in Lampe 2006. This implies that behavioural functions depend on margins as explained above.

The cost function C(**prc**, **v**) incorporated in the profit maximisation model above facilitates the derivation of input demands for other inputs used in the processing of raw products for given processing levels $\mathbf{prc_i}$. In combination with the revenue maximisation approach, this specification is suited for linkages with other models providing prices $\mathbf{p_i}$ (or margins $\mathbf{mar}_i$) for the processing of raw products.

Another type of cost function becomes relevant if information on output quantity levels from processing is available. Separating this processing behaviour becomes relevant if the considered model does not include a market for processed products, but rather treats demand as fixed (exogenous output quantities), or if anything other than competitive market structures for processed products are to be represented. The underlying cost-minimisation problem – maintaining the assumption of fixed processing coefficients – can be written as:

Equation (9) $$\min_{\mathbf{prc},\mathbf{q}}\left\{\sum_i \left(w_i - \sum_{j\neq e}\gamma_{ij}\, p_j\right)prc_i + \sum_k v_k q_k \;:\; T(\mathbf{prc},\mathbf{q},\mathbf{y}) = 0\right\} = C(\mathbf{nw},\mathbf{v},\mathbf{y})$$

where

q= non-agricultural input quantity

nw (= $w_i - \Sigma_i\, \gamma_{ij}\, p_i$): net cost of raw product i after deducting the value of by-products

y = output j, (bioethanol etc.)

k: Index for non-agricultural inputs.

The derivative of the cost function with respect to the net cost yields, for example, the demand for sugar beet processed to bioethanol, may also be expressed in terms of bioethanol from sugar beet, in this case of fixed processing coefficients. The cost function approach in Eq. 7 is sometimes applied in a modified form. In LEITAP, for example, by-products such as oil cakes are not explicitly incorporated. However, for an agricultural sector model, the by-products are highly relevant for the linkages between agricultural activities and should be included.

For an agricultural partial equilibrium model, it is reasonable to stop here and not to consider the substitution between biofuels and other (fossil) transport fuels, as this requires the incorporation of overall, or market, transport fuel supply behaviour. If this is the modelling choice, then simulating the impact of energy policies, such as obligatory shares of biofuels in transport fuels or of energy market developments on the agricultural sector, requires linking the partial equilibrium model with other specialised energy or general economy (CGE) models. For the profit maximisation representation of biofuel processing, a model capable of providing biofuel prices under different scenarios is needed. Implementing a cost-minimisation approach in the agricultural sector model requires a model that generates biofuel demand quantities for a given production cost of biofuels generated by the partial equilibrium model. The linking can be methodologically achieved by applying a sequential calibration approach as suggested by Rausch and Rutherford (2007) and applied in Grant, Hertel, Rutherford (2006).

A notable exception in this respect is FAPRI, where total fuel demand was endogenously incorporated through a Marshallian demand and the substitution between biofuels and other fuels represented by an upper level cost-minimisation problem. Such a solution becomes relevant if other models are not readily available or the conceptual and computational effort to link two separate models is deemed too cumbersome for the considered analysis. Staying within the framework of cost minimisation, an alternative to FAPRI's nested approach (biofuel processing explicitly represented and nested within the total fuel cost-minimisation problem) could be the specification of more aggregate biofuel and other fuel demand functions depending on total fuel output, prices of raw agricultural products, crude oil price, and other input prices. Combining this with a demand function for total fuel based on marginal cost pricing and a market-clearing identity would also result in a full representation of the fuel market within the (otherwise) partial equilibrium model such as in the FAPRI case. Lampe 2006 omits the total transport fuel production in the model, presumably considering it as fixed during AGLINK simulations, and its change over time was built into the baseline shifters[17].

5.2 Implementation choices regarding functional form

Considering the processing of raw agricultural products to biofuel, the theoretical discussion above has some direct implications for the choice of functional form. Assuming fixed processing coefficients, demand for raw products may be written as a function of processing margins. A pragmatic solution for IPTS-monitored models CAPRI, CAPSIM, and perhaps AGMEMOD, appears to be the following: Demand for agricultural raw products is derived from a cost function approach as in the following equation. An attractive functional form - due to its simplicity - appears to be the asymmetric normalised quadratic form with the non-agricultural input price index as a natural numeraire. The output would be the biofuel production quantities (y):

Equation (10) $$C(\mathbf{nw}, v, y) = a_0 + \sum_i a_i \frac{nw_i}{v_0} y + \sum_i \sum_j a_{ij} \frac{nw_i}{v_0} \frac{nw_j}{v_0} .$$

Derivatives of this function with respect to the (normalised) net cost nw_i/v_0 yield linear-in-net-costs demand functions for raw agricultural inputs[18].

[17] Processing demand is apparently independent from other macroeconomic variables such as the crude oil price and exchange rate, even though we would expect a summary indicator like GDP, or, more precisely, total transport volume, to be a driver for total fuel demand. This may therefore be interpreted as a simplification which is useful if GDP or total transport volume is hardly affected by the biofuel scenarios.

[18] It does not really matter whether the driving variable is considered the margin in the processing of the raw product *mar* or the net cost *nw* of one of the outputs, as both may be mapped into each other.

Apart from the linearity argument, the quadratic functional form is considered to be the right balance between flexibility and simplicity in such an applied modelling context. More simple functional forms such as the Constant Elasticity of Substitution (CES) or the Cobb-Douglas functional form have a smaller number of parameters, but might be too restrictive to capture realistic simulation behaviour beyond just marginal changes. On the other hand, higher order flexible functional forms imply a cumbersome calibration effort and generally do not comply with the robustness required for simulation exercises, as they are well behaved (for example with respect to curvature) only over a limited range of variable values. Alternative second order flexible functional forms could be taken into account if they allow a global or wide-ranging imposition of theoretical restrictions. However, they are unlikely to provide general advantages over the quadratic functional form and should only be suggested if empirical evidence of processing responses can be better captured by these alternative functional forms.

The above cost function approach provides simple linear behavioural equations without any dynamics and distinctions of capacity expansion or capacity utilisation (as features in PRIMES, AGLINK, or the FAPRI bioethanol model). These sorts of dynamic elements would certainly be useful and in line with the given model structure of AGMEMOD. However, the AGMEMOD team's current biofuels planning is in flux. In general, the static processing demand formulations suggested here could be integrated into a dynamic framework that updates demand shifters based on determinants of models with endogenous investment.

It might be worthwhile to relax the assumption of fixed processing coefficients for two reasons: (1) The possibility of substituting different processing products (oils and cakes) might exist in reality. There are various types of oil mills with different extraction rates (solvent extraction, mechanical extraction) and some investors may choose among these technologies based on (expected) prices. However, the price responsiveness of processing yields following from investment decisions will likely be quite small. There are only limited options to vary heat and other determinants. In the past, technological development has approached the maximum feasible oil extraction rate, as oils were always the most valuable components of oilseeds. This holds at least for given quality of oilseeds, which varies from year to year and has improved on average over time. (2) Margin-dependent formulations might create computational problems when solving the overall model. Experience from the CAPRI market module application shows that feasibility problems frequently originate either in the oilseeds or dairy sectors, both of which are characterised by linear behavioural functions written in terms of margins (Eq. 6). As a consequence, model developers in the CAPRI team have already experimented with a Constant Elasticity of Transformation (CET) form for the revenue function R(.) from above to relax the strict assumption of fixed processing coefficients[19]. The behavioural function in ESIM (driven by derived and raw product prices) potentially avoids such numerical problems as well, but the approach seems theoretically not fully consistent at this point[20]. Here, further experiments are recommended with fully consistent approaches

---

[19] Incorporated in the standard ('trunk') version of CAPRI in early June 2007.

[20] With fixed-processing coefficients, the profit-maximisation problem, and thus processing demand equations for the processing industry may be considered a function of processing margins as indicated in Eq. 4. The elasticities of processing demand with respect to prices of derived products (oils and cakes) and raw products (seeds) are thus linked according to the definition of processing margins (as $\partial prc_i/\partial p_j = -\gamma_{ij} \cdot \partial prc_i/\partial w_i$) and may not be specified independently. The ESIM specification neglects these theoretical linkages of elasticities, a point which is independent of the Cobb Douglas Form chosen in the empirical

that relax the assumption of fixed processing coefficients but limited substitutability, and use the linear-in-margin formulation as a back-up approach. Alternatively, the normalised quadratic functional form could also be employed (to the CET form) in this more general specification if it is expressed in raw agricultural product prices instead of margins.

The above discussion applies to approaches which incorporate substitution between biofuels and other fuels as well, i.e. in cases where full representation of the biofuel market is considered to be included in the partial equilibrium model as motivated in the previous section. In this case, the linear (or non-linear) demand functions derived from cost minimisation include other relevant variables such as total fuel quantity as an output variable (possibly captured by GDP as an overall indicator of economic activity) and prices for other fuels (or the price of crude oil).

implementation. However, just as it is sometimes inappropriate to impose the symmetry condition in demand system estimations, the less theoretically consistent specification may have empirical advantages.

6 Assessment: Calibration issues

6.1 Introduction

The relevant calibration issues in the context of the study are related to behavioural responses for (regional) supply and demand of agricultural raw products for biofuel processing and demand for processed biofuels.

In general, the relevant calibration problem is parameterising behavioural functions or optimisation models in such a way that a desired response to changes in economic conditions is reproduced by the models. This is to be distinguished from other calibration concepts that only refer to the recovery of base year data by the model. 'Desired responses' are ideally determined by statistically estimated parameters or elasticities. Given a set of elasticities, for example, all models could be calibrated to reproduce – at least approximately – the implied reaction of farmers or firms to changing prices, by adjusting specific model parameters (see below).

However, the key characteristic of the current calibration problem, independent of the model considered, is the lack of sufficient empirical evidence on farmers' and processing firms' response behaviour. Relatively recent political support policies, as well as the rapid development of processing technologies, do not allow direct base calibration on estimated parameters or elasticities. Consequently, the empirical base of any conceivable calibration exercise is subject to considerable uncertainty and suggests performing the analysis of policy options or market outlooks based on a set of sensitivity experiments, i.e. performing simulations for different assumptions of response parameters.

These sensitivity experiments cannot in all cases be based simply on different sets of demand and supply elasticities, as the underlying changes might be of a fundamental nature. For example, regionally differentiated analysis might imply that certain raw products for biofuel processing have not, or have hardly been, produced in a region up to this date (for example, maize for fermentation in arable crop regions). Constant or average elasticities are of no use in such a case, as considerable changes of elasticities over the range of simulations are likely. Consequently, assumptions on response behaviour should be described by production quantities (and corresponding areas) expected for given product prices, i.e. basically in terms of price-quantity relationships under otherwise unchanged conditions. The model parameters should then be determined to follow these response functions as closely as possible. As shown below, it is common practice to use parameters of other products to introduce new products.

6.2 Difficulties in ex post calibration

Even though it was stated above that the simple reproduction of some base year data sets is not the main calibration problem, base year reproduction nonetheless has some advantages:

The interpretation of any simulation experiments starting from a base year situation identical to observed data is certainly easier than a comparison with a hypothetical situation which nonetheless coincides with historical data for key variables (base period prices, etc.). This is different from the use of a projected future reference situation where all variables differ from the observed initial point.

Confidence in simulation results will be higher if at least the base year situation is reproduced by the simulation tool.

Behavioural parameters which are strictly valid only locally (elasticities) may be specified more reasonably if the initial situation resembles observed data. Our a priori information in terms of technical knowledge (say, on processing coefficients) will usually also refer to the historically observed data.

In spite of ex post calibration having some merits, there are particular difficulties affecting analyses of bioenergy. One of these is the lack of statistical data on some variables, for example the composition of different feedstocks used for biodiesel production in EU Member States. As a consequence, researchers had to make more or less plausible assumptions (compare the detailed information on ESIM and AGLINK) which could be influential for simulation results. Better and more complete databases would therefore certainly increase the quality of modelling efforts.

Historical policy interference is another difficulty for useful ex post calibration. Most modelling systems reviewed in this report attempt to represent the relevant policies for bio energy use in some detail, for example regarding the set-aside regime and energy crop premium.

In ESIM, for example, there are two area allocation functions for each biofuel crop: on non-set-aside area as a function of input prices, direct payments, output prices for all other crops and the special energy crop premium. The second area allocation function is for biofuel crops produced on set-aside area, which is a function of input prices, direct payments, and output prices only for those crops used for biofuel production, which may alternatively be grown on set-aside area. These two separate functions have been calibrated based on EU-Commission data.

Detailed treatment of policies is strongly recommendable, as a more cursory treatment would otherwise wrongly translate the influence of initial period policies into certain parameters of the model which are likely to be maintained in the analysis, even if the policy changes in the future. While EU policies will be covered quite explicitly in many modelling systems, this does not necessarily hold for national policies. Here, some stocktaking has been performed showing that national policies change frequently and may be incorporated only at a high cost.

6.3 Difficulties in calibration of behavioural responses

A key problem in the analysis of future energy crops use is the lack of historical observations, which precludes a standard econometric approach to model specification. The surge in biofuel consumption is very recent, meaning that at most a few years of observations are available, and at first sight these usually resemble an exponential growth pattern. Of course the logistic form is better suited to represent growth processes and is often applied in energy models such as POLES or PRIMES. Nonetheless, empirical results will be very unstable until sufficient observations become available.

Options to cope with these ‘ill-posed’ problems by using appropriate econometric techniques may be available (say, Bayesian or Entropy approaches). Furthermore, it may be possible to obtain more observations by pooling data from several regions or related products (say, different oilseeds).

On the other hand, there are examples, such as 2nd generation biofuels, which have not been observed at all in historical data and yet are likely to become significant in a few years. In these cases, the application of econometric techniques to historical data is not possible. Different strategies are therefore needed.

6.3.1 Calibration based on experimental style observations

A gradual transition to the econometric approach would rely on a priori information in the form of artificial price quantity observations, which could be fit by some functional form. Sometimes expert assessments on the likely extent of biofuels' market penetration given certain prices of both it and competing fuels, could be expressed in this form. This format may easily represent zero production under certain conditions. For example, regionally differentiated analysis might imply that certain raw products for biofuel processing have not or have hardly been produced in a region prior to a particular date (for example, maize for fermentation in arable crop regions). Constant or average elasticities are of no use in such a case, as considerable changes of elasticities over the range of simulations are likely, but expectations of market entry at certain trigger prices can be easily expressed with a set of artificial observations.

If these observations differ only in one or a few variables and hence meet the 'all else equal' condition, they will be easy to translate into price-response parameters of behavioural functions, particularly if there is only one free parameter per price variable.

Of course, the question of how to obtain these artificial observations remains. One source could be collaborating with a specialised modelling system designed to tackle energy demand in more detail (see Section 5). Or perhaps in the future, engineering-type agricultural supply models designed to consider alternative production activities not observed in the past could be employed (for example, the System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS)). Another approach might be to collect observations from a survey among market experts. However, while this is a common technique in commercial marketing research, it is rarely used for aggregate modelling.

6.3.2 Calibration based on expert outlook data

If the 'all else equal' condition is not required, it may be easier to collect expert data on the future development of biofuels consumption, as many agencies offer outlooks. The additional difficulty, however, is that these outlooks will usually have more than one 'driving force' such that the given information on the future outlook for rape seed demand for biofuel production processing will also depend on assumptions for macroeconomic growth, the exchange rate, crude oil prices, wages and technological progress (leading to optimised content) in the agriculture and processing industries.

Unless there is a larger set of conditional projections clearly related to one discriminating variable, the problem of parameter estimation is similar to the ill-posed case with too few degrees of freedom relative to the number of free parameters.

6.3.3 Calibration with parameter assumptions

If little data or prior information is available on the behavioural responses of farmers and processing firms, assumptions on related model parameters must be made. In classical programming models, these assumptions refer to technological input and output coefficients of production activities. Engineering information will typically provide an idea on the range of plausible values of these parameters. For behavioural functions based model structures, the parameters are often identical or closely related to typical indicators of agent's response behaviour (elasticities). This generally allows for a rather transparent interpretation of consequences of chosen parameter assumptions. More problematic are assumptions on PMP parameters in the realm of agricultural optimisation models. These are related to actual response behaviour in an often complex fashion, especially if the models contain a larger set of constraints. It would generally be desirable to make assumptions on (local) supply elasticities or reasonable price-quantity combinations and calibrate the PMP parameters to fit these assumptions as close as possible.

The general uncertainty regarding parameter values which is introduced in this section creates a case for the execution of sensitivity experiments over the range of plausible parameter values. In case of larger numbers of parameters, stochastic generation of parameter sets would be useful. Distributions of results would give some idea on the relevance of parameter uncertainty for the uncertainty on results of interest.

These sensitivity experiments cannot in all cases be based simply on different sets of demand and supply elasticities, as the underlying changes might be of a fundamental nature. Coming back to the example of regional levels of maize for fermentation in arable crop regions, its value may be zero in many regions under unfavourable circumstances and significant with supporting conditions. This would require the general price quantity format of (alternative) a priori information to be re-checked for sensitivity, see above.

7 Assessment: linkages to non-agricultural modelling systems

Linkages between agricultural sector models and other modelling systems are quite common in applied work. The most prominent example in the agricultural partial equilibrium world is probably the FAPRI model, which strictly speaking is not a single model at all but a kind of network of several agricultural modelling systems (see Section 3). The basic objective of most model-linking activities is to extend analytical capability by combining complementary modelling systems. Here, complementarity is typically defined by one model allowing variables of interest, which are exogenous to the other model, to be endogenously simulated. For example, an agricultural sector model takes non-agricultural input prices as given. A link with a general equilibrium model allows endogenising these prices in the overall system while keeping the details of the partial equilibrium models when representing agricultural products, thereby providing – in turn – endogenous sub-sector output shares compared to the separate application of the more aggregate general equilibrium model. Links between partial and general equilibrium models have already been applied, for example when investigating accession impacts for the New Member States (Tangermann, Banse 2000, Ch. 4 and 5). Links are also currently being developed between the land use policy information system SENSOR (New Econometric Model for Environment and Sustainable development Implementation Strategies (NEMESIS)) and sectoral models including CAPRI)[21] and the agricultural integrated assessment framework SEAMLESS (CAPRI and GTAP)[22]. In a similar fashion, the agricultural economic institutes of the German FAL apply a model network consisting of GTAP, AGMEMOD, RAUMIS and the farm group model FARMIS (which is a further development of the FAL network of complementary models) to carry out comprehensive agricultural policy studies that require in-depth analysis in the fields of economics and trade, agricultural markets and trade of the EU, and agricultural supply on both regional and farm levels in Germany.

There are different degrees of model linking. A full integration of models can be considered the strongest form, for example by implementing a differentiated sector model within a CGE model. Although conceptually the most elegant and consistent approach, full integration comes at the cost of increasing complexity in maintenance as well as computational burden. The term 'linking' also typically refers to the case where each model involved keeps its technical identity and independent path of maintenance and further development. The linking is implemented via technical interfaces transmitting key variables between the models. This approach is more flexible compared to full integration, which implies less costly changes to the models involved with accommodating different objectives of analysis.

But even in the context of linking separate models, different degrees of linking exist. Sequential application of models is sufficient if only one model's endogenous output exerts a relevant impact on the other model, but not vice versa. For a small agricultural sector

[21] See www.sensor-ip.org

[22] See www.seamless-ip.org

compared to the rest of the economy, feedback from the partial equilibrium to the general equilibrium model might not be required. When simultaneous feedbacks are relevant, the strongest model link is provided by sequential recalibration techniques (Grant, Hertel, Rutherford 2006; Rausch and Rutherford 2007), which is a procedure that calibrates each model to the outputs of the other model in iterations until convergence is achieved. This approach is also envisaged for the CAPRI-GTAP link in SEAMLESS. Because of the sometimes considerable computational problems involved, this approach might not be feasible and can be reduced to a limited number of iterations. In its extreme, ad hoc ‘cross checks’ of consistency for key variables after just one iteration are sometimes applied (as in the case of the FAL model family).

Reducing computational burden at the time of scenario analysis can be achieved by employing so-called response functions. Here, the models are applied many times in advance for different values of input variables (parameterisation), thus facilitating the depiction of a functional relationship between the input variables and key output variables of the model. This functional or ‘meta-model’ representation is then used at the time of scenario analysis to quickly obtain model results for specific input variable values coming from other model applications. Such an approach is a key concept of the policy analysis tool employed by SENSOR. However, this approach is not suitable if the scenario analysis requires more than just a few key input and output variables from the models involved, as the computational effort necessary to derive the response functions increases exponentially.

As already hinted at in previous sections, the basic idea of using the model most suited for the variable in question and communicating this information with other systems is especially relevant for the bioenergy issues considered here. The current bioenergy developments at the political and economic level create strong linkages between energy markets (and thereby the general economy) and the agricultural sector. Consequently, the consistent application of corresponding and already-existing modelling systems is an ideal tool for analysing new policies and developments.

Some of these linkages are already under preparation. In the context of a model network for analysing the repercussions of increased biomass production on the energy market (project ‘Nachwachsende Rohstoffe und Landwirtschaft (NaRoLA)’, funded by the German Ministry of Education and Research) RAUMIS will be coupled to the Dynamic Applied Regional Trade (DART) Model developed for analysing international climate policies at the Kiel Institute for World Economics (Klepper, Peterson & Springer, 2003). DART is a multi-sectoral, multi-regional, dynamic computable general equilibrium model based on GTAP.

If the cost function approach outlined in Section 4 is pursued, there would be several linkages to energy models such as PRIMES or other modelling systems with a strong focus on processing of biofuels.

- The cost function approach requires projections of output variables to be either quite general in form, such as GDP, or more specific, such as ‘total diesel demand’. These might also be outputs from energy models. This link is currently under construction between LEITAP and the Targets IMage Energy Regional Model

(TIMER) model developed at MNP, Bilthoven (The Netherlands) as a part of the IMAGE model family[23].

- Parameters on the substitution of biodiesel for petroleum-based diesel (a_{ij} in Eq. 8) could be estimated from auxiliary simulations with any model possessing an in-depth description of economic choice between different feed stocks (e.g. PRIMES). An alternative source of parameters could be the estimates or calibration results of LEITAP or Lampe 2006.

Regarding auxiliary simulations with PRIMES, it appears that time requirements are significant, at least if full application of all model components is needed to obtain the following information: What would be the demand for certain biofuels (bioethanol, biodiesel) provided that these biofuels are supplied at a certain price. In PRIMES there is an exogenous demand for transport services, which motivates a cost-minimising, derived demand for conventional fuels or biofuels depending on prices. This non-agricultural demand for biofuels associated with a certain price is exactly the information needed for agricultural modelling. A small technical difficulty might be that biomass supply from agriculture is already represented by a supply function in PRIMES such that some adjustment will be needed to obtain a special model version for the auxiliary simulations. Apart from applying the sequential recalibration approach explained above, the following simpler solutions could be considered as well:

- Different costs of biomass production in agriculture could be translated into the parameters of the biomass supply function such that the auxiliary simulations would rely on different supply functions.

- Different costs could be directly fed into PRIMES if the standard supply function were replaced with an exogenous price assumption (and probably an exogenous capacity as a technical safeguard).

More details of such collaboration will be worked out in an ongoing project with the PRIMES team titled the European Consortium for Modelling of Air Pollution and Climate Strategies (EC4MACS), which also implies intensified communication. Similarly, it is foreseen that EUFASOM will be equipped with an explicit processing demand sector. Though the development of 'ENFA'[24] is proceeding intensively (given its duration from 2005 to 2008) it is still difficult to anticipate its final shape. EC4MACS is a medium-run research project coordinated by IIASA, Laxenburg[25], which aims to develop a network of well established modelling tools for a comprehensive, integrated assessment of the policy effectiveness of emission control strategies for air pollutants and greenhouse gases. The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) network will include the Regional Air Pollution INformation and Simulation (RAINS)/GAINS model for air pollution and greenhouse gases, the PRIMES energy model, the Transport and Emissions Simulation Model (TREMOVE), the CAPRI agriculture model, and EUFASOM for the integrated assessment of mitigation and enhanced carbon sinks. As EC4MACS runs through 2011, results of the project are not yet available.

[23] See http://www.mnp.nl/en/themasites/image/model_details/agricultural_economy/Relationsinputand-output.html

[24] See http://www.fnu.zmaw.de/European_Non-Food_Agriculture.5700.0.html

[25] See http://www.ec4macs.eu/home/index.html.

8 References

Abrham, Z., M. Kovárová, T. Kuncová (2004): Technology and economy of energy crops. Research in Agricultural Engineering 50 (4) 123-129.

AGMEMOD Partnership Members (2007). Impact analysis of the CAP reform on main agricultural commodities. Draft Final report. (Contract no 150267-2005-FIED-NL). 31 January 2007.

Amon, T. et al. (2003): Optimierung der Biogaserzeugung aus den Energiepflanzen Mais und Kleegras, http://www.nas.boku.ac.at/fileadmin/_/H93/H931/AmonPublikationen/Optimierung_der_Biogaserzeugung_aus_Mais_und_Kleegras.pdf (21.2.2007).

Austrian Government, Bundesgesetz BGB1. I Nr. 149/2002, 2002.

Banse, M., H. Grethe and S. Nolte (2005). European Simulation Model (ESIM) in GAMS: User Handbook. Göttingen and Berlin.´

Banse, M., A. Tabeau, G. Woltjer, G. and H. van Meijl (2007): Impact of EU Biofuel Policies on World Agricultural and Food Markets. Paper presented on the 10th Annual GTAP Conference 2007. June 7-9, 2007. Purdue University.

Breuer, T. und K. Holm-Müller (2006): Abschätzung der Chancen aus der Förderung von Biokraftstoffen für die ländlichen Regionen in Nordrhein-Westfalen. Landwirtschaftliche Fakultät der Universität Bonn, Schriftenreihe des Lehr- und Forschungsschwerpunktes USL. Nr. 137. Bonn.

Breuer, T., Delzeit, R. & A. Becker (forthcoming): Biofuels: Die globale Renaissance der Kraftstoffe vom Acker. Geographische Rundschau.

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

Coordination Paysanne Européenne (CPE) (2007): Press release on energy, climate, agriculture, 23.02.2007, Bruxelles.

Clashausen, D. (2006): Biokraftstoffe – was ist technisch möglich?. Entwicklung & ländlicher Raum 6/2006, 7-9.

Cypris, Ch. (2000). Positive mathematische Programmierung (PMP) im Agrarsektormodell RAUMIS. Schriftenreihe der Forschungsgesellschaft für Agrarpolitik und Agrarsoziologie e.V. Bd. 313., zugl. Dissertation Universität Bonn, Bonn.

DEIAgra (2006): Study On Implementing The Energy Crops CAP Measures And Bio-Energy Market. Bolgona, http://ec.europa.eu/agriculture/eval/reports/bio_energy/index_en.htm.

De Vries et al. (2003): Renewable electricity policies in Europe-Country fact sheets 2003, Amsterdam.

EEA (2006): How much bioenergy can Europe produce without harming the environment?. EEA Report No. 7/2006. Copenhagen.

Elobeid, A. and S. Tokgoz (2006a). "Removal of U.S. Bioethanol Domestic and Trade Distortions: Impact on U.S. and Brazilian Bioethanol Markets". Working Paper 06-WP 427. Center for Agricultural and Rural Development. Iowa State University. Ames.

Elobeid, A. and S. Tokgoz (2006b). "U.S. and Brazilian Bioethanol Markets: A Policy Analysis". Presentation on the OECD World Outlook Conference, Banff, Canada, 23-25.05.2006.

Energy Economics Group (2004): Final Report on the Project GreenX under the Vth EU Framework Program , Vienna University of Technology, Vienna.

EUROBSERVER, Biofuels Barometer Mai 2006, 2006.

European Biodiesel Board (EBB) (2007): Biodiesel Production 2005 by Country.

European Commission (2003). World energy, technology and climate policy outlook 2030. DG Research. Brussels.

European Commission (2005): Member States Reports in the frame of Directive 2001/77/EC. Brussels.

European Commission (2006): Member States Reports in the frame of Directive 2003/30/EC. Brussels.

European Commission (2007a): Impact assessment, Commission Staff Working Document, Accompanying Document to the Renewable Energy Road Map, SEC(2006) 1719, 10.01.2007, Brussels, http://ec.europa.eu/energy/energy_policy/doc/05_renewable_energy_roadmap_full_impact_assessment_en.pdf.

European Commission (2007b: Review of economic and environmental data for the biofuels progress report, Commission Staff Working Document, Accompanying Document to the Biofuels Progress Report, SEC(2006) 1721, 10.01.2007, Brussels.

European Commission (2007c): The impact of a minimum 10% obligation for biofuel use in the EU27 in 2020 on agricultural markets, Impact assessment of the Renewable Energy Roadmap - March 2007, DG Agri, AGRI G-2/WM D(2007), 30.04.2007, Brussels, http://ec.europa.eu/agriculture/analysis/markets/biofuel/impact042007/text_en.pdf.

EU Commission (2007d): DG TREN, EC Fact sheets by Country, Brussels, http://ec.europa.eu/energy/energy_policy/facts_en.htm (02.04.2007).

European Parliament and Council (2001): Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. Brussels.

European Parliament and Council (2003a) Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport. Brussels.

European Parliament and Council (2003b): Directive 2003/30/EC, Brussels.

Eurostat (2006): Energy, transport and environment indicators.

Eurostat (2006b).

E3Mlab – ICCS/NTUA (2000). The PRIMES Energy System Model , Summary Description, http://www.e3mlab.ntua.gr/manuals/PRIMsd.pdf.

E3Mlab – ICCS/NTUA (2005). PRIMES Energy System Model: Reference Manual, http://www.e3mlab.ntua.gr/.

Fagernäs, L. et. al. (2006): Bioenergy in Europe. Opportunities and Barriers. VTT Tierdotteita Research Notes 2352. Helsinks.

Fachagentur Nachwachsende Rohstoffe (FNR) (2005): Handreichung Biogas (2nd Ed.). Gülzow.

Fachagentur Nachwachsende Rohstoffe (FNR) (2006): Biokraftstoffe: eine vergleichende Analyse. Gülzow.

Food and Agricultural Organisation of the United Nations FAO (2006). Statistical Database. http://faostat.fao.org/default.aspx.

Food and Agricultural Policy Research Institute FAPRI (2006). FAPRI Agricultural Outlook 2006, http://www.fapri.iastate.edu/outlook2006/.

Freire, F., J. Malca, S. Rozakis (2004): Integrated Economic and Environmental Life Cycle Optimization: An Application to Biofuel Production in France. In: Multiple Criteria Decision Aiding. http://www.eq.uc.pt/cem/glicerol/Malca_Freire_2004_Book_Chapter.pdf (15.2.2007).

Geber, U. (2002): Cutting frequency and stubble height of reed canary grass: influence on quality and quantity of biomass for biogas production.

Gömann, H., Kreins, P., Breuer, T. (2007a): Germany – The European Energy-Corn-Belt. in Agrarwirtschaft, in Press.

Gömann, H., Kreins, P., Breuer, T. (2007b): Einfluss steigender Weltagrarpreise auf die Wettbewerbsfähigkeit des Energiemaisanbaus in Deutschland. forthcoming.

Grant, J.H., Hertel, T.W. and T.F. Rutherford (2006): Extending general equilibrium to the tariff line. US dairy in the Doha development agenda. Paper presented at the member meeting of the International Agricultural Trade Research Council (IATRC), St. Petersberg, December 2006.

Hale, R., S. West (2006): Biofuel Supply Options. http://www.transport.govt.nz/assets/NewPDFs/Biofuels-Supply-Report-Final-24-07-06.pdf (22.2.2007).

Havlik, P., Schneider, U. (2007): GLOBIOM _- Global Biomass Optimisation Model, Presentation in the Forestry Program of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, September 6, 2007.

Heiermann, M., M. Plöchl (2004): Crops – a big potential for biogas production. Presentation at the World Renewable Energy Congress.

Henniges, O. (2007): Die Bioethanolproduktion: Wettbewerbsfähigkeit in Deutschland unter Berücksichtigung der internationalen Konkurrenz. Lohmar.

Henniges, O. und Zeddies, J.: Conflicts of Objectives in the Use of Biofuels. In: FO Licht's World Sugar Yearbook 2006, 67th edition (engl.), Tunbridge Wells 2005, S. D24 - D32.

Henrichsmeyer, W., et al. (1996). Entwicklung eines gesamtdeutschen Agrarsektormodells RAUMIS96. Endbericht zum Kooperationsprojekt. Forschungsbericht für das BML (94 HS 021), vervielfältigtes Manuskript Bonn/Braunschweig.

Herle, J. van, Y. Membrez, O. Bucheli (2004): Biogas as a fuel source for SOFC co-generators. Journal of power sources 127 (1-2) 300-312.

Hertel, T.W. (1997). Global Trade Analysis: Modelling and Applications (Cambridge University Press, Cambridge).

Howitt, R.E. (1995). Positive Mathematical Programming. American Journal of Agricultural Economics 77, p. 329-342.

Ignaciuk, A.M., R.B. Dellink (2005): Multi-Product Crops for Agriculture and Energy Production – an AGE Analysis for Poland. Milano.

International Energy Agency (IEA) (2006): Monthly Electricity Statistics November 2006. Paris.

International Energy Agency (IEA) (2007): Energy Technology Essential. Jan. 2007 - Internet source: www.iea.org/textbase/techno/essentials.htm , 14.05.2007.

Kallivroussis, L., A. Natsis, M. Martinez, J. Aracil (2002): The energy balance of sunflower production for biodiesel in Greece. Biosystems Engineering 81, 347-354.

Klepper, G., Peterson and K. Springer (2003): DART97: A description of to Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper No. 1149. Institute for World Economics, Kiel.

Hoogwijk M, A. Faaij, B. Erickhout, B. de Vries and W. Turkenburg (2005), Potential Biomass Energy out to 2100 for Four IPCC SRES Land-use Scenarios. Biomass and Bioenergy 2005;29:225-257.

Kouvaritakis, N. (2007). Development of BIOMASS Supply and Demand in the PRIMES Energy Model, unpublished document, Athens.

Kreins, P. and C. Cypris (1999). Entwicklung der regionalen Wettbewerbsfähigkeit im Bereich der Milchproduktion und Folgen für die Landnutzung. Vervielfältigtes Manuskript für die 39. Jahrestagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e. V. in Kiel, 4.-6. Oktober 1999.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) (2005): Faustzahlen für die Landwirtschaft. 13. Auflage. Darmstadt.

Ledebur, O. von; Elmahdi, K.; Wagner, S. (2007): Market Impact Analysis of Biofuel Policy Implementation. Report within the EU project SSPE-CT-2004-503604 'Impact of Environmental Agreements on the CAP'. http://www.ieep.org.uk/research/MEACAP/MEACAP_Home.htm. July 2007.

LEPPII Laboratoire d'Economie de la Production et de l'Intégration Internationale (2006). The POLES model: State of the Art. LEPII-EPE, CNRS, Grenoble.

LEPPII Laboratoire d'Economie de la Production et de l'Intégration Internationale (2005). The POLES model. Short description. LEPII-EPE, CNRS Grenoble, May 2005.

Ma, F., M.A. Hanna (1999): Biodiesel production: a review. Biosource Technology 70 (1) 1-15.

McDonald, S., S. Robinson and K Thierfelder (2004). Impact of Switching Production to Bioenergy Crops: The Switchgrass Example. Paper presented on the 8th GTAP Conference in Luebeck (Germany), July 2004, https://www.gtap.agecon.purdue.edu/resources/download/2095.pdf.

Nowicki, P., H. van Meijl, A. Knierim, M. Banse, J. Helming, O. Margraf, B. Matzdorf. R. Mnatsakanian, M. Reutter, I. Terluin, K. Overmars, D. Verhoog, C. Weeger, H. Westhoek (2007). SCENAR 2020 - Scenario study on agriculture and the rural world. Contract No. 30 - CE - 0040087/00-08. European Commission, Directorate-General Agriculture and Rural Development, Brussels.

OECD (2002), OECD Agricultural Outlook 2002-2007, OECD, Paris.

OECD (2005): OECD Agricultural Outlook 2005-2014, OECD, Paris.

OECD (2006). "Documentation of the AGLINK-COSIMO model," Working Party on Agricultural Policies and Markets, Directorate for Food, Agriculture and Fisheries, Committee for Agriculture, Organization for Economic Cooperation and Development, AGR/CA/APM(2006)16, 22 September, 2006, Paris.

OCED-FAO (2007). OECD-FAO Agricultural Outlook 2007-2016, OECD, Paris and FAO, Rome.

OEKO/ Alterra (2006): Environmentally compatible biomass potential from agriculture. Darmstadt/ Wageningen.

PARCOM (Paris-Konvention zur Verhütung der Meeresverschmutzung) (1993): Dritte Sitzung der Ad-hoc-Arbeitsgruppe zur Reduzierung der Nährstoffeinträge aus der Landwirtschaft – Anlage 1: PARCOM-Richtlinien für die Berechnung von Mineralbilanzen.

Pimentel, D. (2003): Bioethanol Fuels: Energy Balance, Economics and Environmental Balance are Negative. Earth and Environmental Science 12 (2) 127-134.

PREMIA (2007): Biofuels in the EU: potential and obstacles, unpublished draft discussion paper for the regional PREMIA workshop.

Ragwitz, M. et. al. (2005): Monitoring and evaluation of policy instruments to support renewable electricity in EU Member States. Karlsruhe.

Rausch, S. and T.F. Rutherford (2007): Computation of equilibria in OLG models with many heterogeneous households. Ruhr economic papers #15, Ruhr Graduate School of Economics.

Reinhold, G., T. Hering (2003): Vergleichende Bewertung von Getreideverbrennung und Vergasung. KTBL-Schrift. Darmstadt.

Risnes, H. et al. (2003): Calcium addition in straw gasification. Fuel 82. 641-651.

Schmitz, N. (2006): Bioethanol als Kraftstoff – Stand und Perspektiven. Technikfolgenabschätzung 15 (1) 16-26.

Schneider, U.A. and D.E. Schwab (2006). The European Forest and Agricultural Sector Optimization Model. Working Paper. Hamburg University..

Smeets, E., Junginger, M. and Faaij, André (2005), Supportive study for the OECD on alternative developments in biofuel production across the world. Consultancy report for the OECD Secretariat, http://www.chem.uu.nl/nws/www/publica/Publicaties2005/E2005-141.pdf.

Smeets, E., A. Faaij, I. Lewandowski and W. Turkenburg (2006), A bottom up quickscan and review of global bioenergy potentials to 2050. Progression in Energy and Combustion Science 33, p. 56-106.

Thrän, D. et al. (2005): Nachhaltige Biomassenutzungsstrategien im europäischen Kontext. http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/biohandel_endbericht.pdf. (15.2.2007).

Tangermann, S., Banse, M. (eds.) (2000) Central and Eastern European Agriculture in an Expanding European Union, Wallingford, UK: CABI Publishing.

Vetter (2006): Standortgerechte und umweltverträgliche Produktion von Energiepflanzen. http://daf.zadi.de/download/PPT_Vetter.pdf.

von Lampe, M. (2006). "Agricultural Market Impacts of Future Growth in the Production of Biofuels," Working Party on Agricultural Policies and Markets, Directorate for Food, Agriculture and Fisheries, Committee for Agriculture, Organization for Economic Cooperation and Development, AGR/CA/APM(2005)24/FINAL, February 1, 2006, Paris, http://www.oecd.org/dataoecd/58/62/36074135.pdf.

Weiland, P. (FAL, Institute of Technology and Biosystems Engineering, 2006): Personnel communication.

WorldWatch Institute (2006): Biofuels for Transportation: Global Potential and Implications for sustainable agriculture and energy in the 21st century. Washington.

Zeddies, J. (2006): Rohstoffverfügbarkeit für die Produktion von Biokraftstoffen in Deutschland und in der EU25. Universität Hohenheim.

Annex 1: Overview of models described in the Study

	LEITAP	ESIM	FAPRI	AGLINK	AGMEMOD	RAUMIS	POLES	PRIMES	EUFASOM/ENFA
Type	General equilibrium	Partial equilibrium	Partial equilibrium	Partial equilibrium	Partial equilibrium	PMP approach	Partial equilibrium	Partial equilibrium	Partial equilibrium
Regional coverage	Global	Global EU focus at MS level	Global	Global	European focus, MS level	Germany at NUTS-III	Global	European focus	Global EU regions modelled at grid level
Commodity coverage	87 sectors (8 crops, 4 livestock, 8 processed food) 57 regions	15 crops, 6 livestock and 14 processed products	Linked models for crops cotton, dairy, livestock, oilseeds, rice, and sugar markets	15 agri-food products	9 crops, 9 livestock and 9 processed food products	31 plant and 16 livestock	11 sectors, agriculture one sector	Biomass system: 20 primary resources, 30 transformation processes produce 12 final biomass energy products l	15 crops, 10 energy crops, 20 tree species, 10 livestock
Biofuel crops	Wheat, sugar and oilseeds as biofuel crop input	Cereals (wheat, corn), sugar, rapeseed and sunflower seed with by-products	Cereals and sugar for the bioethanol production with by-products	Oilseeds as input for biodiesel, cereals and sugar as inputs for bioethanol with by-products	Rape-oil for biodiesel (for the German model version only)	Rape seed on set aside Energy maize	No special crops identified	5 biomass categories: energy crops, agric. residues, forestry, aquatic biomass, wastes	Detailed presentation of 1st generation and 2nd generation biofuel crops
Scenarios calculated	Biofuel Directive as minimum blending target in petroleum industry	Biofuel Directive as minimum target of 10% in 2010, removal of import tariffs for bioethanol	Removal of US import tariffs on bioethanol and removal of tax credit for refiners blending bioethanol	Biofuel Directive and impact of high crude oil prices	Biofuel Directive as minimum target of 5.75 % in 2010	Increase in agricultural prices at different rates	Projection of future energy demand	Projection of future energy demand	Global increase of biofuel use in transport from 1 % up to 35 % (application of GLOBAL FASOM)

Annex 1 (continued): Overview of models described in the Study

	LEITAP	ESIM	FAPRI	AGLINK	AGMEMOD	RAUMIS	POLES	PRIMES	EUFASOM/ENFA
Main Findings	Strong increase in world prices for biofuel crops, EU becomes a net-importer in biofuel crops. Decline in crude oil price; Biofuel consumption declines in Non-EU countries	Strong increase in world prices for biofuel crops, decline in prices for by-products; EU becomes a net-importer in biofuel crops and biofuels. EU agricultural area expands by 0.5 % due to biofuel directive	23 % increase in world bioethanol price; strong increase in US bioethanol imports; increase in Brazil bioethanol exports	For EU countries, between 30-70 % of crop area required to replace 10 % of transportation fuel, strong increase in world prices (2 % oilseeds, 60 % sugar)	n.a.	Increase in energy maize area between 1.0-1.8 mm. ha		Biofuel targets not reached w/o policy intervention	Strong increase of wheat prices if land scarcity increases. Prices in Western Europe may double with a required biofuel share of 20 %, in spite of using woody crops
Results published	Yes	Yes	Yes	Yes	Not yet	Yes	Yes	Yes	

European Commission

EUR 23355 EN – Joint Research Centre – Institute for Prospective Technological Studies
Title: Modelling of Energy-Crops in Agricultural Sector Models - A Review of Existing Methodologies
Authors: Peter Witzke, Martin Banse, Horst Gömann, Thomas Heckelei, Thomas Breuer, Stefan Mann, Markus Kempen, Marcel Adenäuer, Andrea Zintl.
Editors: Ignacio Pérez Domínguez and Marc Müller
Luxembourg: Office for Official Publications of the European Communities
2008
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-08887-2
DOI 10.2791/11341
Abstract

The present report provides an overview of the different methodologies applied in partial and general equilibrium models used to analyse biofuel policies in Europe, as well as their methodological pros and cons. While the LEITAP model is included as a general equilibrium model covering biofuel demand, partial equilibrium models are represented by ESIM, FAPRI, AGLINK/COSIMO, RAUMIS, AGMEMOD (agricultural models); POLES and PRIMES (energy sector); and EUFASOM/ENFA (forestry sector). The study is highly relevant for the current modelling work at IPTS, where models such as ESIM and AGLINK play an important role in the Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP) of the AGRILIFE Unit. Additionally, the POLES model is currently part of the model portfolio used by the Competitiveness & Sustainability Unit in several studies analysing possible technological pathways of energy production and demand for bioenergy in Europe, a result of implementing the biofuel directive. This compilation of information is also important since the implicit and explicit treatment of bioenergy, either as a demand shock to the processing of oilseeds or feedstock for bioethanol and biodiesel, or as the introduction of a biofuel-sector into a computational general equilibrium (CGE) is foreseen in the short-term by other economic models used at IPTS.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LF-NA-23355-EN-C

EUROPEAN COMMISSION

ISBN 978-92-79-08887-2

9 789279 088872

Publications Office
Publications.eu.int