Bioenergy and biomass trade: Evaluation of models' suitability for analysing international trade of biomass and bioenergy products

A study for IEA Bioenergy Task 40

by

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FOREWORD

This report presents the results of the study *"Evaluation of international (trade) models with emphasis on the possibility to include bioenergy"*, initiated during the autumn 2006 by the IEA Bioenergy Task 40. The study has been led by Prof. Birger Solberg, the Norwegian University of Life Sciences, and he and Dr. Veronika Dornburg, Utrecht University have done most of the initial writing of the report. The other authors have contributed significantly by commenting, correcting and adding to the initial report.

Preliminary results were presented during the IEA Task 40 meetings in October, 2006 in Finland and in February, 2007 in the Netherlands. The study has been reviewed externally by Dr. Detlef van Vuuren and Drs. Bas Eickhout (working for the Dutch MNP/RIVM), and sent to all Task 40 members for comments. The report will be published as a working paper at the IEA Task 40 web site.

The authors thank all persons who kindly have contributed to the content of the report, in particular the external reviewers.

SUMMARY

This report evaluates existing international economic models of the forest sector, the agricultural sector and/or the energy sector in order to assess their strong and weak points for analysing international trade of biomass and bioenergy products. The overview is mainly focused on public models used by academia, based on publicly available data sources. These models usually have a time horizon of several decades. Commercial trade models, which typically have a time horizon of month or a few years, are not considered.

Many models were found of interest for this study, and after a preliminary search it was decided to concentrate on:

- The agricultural sector models CAPRI and AGLINK/COSIMO
- The forest sector (i.e. forestry and forest industries) partial equilibrium models EFI-GTM, PELPS and GFPM
- The partial equilibrium models EU-FASOM and ENFA, which include the agriculture and the forest sectors
- The energy models BIOTRANS and PEEP
- The energy model TIMER as sub-model in IMAGE
- The general equilibrium model GRACE, as a representative of GTAP models which include forestry and forest industries.

The comparative evaluation of the models was based on the following criteria (cf. chapter 2 for more detailed description):

C1. Link to economic theory
C2. Spatial considerations
C3. Dynamic features
C4. Link to other sectors and land use issues
C5. Model and data availability and model adjustments needed.

Table 1 presents a summary comparison of the models based on the five criteria.

It is concluded that none of the existing models are capable of performing good analyses of international trade of biomass and bioenergy products, and that a combination of models is necessary. Several alternatives exist for that, but it has not been possible to go into very detailed analysis here as it would require discussions with persons who know in details each of the models in questions, and also a specification of what types of biomass trade to be analysed (e.g. sugar crops globally or wood products regionally, in reaction to CAP policy reforms). However, the following combination of models is mentioned as promising: CAPRI covering the agriculture sector rather detailed, EFI-GTM covering the forest sector rather detailed, a global CGE model having both agriculture, forestry, forest industries and energy, and a global land-use change model. As such a combination of CAPRI, EFI-GTM, GRACE and IMAGE seems promising.

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1 INTRODUCTION

1.1 Background

Biomass and bioenergy markets are expected to grow substantially in the next decades as a result of increasing prices of fossil fuels, concerns regarding the security of supply, the aim to diversify fuel supplies, high costs of carbon emissions and subsequent strong political willingness to support bioenergy and other renewable energy sources.

Fischer and Schrattenholzer (2001) and Berndes et al. (2003) review global studies on bioenergy potentials, and it appears that despite the optimistic expectations regarding future use of bioenergy, there is a lack of studies analyzing economic potentials and impacts. In particular, there appear to be lack of studies addressing important links between agricultural and raw-material markets, including for example alternative uses of wood, and the bioenergy market. Also, impacts on other sectors - such as forestry, forest industries and agriculture - of a growing bioenergy sector do not seem to be clearly understood, probably due to limited availability and use of models integrating the different sectors in appropriate ways.

A recent review of studies analysing global bioenergy potentials concludes as follows (Berndes et al. 2003): "A refined modelling of interactions between different uses and bioenergy, food and materials production – i.e. of competition for resources, and of synergies between different uses – would facilitate an improved understanding of the prospects of large-scale bioenergy production and future land-use and biomass management in general".

In 2006, IEA Task 40 discussed models for analysing biomass trade. It was found that several models existed which could potentially be of interest, but no overview evaluation of their weak and strong points related to analysing biomass trade was found. It was therefore decided to establish a project under the Task 40 supervision to produce such an overview. This effort has resulted in the following report, produced by a team of researchers from the Norwegian University of Life Sciences and the Utrecht University.

1.2 Objectives and scope

The main objectives of the project and the report are to evaluate existing international economic models of the forest sector, the agricultural sector and/or the energy sector in order to assess their strong and weak points for analysing international trade of biomass and bioenergy products.

The overview will mainly focus on public models used by academia, based on publicly available data sources. These models typically have a time horizon of several decades. The overview did not consider commercial trade models, which typically have a time horizon of month or a few years.

2 METHODOLOGY

The project has been conducted as a literature study, going through written documents/reports about the various models.

Many models exist of interest in analyses of bioenergy trade, and as the project resources were limited, we had to make a selection at the initial stage of the project. After a preliminary search, we decided to concentrate on the following models:

- The agricultural sector models CAPRI and AGLINK/COSIMO
- The forest sector (i.e. forestry and forest industries) partial equilibrium models EFI-GTM, PELPS and GFPM
- The partial equilibrium models EU-FASOM and ENFA, which include agriculture, forestry and forest industries
- The energy models BIOTRANS and PEEP
- The energy model TIMER as sub-model in IMAGE
- The general equilibrium model GRACE, as a representative of GTAP models which include forestry and forest industries.

It was decided (in the contract of the project) that the comparative evaluation of the models should be based on the following criteria:

C1. Link to economic theory

By link to economic theory we here mean what the model assumes regarding agent (consumers and producers) behaviour - like profit maximizing producers, utility maximizing consumers, market competitiveness, and market clearance (i.e. that demand equals supply for each product in each market and time period considered). A clear link to economic theory was assumed to be an advantage since it secures that the model results are consistent with respect to economic growth, demand and supply.

C2. Spatial considerations

Biomass markets are expected to become more internationalized and international trade is also the core of Task 40. Spatial considerations and internationalisation, taking costs of transport into account is therefore a crucial evaluation parameter

C3. Dynamic features

This criterion describes how the time dimension is taken into account in the model. Supply and demand relations as well as policies develop over time. The way these dynamic considerations are included is important. In terms of time horizon, a long-term time horizon (i.e. until 2030 and beyond) was considered a strong point. On the other hand, large time steps (e.g. 5 or 10 years) were considered a weak point.

C4. Link to other sectors and land use issues

The development of the bioenergy sector depends on what is happening in the forest, agricultural, environment and more general energy sector, and vice versa. The link to the other sectors mentioned and also to the economic development in general is evaluated for each model. The forest sector is of particular importance since 80% of the biomass needed for EU to reach the 12% target is anticipated to be based on woody biomass.

C5. Model and data availability and model adjustments needed.

This criterion includes an assessment of which data would be needed, the availability of those data and the model, and adjustments needed to include bioenergy in a satisfactory way.

To make possible an evaluation using these criteria, it was decided that the description of each model should, as a minimum, be structured according to the 6 headings (with corresponding main questions to be answered) shown in Box 1:

Box 1: Description of models

1. Introduction

Model purpose and main outputs

- Which main issues are the model constructed for analysing?
- What are the main outputs of the model?
- What are the main (current) applications of the model?

2. Model structure

Agent behaviour assumed in the model

- What is assumed regarding agent behaviour?
- How is that modelled?

Spatial aspects and time horizon

- How is trade included?
- Which regions are included?
- What is the time horizon of the model?

Dynamic features

- What are the dynamic factors in the model – i.e. which factors drive changes over time
- How is technological change incorporated?
- How is investment in new capacities incorporated?
- What is modelled endogenously, what exogenously?
- Are scenarios included (e.g. on land use change, energy prices and climate change policy)? If yes, how?

3. Level of detail of the model

Forestry

- How detailed are the forestry growth and fibre supply modelled?

Forest industries

- How detailed are the forest industries described?

Bioenergy

- How detailed are the various bioenergy production possibilities modelled?

Other sectors

- Which other sectors are included and how (detailed) are they modelled?
- Which exogenous factors are included and how?

4. Model and data availability

Data

- What is base year (starting year) for the model?
- How easy is the data available?
- What are the most uncertain data?

Model availability

- Is the model operational or at testing stage?
- Where is it in use? References to model description and recent use
- Which program language is used?
- Has the model been validated – if so, where and how?

5. Other factors

Model and data improvement

- Are model improvements underway/planned?
- What type of model improvements would be necessary to incorporate bioenergy trade in a meaningful way?
- Is data improvement underway?
- What data improvement would be necessary to incorporate bioenergy trade in a meaningful way?

Other factors

6. Overall evaluation of strong and weak points related to analysing international trade of bioenergy

3 DESCRIPTION OF INDIVIDUAL MODELS

In the following each model is described according to the points 1-6 outlined in Box 1.

3.1 CAPRI

3.1.1 Introduction

CAPRI stands for Common Agricultural Policy Regionalised Impact Analysis and has as main purpose to assess the regional effects of CAP (Common Agricultural Policy) instruments at EU and Member State level, and at sub-national level as well. The following description is based on Britz (2005).

The development of CAPRI since 1997 was mainly based on funds from the EU framework research programs, in the context of several FP IV – FP VI projects. Operational since 1999, CAPRI is currently the core agricultural model used in the two large Integrated Projects SENSOR and SEAMLESS. CAPRI was used for a wider range of policy impact studies of which some are listed below, inter alia for DG-ENV, DG-AGRI, DG-JRC/IPTS, the EAA and industry stakeholders.

The main outputs of the model are estimates of protection quantities, equilibrium prices, and trade of about 50 agriculture products. The model also provides GHG emission estimates from two sources of emissions:

- CO_2, CH_4 and N_2O from mineral fertilizers
- CH_4 from animal production

Based on this, the contribution to Global Warming Potential (GWP) equivalent emissions is estimated.

During the years, CAPRI has been applied to a wide range of different analyses. The very first application in 1999 analysed the so-called "Agenda 2000" reform package of the CAP. Shortly afterwards, a team at SLI, Lund, Sweden applied CAPRI to analyse CAP reform option for milk and dairy. FAL, Braunschweig looked into the effects of an increase of biological production systems. WTO scenarios were analysed by the team in Bonn in 2002 and 2005. Moreover, CAPRI was applied to analyse sugar market reform options at regional level, linked to results of the WATSIM and CAPSIM models. In 2003, scenarios dealing with the CAP reform package titled "Mid Term Review" were performed by the team in Bonn and tradable permits for greenhouse gas emission from agriculture analysed. The team in Louvain-La-Neuve, together with the group in Bonn, analysed sugar market reform options, applying the market module linked to the regional supply models. In 2004 followed an analysis of a compulsory insurance paid by farms against Food and Mouth disease by SLI and runs dealing with methane emission by the team in Galway, Ireland. In the same year, CAPRI was installed by DG-AGRI in Brussels and was since then used to complement DG-AGRI's outlook projections and for policy impact analysis.

3.1.2 Model structure

Agent behaviour assumed in the model

The model is based on the assumption of profit maximizing producers and competitive agriculture markets. Since market and activity specific policy instruments require a highly disaggregated modelling approach, a simultaneous system, which would optimize producers

and consumer surplus for 200 regions and some 50 products, is computationally infeasible. Therefore, the model is conceptually split into a supply model and a market model.

The supply model consists of individual programming models for about 250 NUTS II regions and about 2000 farm type models which break down NUTS II regions into a farm typology by farm size and farm specialisation. Each of the models being an independent aggregate non-linear programming model representing activities of all farms at regional or farm type level captured by the Economic Accounts for Agriculture (EAA). These programming models are a kind of hybrid approach, as they combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities, with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. The non-linear cost function allows for good calibration of the models and a smooth simulation response rooted in observed behaviour. The models include in detail the premiums paid under CAP, NPK fertilizer balances and a module with feeding activities covering nutrient requirements of animals. Main constraints outside the feed block are arable and grassland, set-aside obligations and milk quotas. The complex sugar quota regime is captured by a component maximising expected utility from stochastic revenues. Prices are exogenous in the supply module and provided by the market module. Grass, silage and manure are assumed to non-tradable and receive internal prices based on their substitution value and opportunity costs.

The market model consists of two sub-models. The sub-model *for marketable agricultural outputs is a spatial, non-stochastic global multi-commodity* model for about 50 primary and processed agricultural products, covering about 40 countries or country blocks in 28 trading regions. Bi-lateral trade flows and attached prices between these regions are modelled based on the Armington assumption (i.e. that the demand from domestic sales and different import origins depends on price relationships according to bilateral trade streams, allowing the model to reflect trade preferences for certain regions that cannot be observed in net trade models). The behavioural functions for supply, feed, processing and human consumptions apply flexible functional forms where calibration algorithms ensure full compliance with micro-economic theory including curvature. The parameters are synthetic, i.e. to a large extent taken from the literature and other modelling systems. Policy instruments cover Product Support Equivalents and Consumer Support Equivalents (PSE/CSE) from the OECD, (bi-lateral) tariffs, the Tariff Rate Quota (TRQ) mechanism and, for the EU, intervention stocks and subsidized exports. This sub-model delivers prices used in the supply model described below and allows for market analysis at global, EU and national scale, including a welfare analysis. A special second sub-model deals with prices for young animals.

The prices of the market model are fed into the supply model at EU national level, and market clearing prices are obtained for each year through iterative static optimization. As the supply models are solved independently at fixed prices, *the link between the supply and market models* is based on an iterative procedure. After each iteration, during which the supply model works with fixed prices, the constant terms of the behavioural functions for supply and feed demand are calibrated to the results of the regional aggregate programming models aggregated to Member State level. Solving the market model then delivers new prices. A weighted average of the prices from past iterations then defines the prices used in the next iteration of the supply module. Equally, in between iterations, CAP premiums are re-calculated to ensure compliance with national ceilings.

CAPRI allows for *modular applications* as e.g. regional supply models for a specific Member State may be run at fixed exogenous prices without any market module. The farm type model

layer may be switched ON or OFF. Equally, the model may be used in a comparative-static or recursive-dynamic fashion.

Spatial aspects and time horizon
The *global market model* is regionalized at two levels. There are 28 single countries or country aggregates (as EU15, China, India, USA, Least Developed countries …) which are linked via trade flows according to the Armington assumption. Some of those country aggregates (EU15, EU10, Bulgaria & Romania, Western Balcans, An aggregate of some Mediterrean countries) are further broken down to individual countries based on own behavioural functions for supply and demand.

The supply model covers EU27, Norway and the Western Balcans, broken down into NUTS II regions (about 250), with a statistically based down-scaling allowing to generate crop shares, animal stocking densities and nutrient balances at the 1x1 km grid for EU27.

The time period for modelling is usually 10-20 years.

Dynamic features
Main endogenous variables are prices, produced quantities and import/export of the agriculture commodities for each year and each region. The development of a recursive-dynamic version was abandoned given the resulting high response times, but technical progress may allow for such a solution in the future.

Main exogenous variables are:

- Economic growth
- Production costs for the various crops
- Demand and supply elasticities
- Initial land use and farm types
- Rates of technological change

Main dynamic factors (i.e. factors driving changes over time) in the model are the combined interactions of the exogenous and endogenous variables.

Technological change is included through exogenous specified changes over time according to crops produced, and the choice of crops as a result of profit maximizing farmers.

3.1.3 Level of detail of the model

Forestry and forest industries
Forestry and forest industries are not included.

Bioenergy
Bioenergy is today included as production of bioethanol from agriculture crops.

Other sectors
No other sectors are included.

3.1.4 Model and data availability

The model demands a high set of data which is available at the model group center (cf. below).

The *technical solution* of CAPRI is centred on the modelling language GAMS which is applied for most of the data base work (and CONOPT applied as solver for the different constrained (optimisation) problems). The different modules are steered by a Graphical User Interface currently realised in JAVA. The different data bases are stored in internal GAMS formats with the possibility to export to external text files as CSV or to use a SQL link. Exploitations tools in Java allow for the generation of interactive maps and tables.

3.1.5 Other factors

Post-model analysis includes the calculation of different income indicators as variable costs, revenues, gross margins, etc., both for individual production activities as for regions, according to the methodology of the EAA. A welfare analysis at Member State level, or globally, at country or country block level, covers agricultural profits, tariff revenues, outlays for domestic supports and the money metric measure to capture welfare effects on consumers. Outlays under the first pillar of the CAP are modelled in very high detail. Environmental indicators cover NPK balances and output of climate relevant gases according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC). Further on, an energy indicator for agricultural production activities attributes total energy consumption to agricultural production activities, accounting for indirect and direct energy use of intermediate includes including depreciation of investment goods allowing to analyse the energy efficiency of agricultural production systems.

In the context of SENSOR and SEAMLESS, CAPRI is linked to models for other economic sectors, and further developments to enforce the link with other economic models are under way.

Methodological development, updating, maintenance and application of CAPRI are based on a *network approach* which is currently centred in Bonn. The team in Bonn acts as a “clearing house”: any changes introduced in CAPRI are reviewed by it and, when accepted, become part of the master version. The master version, covering data bases, software and documentation is distributed to all participants of the network usually in the context of training sessions which bring the network together at least once per year. The CAPRI modelling system may be defined as a “club good”: there are no fees attached to its use but the entry in the network is controlled by the current club members. The members contribute by acquiring new projects, by quality control of data, new methodological approaches, model results and technical solutions, and by organising events such as project meetings or training sessions. So far, the network approach has worked quite successfully, but it might need revision if the club exceeds a certain size.

3.1.6 Overall evaluation

CAPRI is strong on criteria C1 and C5. On criterion C2 the model is strong on Europe, but weaker for the rest of the world. On criterion C3, the time frame is short (10-20 years). The main weakness related to bioenergy and biomass trade is on C4 as no other sectors than agriculture and GHG emissions are included. This is a quite serious limitation especially for medium- to long-term bioenergy analyses where forest (woody) biomass is expected to be utilised for liquid biofuel (bioethanol, biodiesel) production.

3.2 AGLINK-COSIMO

3.2.1 Introduction

AGLINK and COSIMO are agricultural market models of respectively OECD and FAO. The AGLINK model has been developed by the OECD Secretariat to assess future trends and prospects of the world agricultural market. AGLINK models the agricultural markets in OECD countries and regards the market in developing countries as exogenous. The FAO has developed the counterpart model COSIMO that analyses agricultural market in developing countries. Since 2004, these two models have been combined to the AGLINK-COSIMO model.

The main outputs of the model are projections of annual prices, demand and supply of main agricultural commodities, e.g. wheat, beef. These projections are done for various regional and world markets including traded commodities. The OECD publishes annually the OECD Agricultural Outlook that provides medium term assessments of the agricultural market using the results of the AGLINK-COSIMO model.

3.2.2 Model structure

Agent behaviour assumed in the model

Buyers and sellers are assumed to have no market power, and the model determines equilibrium prices under assumption of perfect competition, including regional markets and trade barriers. AGLINK-COSIMO is a partial equilibrium model that uses 17 world market clearing prices for main agricultural commodities. Agricultural markets can be global or regional. Supply and demand curves are assumed to be linear in the logarithms with partial elasticity determining the equations.

Spatial aspects and time horizon

In first instance, it is assumed that agricultural commodities are traded globally, i.e. there is no distinction in the demand between foreign and domestic commodities. Some markets, however, are regionally or internally limited as for example the foot and mouth disease free meat market. Trade can also be influenced by policies as level of imports and exports in regions/countries can be set exogenously and prices that determine trade can be adjusted by exchange rates or tariffs.

In the model a large number of single countries and regions are included. The AGLINK model part covers the OECD-8 (Australia, Canada, EU-25, Japan, Korea, Mexico, New Zealand and USA) and four non-member countries (Argentina, Brazil, China, Russia). The EU-25 again is split into the EU-15, Hungary, Poland and the remaining countries. The COSIMO model part includes Turkey, 23 non-OECD countries (Bangladesh, Chile, Columbia, Algeria, Egypt, Ghana, Indonesia, India, Iran, Mozambique, Malaysia, Nigeria, Pakistan, Philippines, Paraguay, Saudi Arabia, Thailand, Tanzania, Ukraine, Uruguay, Vietnam, South Africa, Zambia) and 15 remaining regions. Finally, some countries are considered exogenously, i.e. Norway, Switzerland, other Western European countries and other Central American countries.

The projections in the agricultural Outlook cover a 10 year period..

Dynamic features

AGLINK-COSIMO is a recursive dynamic model that clears agricultural commodity prices on an annual basis. Main drivers for the change over time are macroeconomic key parameter.

Technological change is incorporated in improvement of crop yields over time. While investment in new agricultural production capacities is not explicitly included, the area on which a crop is produced is endogenously influenced by prices. Competition for land is, thus, modelled by cross-price effects. Also some crop yields depend on price and are, thus, modelled endogenously. Production costs of agricultural commodities are approximated using the commodity production costs index which in turn depends on macro-economic parameters (GDP deflator, world oil price and exchange rate).

All non-agricultural markets are exogenous, and as such time-dependent developments of key macroeconomic variables are determined independently of the model.
Key macro-economic variables are:

- GDP as a proxy for consumer income
- Private consumption expenditure deflator that is used to deflate consumption prices
- Gross domestic product deflator as a proxy for economy-wide prices
- Exchange rates
- World oil prices

The main output of the model are baseline projections for the medium term which can be compared to scenario projections that represent regional or individual countries' policy on agricultural markets. These policies can be modelled assuming changes in the demand and supply of agricultural commodities as well as limiting trade. Also macro-economic parameters and crop yields can be varied in scenario analyses.

3.2.3 Level of detail of the model

Forestry and Forest industries
AGLINK-COSIMO is an agricultural model and does not include forestry and forest industry.

Bioenergy
In the model, non agricultural-sectors are treated exogenously. The agricultural commodities are modelled using a generic demand curve, i.e. the use of biomass for other purposes than food or feed is not modelled endogenously. Other uses of biomass are represented as a function of commodity prices, GDP and/or time trend variables. This allows for a scenario analysis investigating the impact of increased bio-energy demand on agricultural markets as has been done for biofuels in the Agricultural Outlook 2006-2015.

Other sectors
The only sector that is modelled endogenously is the agricultural sector. The commodities that are modelled are: wheat, coarse grains, rice, oilseeds, oilseed meals, vegetable oils, milk, butter, cheese, whole milk powder, skim milk powder, fresh dairy product, whey powder, casein, beef and veal, pig meat, poultry meat, sheep meat, eggs. The exogenous and endogenous variables for this sector are described in 2.4.

In order to account for annual variation in weather and, thus, resulting in varying crop yields as well as for variation in macro-economic developments, the latter two parameters are partially modelled stochastically. The scenario results represent the influence of these variations on the agricultural markets.

3.2.4 Model and data availability

Data

The model contains historic data that dates back to 1970. Most data result from statistics describing supply and use balances are available, as well as domestic and international commodity prices. The database of the model also describes commodity and trade policy information. This standard database is readily available with the model.

The most uncertain data are the annual variation in weather as well as variations in macro-economic developments. To account for these variations, crop yields and macro-economic parameters are partially modelled stochastically. The scenario results represent the influence of these variations on the agricultural markets.

Model availability

AGLINK-COSIMO is operational and AGLINK has started in 1992. The model is used at the OECD secretariat and the FAO in order to produce the annual Agricultural Outlook. Moreover, the model is used in national agencies.

The country modules of OECD countries in AGLINK are calibrated using baseline projections from the participating countries. This calibration process is a participatory process in which the baseline projections and the model outcome are adapted iteratively. The regions modelled in COSIMO are not calibrated in such a process.

3.2.5 Other factors

Model and data improvement

The model is used annually and as such undergoes current improvement. By calibrating the outcomes with the estimates of member countries, the dataset is continuously improved. In order to include bio-energy trade, detailed information about the demand functions for bio-energy crops would be needed. It may also be desirable to model the bio-energy sector separately. Finally, herbaceous bio-energy crops, residues and forestry are currently not included in AGLINK-COSIME. These commodity supplies are necessary to model bio-energy trade as they compete for land with traditional food products.

Other factors

Currently, the model and detailed description is only available to those working with AGLINK-COSIMO.

3.2.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

The AGLINK-COSIMO model is strong on criteria C1 and C2, but has a short time horizon (C3). It is not primarily suited to analyse bioenergy trade as it does not include forestry and perennial energy crops, and thus weak on criterion C4. However, the model is a partial equilibrium model that takes into account competition for land between different crops and that is suited to model the influence of agricultural and trade policies. As such, it could be suited to determine regional supply, demand and prices of bio-energy under different policy regimes if extended for bio-energy crop demand and supplies.

3.3 EFI-GTM

3.3.1 Introduction

EFI-GTM (*European Forest Institute – Global Trade Model*) is a regional and multi-periodic partial equilibrium model of the global forest sector now up-dated and operated by the European Forest Institute in Joensuu, Finland (Kallio, Moiseyev and Solberg 2004). The model originates from the global trade model (GTM) of the forest sector products developed and described by Kallio, Dykstra and Binkley (1987), and has successively been improved over the years. The model is constructed to enable consistent analysis of issues in the forest sector where economic competitiveness, regional trade, production costs, and forest situation are important.

EFI-GTM is a forest sector model. By forest sector models we mean models which include both forestry (as a supplier of roundwood and forest fibre) and the forest industries (as consumer of the roundwood and chips). A vital element of the model is that transport costs are endogenously included between each of the regions and for all products.

The main outputs of the model are production quantities (including forest harvest), prices and trade for all products and regions included in the model for each period which the analysis covers. It has recently been used to analyse the economic impacts of accelerating growth in Europe (Solberg, Moiseyev and Kallio 2002), increased biodiversity protection in forestry (Kallio, Moiseyev and Solberg 2005), and of the impacts on the European forest sector of investments in tropical forest plantations (Moiseyev, Kallio and Solberg, in prep).

3.3.2 Model structure

Agent behaviour assumed in the model

The model consists of a group of competing economies that are willing to trade forest sector commodities whenever the trade increases economic welfare in the regions. In each economy, consumers are assumed to maximize their utility and producers are assumed to maximize their profits. For each region demand functions are defined for the final products (mechanical forest industry products, paper and paperboard), supply functions are defined for waste paper and timber, as well as a set of technologies are defined for producing intermediate (pulp, chips) and final products.

Following Samuelson (1952), this multi-regional multi-agent forest sector model is cast into a single mathematical non-linear programming problem with a clear economic interpretation. Each region maximizes its social welfare function, which is the sum of consumer and producer surpluses less the transportation costs resulting from trade with the other regions. The model maximizes this surplus restricted by resources, capacity and budget constraints, as well as by possible barriers of trade. The model solutions of this maximization thus simulates the market outcome, given the assumptions made.

Spatial aspects and time horizon

Trade is included endogenously in the model, so that (net) export and import take place whenever it is profitable - for each product and between each of the regions included in the model. The trade between specific regions can also be kept within certain limits in the model by applying constraints, if for certain reasons that should be an advantage (for example to reduce the model solving time).

The present model includes a global coverage of 61 regions. Each country in Europe (except the Be-Ne-Lux countries, which is aggregated in the model into one region) constitutes one region, resulting in 30 regions, and the rest of the world is divided in 31 regions: 10 Asian, 5 North American, 3 Russian, 6 Latin American, 2 Oceanian, and 4 African regions.

The model can in principle be run for as many years (periods) one wants. But because of uncertainty aspects (for example regarding technological development and products demand), the usual time horizon covered by the model analyses is 20-30 years.

Dynamic features

The dynamic changes from year to year are modelled by recursive programming. That is, the long run spatial market equilibrium problem is broken up into a sequence of short run (yearly) market equilibrium solutions found by static optimization. After each period, the data on market demand, timber supply and changes in production costs and available technologies, are updated. Thereafter, a new equilibrium is computed subject to the new demand and supply conditions, new technologies available, and new capacities. Hence, the model assumes that the decision makers in the economy have imperfect foresight.

Technological change is included in three ways in the model. First, the production capacity at the initial year is – for each product and each region in Europe – divided on three technological vintages: old, new and medium aged mills reflecting respectively high, low and medium production costs. Second, it is possible to state exogenously - for each product - technological improvement (as % per period) giving a corresponding decrease of production costs. Third, new investments (see below) enter with the most modern technology (which is specified exogenously).

For each product new capacities enter when the total production costs (fixed + variable costs+ a profit/risk margin exogenously determined) are lower than the market price per ton produced.

Main endogenous variables are:

- Prices and produced quantities (for each period and region) for the timber (wood fibre), forest products, and recycled papers
- Transport quantities from/to each region and total use per year of production inputs (labour, electricity, bioenergy, fossil fuel) for each region

Main exogenous variables are:

- Economic growth in each region (driving the demand for final forest products)
- Initial production technologies and production structure/capacity in each region for each industry
- Initial forest structure and roundwood supply elasticities in each region
- Production costs (labour, electricity, fossil fuel, chemicals, etc.)
- Foreign exchange rates
- Future land availability for forestry and fibre production
- Future forest growth changes due to climate change

In principle, any scenario could be possible to link to the model if the scenario can be specified consistently by using the exogenous variables described above.

3.3.3 Level of detail of the model

Forestry

At present the forestry submodel in each region consists of a standing stock module, a growth module which increases the standing stock a certain (exogenously defined) % per period, and a harvest module which endogenously determines the harvest volume per period. The growing stock in subsequent period therefore equals growing stock in previous period + net growth – harvested volume.

The fibre supply in each region is determined through price elasticities, and is divided on the various log assortments according to the forest industries' derived demand and the situation in the initial year. In addition, a growing stock elasticity shifts the roundwood supply according to changes in growing stock. For the moment the model includes 6 assortments: hardwood and softwood, each divided on pulpwood, sawlogs and chips.

Forest industries

The model today incorporates for each region 26 forest industry products and 4 waste paper grades. The demand for forest industry products is based on demand elasticities estimated from FAO data bases.

Bioenergy

Bioenergy is today only included through the use of bioenergy in the forest industries. However, as mentioned in section 5, some bioenergy (e.g. pellets production) will be included in the EFORWOOD project. In principle the model can incorporate easily all kinds of wood bioenergy, but the main problem is lack of data on production costs and capacities etc.

Other sectors

No other sectors than described above are included. One may say that the assumed economic growth is the main link to the other sectors.

3.3.4 Model and data availability

Data

Base year for the existing model is 1999. In the ongoing EFORWOOD project new data will be collected so the base year will be 2005.

It is difficult to obtain data for all regions and products. Part of the data are taken from public statistics, and the rest from own research and company reports.

The most uncertain data are probably the production costs.

Model availability

The model is operational at present as described in section 1. The program language is written in GAMS. The model has been broadly validated for the base year 1999 for some countries and show realistic solutions. In concrete projects, the model and data are made available by EFI.

3.3.5 Other factors

Model and data improvement

The model will be improved in the ongoing EU-financed research project EFORWOOD. To incorporate bioenergy appropriately, it is necessary to have production costs, production capacities, transport costs and demand for each bioenergy alternative and for each region.

Data improvements are underway – for example the updating to 2005 data in the EFORWOOD project.

3.3.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

Several forest sector global trade models exist, but the EFI-GTM model is the one with the most detailed scope on Europe. It can in principle incorporate all realistic bioenergy alternatives related to the wood fibre sector (like done in Norway by Bolkesjø, Trømborg and Solberg (2006) based on the same model structure). The agricultural and environment sectors and other energy sectors than bioenergy are not included. Land-use is not directly included, but is incorporated indirectly through available growing stock. Data availability on production costs represents the main uncertainty. Compared to the criteria C1-C5 the model's main weakness regarding bioenergy trade lays on C4 – i.e. that no sectors outside forestry and forest industries are included in the model.

3.4 GFPM and other global forest sector models

Besides EFI-GTM, several other forest sector models exist like GFPM (Global Forest Products Model) used by FAO, the PELPS model (developed at University of Wisconsin), and CINTRAFOR-GTM (developed at University of Washington).

All these models are based on the same principles as EFI-GTM, but differ from EFI-GTM in several ways, of which the following are most important for this study:

- Except for GFPM, Europe is only one region in the model.
- In GFPM, trade is not endogenous, but based on historical data, and no bioenergy products are included.

EFI-GTM is therefore, on all aspects relevant for this study, better than the other forest sector models, and, consequently, we do not discuss them further in the report.

3.5 EU-FASOM

3.5.1 Introduction

The FASOM (Forest and Agriculture Sector Optimization Model) approach originates from the model group of McCarl, TexasA&M University, USA, starting with the ASM (Agriculture Sector Model), which was developed into the ASMGHG model incorporating GHG emission from agriculture. This model was then developed for the U.S. Environmental Protection Agency (EPA) to include forestry, resulting in the the FASOM model, which had as main purpose to evaluate the welfare and market impacts of alternative policies for carbon sequestration by forestry and agricultural land use in a long-term prospective. In 2002-2003 this model was adapted to EU conditions in the INSEA project, resulting in the model EU-FASOM, which now exist in a prototype version (cf. chapter 4).

The main purpose of ASMGHG, FASOM and EUFASOM is to make possible consistent analysis of abatement cost curves for GHG emissions, and how changing policies, technologies and market conditions influence these costs. In the following, the FASOM model
approach is described.

EU-FASOM is a regional, multi-periodic, intertemporal partial equilibrium model depicting land transfers and other resource allocations between and within agricultural and forest sectors. Land is transferred in the model between sectors/type of land-use according to its marginal profitability in all alternative forest and agricultural uses included in the model, over the time horizon of the model. Harvesting decisions (both in forestry and agriculture) are made endogenous.

The main outputs of the model are production quantities (including agriculture and forest harvests and land-use transfers), equilibrium prices and trade for all products and regions included in the model for each period which the analysis covers. The description of EUFASOM in this report is based on Schneider and Schwab (unpubl.). No applications of the model are published at present.

3.5.2 Model structure

Agent behaviour assumed in the model

The agent behaviour is similar to the one described for the EFI-GTM model – i.e. the model consists of a group of competing economic agents that are willing to trade agricultural and forest sector commodities whenever the trade increases economic welfare in the regions, and no agent has power to influence prices – i.e. perfect competition is assumed. In each economy, consumers are assumed to maximize their utility and producers are assumed to maximize their profits. Each region maximizes its social welfare function, which is the discounted sum of consumer and producer surpluses less the transportation costs resulting from trade with the other regions, discounted and summed for each period which the analysis covers. The model maximizes this surplus restricted by resources, capacity and budget constraints, market clearance for each period, as well as by possible barriers of trade. The model solutions of this maximization thus simulate the market outcome, given the assumptions made.

The dynamic changes from year to year are modelled by dynamic optimization (using linear optimization approximation techniques). Unlike EFI-GTM and PELPS, FASOM optimizes over the whole time period covered by the analysis – the objective function is maximised discounted surplus. As such, the model implicitly assumes perfect foresight.

Spatial aspects and time horizon

Trade is included endogenously in the model, so that (net) export/import take place whenever it is profitable – in principle for each product and between each of the regions included in the model (in practice in the model a selection of possible trade regions based on which commodities are assumed to be important is made).

The American FASOM model at present includes 63 political regions, and the EU-FASOM 40 political regions. The EU-FASOM model includes EU agriculture and forestry for Europe. In principle, the regional breakdown is limited only to data availability and operation time for

getting model solutions (which is also linked to the number of time periods included). Within political regions, different land qualities relating to erodibility classes (American FASOM) and soil texture, altitude, slope (EU-FASOM) are portrayed in terms of their area share.

Today, both the American FASOM and EU-FASOM are solved for 20 periods each of length 5 years, thus covering an analysis period of 100 years.

Dynamic features
Main endogenous variables are:

- Prices and harvested quantities (for each period and region) for the agricultural products, for timber (wood fibre), for forest products, and for recycled papers
- Type of land utilization (crop choice, tillage, irrigation, fertilization, soil conservation on agricultural lands; forest type, thinning regime, rotation length on forest land),land transfer between agriculture and forestry), investments in agriculture and forestry primary production, new forest industry production capacities.
- Transport quantities from/to each region and total use per 5-year period of production inputs (labour, electricity, bioenergy, fossil fuel) for each region
- GHG emissions

Main exogenous variables are:

- Economic growth in each region (driving the demand for final forest products)
- Initial land use, production technologies and production structure/capacity for the land-use and forest industries in each region.
- Initial forest structure (land area, growing stock)
- Production costs (labour, electricity, fossil fuel, chemicals, etc.)
- Foreign exchange rates
- Future forest growth changes due to climate change

The initial situation in the base year is first defined, together with the parameter specification of the exogenous variables. Then all endogenous and exogenous factors (cf. above) contribute together to the changes over time estimated by the model.

Technical change is incorporated by first, specifying the production capacity and production input factors (as Leontief production functions) at the initial year – for each product and each region. Second, it is possible to state exogenously - for each product - technological improvement (as % per period) giving a corresponding decrease of production costs. Third, new investments enter with the most modern technology.

New production capacities enter the model for each products if it increases the objective function – i.e. the sum of discounted consumers' and producers' surplus.

In principle, any scenario would be possible to link to the model if the scenario can be specified consistently by using the exogenous variables described above.

3.5.3 Level of detail of the model

Forestry
In EU-FASOM each region has a forestry sub-model which generates harvest schedules alternatives based on the forestry sub-module OSKAR from which the optimization algorithm

chooses (for each period) the optimal harvest. In principle, the forestry growth and fibre supply alternatives could be rather detailed specified if reliable data exist.The forestry model OSKAR, is described in Franklin et al. (2007).

Forest industries
The EU-FASOM model incorporates today 28 forest industry products and one waste paper grade (the data is provided for by the EFI-GTM model in the INSEA project).

Bioenergy
Bioenergy is today included in the agriculture (various conventional agricultural crops used for production of bioethanol etc), but not yet in the forest sector. In principle the model should be able to incorporate all kinds of wood bioenergy, but the main problem is lack of data on production costs, capacities etc.

Other sectors
Agriculture is included very detailed in the model. No other sectors than the forest and agriculture sectors are included, and (as with PELPS and EFI-GTM) one may say that the assumed economic growth is the main link to the other sectors.

A very important feature of FASOM and EUFASOM is their possibility to track net GHG emissions from all type of land uses and productions/consumptions related to the products included in the models.

3.5.4 Model and data availability

Data
Generally, the model demands a huge set of data input, in particular regarding agriculture, but also for the forest sector. The EU-FASOM is based on data from 1999. Part of the data are taken from public statistics, and the rest from research and consulting reports etc.

The most uncertain input data are probably the production costs and the GHG emission information per product.

Model availability
FASOMGHG is in operation in US. The EU-FASOM has been developed in the EU- financed research project INSEA (Integrated Sink Assessment) and a prototype is in operation at IIASA and University of Hamburg. One may say that the EU-FASOM is not fully operational yet, but is in the establishing and testing stage. The model program language is GAMS. Validation of the models seems difficult, and has yet to be done.

3.5.5 Other factors

EU-FASOM is under further development in the EU-financed research project ENFA (cf. below). To incorporate biomass trade better it is (like for EFI-GTM and PELPS) necessary to have improved data for each region on biomass availability and on production costs, production capacities, transport costs and demand for each bioenergy alternative.

3.5.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

The FASOM models (FASOM, FASOMGHG, EU-FASOM) have some features which, at least in some type of analyses, could be advantageous compared to the main existing forest sector models like PELPS and EFI-GTM and to the pure agricultural models like CAPRI and AGLINK/COSIMO: First, the FASOM models incorporate agriculture and forestry so that the competition for land between agriculture and forestry is endogenously modelled. Regarding modelling biomass trade, this might prove important in many countries. Second, the models keep detailed track of the GHG emissions from the various land-use and production/consumption activities included in the model. This might also prove advantageous regarding modelling biomass trade, as in the future it is rather likely that the markets (and corresponding market prices) for GHG emission certificates will increase and influence both land-use prices and the trade of biomass. In addition, the FASOM modelling system is designed to work on the forest and/or agricultural sector either independently or simultaneously. This allows one to study sectoral issues either independently or across the two sectors, and to check how important it is to include endogenously the possibility of land-use changes from agriculture to forestry.

These advantages come with some weaknesses relative to the existing forest sector and agricultural models, like:

- The objective function (optimizing over the whole time horizon) assumes implicitly perfect foresight, including how to weight (in each region) future benefits and costs in relation to present costs/benefits (the choice of discount rates).
- The simultaneous conversion of land from agriculture to forestry and keeping maximum sustainable forest yield might prove difficult to model in a realistic way.
- The FASOM models are very demanding regarding data input. For agriculture it is based on very detailed FADN statistics.
- The FASOM approach is working on 5-years time steps. This means that yearly agricultural production decisions have to be modelled in steps of 5 years. This is acceptable for forest sector decision, but may give misleading results related to modelling impacts of agriculture policy reforms.
- The EU-FASOM is not fully operational yet.
- The EU-FASOM is still not tested much in practice and programming bugs may exist (the large EU-FASOM version contains 6 millions variables and more than 600 000 equations).
- The different FASOM models only include some world regions, i.e. no global coverage

3.6 ENFA

The ENFA ***(European Non-food Agriculture)*** model is a dynamic agricultural and forest sector model for the integrated economic and environmental assessment of non-food alternatives in European agriculture and forestry, under development in the EU financed research project ENFA. Its main objective is to analyse market and environmental impact of non-food biomass use under changing policies, technologies and market conditions. The model is a market equilibrium model based on welfare optimisation. The ENFA model is developed by Hamburg University in the context of the EU-financed research project ENFA.).

Main outputs of the model are the competitive economic potentials of non-food options in the forestry and agricultural sector of these potentials, i.e. production quantities (including

agriculture and forest harvests and land-use transfers), equilibrium prices and trade for all products and regions included in the model for each period which the analysis covers. The model analyses environmental impacts (GHG, biodiversity, water quality and soil erosion), farm welfare, labour demand and land values.

As the ENFA model is an extension of the EU-FASOM described in the preceding chapter (the only difference seems to be the explicit incorporation of bioenergy chains and biodiversity implications), we refer to that description.

3.7 BIOTRANS

3.7.1 Introduction

The model BIOTRANS has been developed by ECN (Energy research Centre of the Netherlands) to optimise biofuel supply chain allocation, i.e. "find the optimal (least cost) configuration of resources and trade, for meeting specified biofuel demand in the transport sector in a group of countries, given and constrained by a number of assumptions on economic and technological parameters in a specific target year" (van Tilburg et al. 2005).

The main outputs of the model are allocations of biofuel supply chains with regard to production, processing, transport and distribution of biofuels including trade. The allocations are described by composition of the biofuel mixes in each year, costs for each biofuel, import and export between countries for each product and CO_2 emission data. Energy flows are an essential part of the results.

The model has been used in the EU project VIEWLS, in order to analyse biofuel implementation scenarios for Europe (Wakker et al. 2005), and currently being used in the Refuel project (Refuel: Planning the road ahead for biofuels, http://www.refuel.eu). Biofuel chains have been determined for each country of the modelling region and resulting net emissions of CO_2 have been reported.

3.7.2 Model structure

Agent behaviour assumed in the model

The model minimises costs of biofuels in the complete transport fuel system, i.e. including biomass production, processing, transports, distribution and end-use. Unit costs of biofuel production are the input for least-cost optimisation.

BIOTRANS is a generalised multi-commodity network flow model with biomass production, processing, export, distribution etc. constituting nodes (or 'vertices'). The nodes are connected by edges that allow for flows in the network. These flows are energy flows that are subject to constraints. These constraints are either 'node balancing' (e.g. efficiency of a conversion technology) or capacity constraints (e.g. limited supply of a certain biomass stream).

Spatial aspects and time horizon

BIOTRANS includes 31 countries: the countries of the EU-27, Norway, Switzerland, Belarus and Ukraine. The model period ranges from 2000 to 2030, and in the recent applications for Refuel, all scenarios focus on the period up to 2030.

Trade of biomass inputs, intermediate products and end-use biofuels between the countries included in the model takes place whenever it reduces the costs of the transportation fuel energy system, and the trade is bilateral (i.e. each county can trade with each other). Transport and handling costs are accounted for. In a scenario analyses, assumption on the limitation of trade flows can be made. Also, scenarios with large imported biomass streams can be analysed, i.e. by increasing the biomass availability.

Dynamic features
Demand targets for biofuels drive the production of biofuels. These targets are specified either at a country specific or an EU level and vary over time. The model optimises the costs for one period at a time (e.g. 2005 or 2010) without direct linking the different periods. Indirectly, the periodic solutions in the model are linked by other time-dependent exogenous data which influence the optimal allocation of biofuel supply chains. These are data on crop production potentials, costs of processes, efficiency of conversion and exogenous biofuel demands.

In the most recent version of BIOTRANS, technological learning has been implemented by using experience curves. For first generation bio-ethanol and biodiesel production, progress ratios from literature have been used For second generation biofuels, a hybrid approach of scale-dependent cost reductions and scale-independent experience curves are used to model cost reductions with increasing capacities and cumulative production. Investment costs are included in the unit costs of biofuel production, which are the target function for cost minimisation.

The BIOTRANS model is largely driven by exogenous data, i.e. the demand for biofuels, technology related data and costs and supply potential of biomass. These data are specified per biofuel supply chain, per region and per time. The allocation of energy flows to the transportation fuel supply chains including trade is modelled endogenously.

In the VIEWLS and Refuel projects, EU biofuel policy targets are analysed. Other scenarios are possible using BIOTRANS including variations of technology data, biomass availability, maximum GHG emission reduction, maximum the biofuel output / minimizing the land requirements. Also the effects of imports of biofuels can be modelled, though this still is done assuming exogenously the available amount and prices.

3.7.3 Level of detail of the model

Forestry and Forest industries
Forestry residues and residues from forest industries are part of the available biomass resources, which are modelled exogenously. Amount of wood production are taken from other studies, e.g. from Nabuurs et al., 2001. The following streams are included: forestry residues (wood residues and thinning wood), logging chips, whole-tree chips, wood processing residues (wood chips, sawdust, residue wood) and demolition wood.

Bioenergy
BIOTRANS only analyses the use of biomass for transportation fuels. The fuel supply chains include raw material production (crops and residues), processing, transport and distribution. The model contains the production and use of biofuels for transportation in a quite detailed manner, i.e. covering 18 crop/non-crop raw materials and 24 conversions steps (including by-products) leading to 11 biofuels and distribution technologies. The cost-supply data for the raw feedstocks are derived from the REFUEL project, it comprises; dedicated bio-energy

crops, agricultural residues, forestry residues and wood processing residues. The cost-supply data for dedicated bio-energy crops are available on NUTS2 (about 260 European administrative regions) level. This level of detail allows regional niches to develop, providing a nuanced representation. All other raw feedstock data are available on NUTS1 (corresponding to national level).

Other sectors
No other sectors are included in the model. The agricultural sector is indirectly included by taking data on biomass supplies from a scenario analysis in VIEWLS.

3.7.4 Model and data availability

Data
Starting year of the model is the year 2000 and the model already contains many data on the biofuel supply chains that can be adapted with other assumptions on technologies.

Model availability
The model is operational and has been used at ECN for the VIEWLS project (Wakker et al. 2005). It is built in the AIMMS modelling environment that is an environment for network flow optimisation. The model has not been validated as it optimises a policy-driven biofuel demand, but does not remodel historical situations.

3.7.5 Other factors

Model and data improvement
Within the refuel project both model and data improvements are being carried out. In order to analyse bioenergy trade in general, other bioenergy uses such as electricity and heat production would need to be included and targets for different types of bioenergy would need to be set. As the model is largely data-driven, an expansion of the model including more countries and biofuel chains could be easily realised. By that, an analysis of biofuel trade could be analysed for a larger region in the world.

3.7.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

The BIOTRANS model is weak on criteria C1, C2 and C4. A positive feature with the model is the technological detail of the included biofuel supply chains. Also it can model the situation for different total biofuel demands in various EU countries. The model determines policy-driven supply of biofuels including trade, but does not solve for market equilibrium. Other disadvantages are the lack of coverage of other world regions and not including the use of biomass for other purposes than biofuels. Improvements on these issues would require model enlargement and more data collection.

3.8 PEEP

3.8.1 Introduction

The PEEP ***(Perspectives on European Energy Pathways model***) model was developed from the Chalmers Viewls model to analyse the European energy and transport system. The main purpose of PEEP is to analyse the European bio-energy use from a cost-effectiveness

perspective and as such give qualitative insights into the development of the EU energy system. (Hansson and Berndes, unpublished)

Main output of the model are the development of different bioenergy options e.g., the share of biomass used in different energy sectors, i.e. heat, electricity and transport fuels, over time. The results are provided per decade and country. The model will be used to analyse the distribution of bioenergy use and its cost-effectiveness under various policy assumptions such as CO_2 targets and biofuel stimulating policies.

3.8.2 Model structure

Agent behaviour assumed in the model

A given energy demand is met using a mixture of primary energy sources and energy conversion technologies, while minimising the costs of the total energy system.

Total energy costs are calculated as net present value costs over the modelling period and costs are minimised using a linear programming model. Underlying assumptions are an ideal market with perfect information.

Spatial aspects and time horizon

From 2010 trade is included endogenously in the model, i.e. biomass and biofuels are traded if this minimises the total energy system cost. For the trade actions transport costs are accounted for. In the model, bio-energy (i.e. biomass and biofuels excluding electricity and heat) can be traded among the modelled European countries, but global bioenergy trade is not included.

The model includes the EU25 excluding Malta and Cyprus, but including Romania and models countries separately.

The time period that can be analysed in PEEP is 2000 – 2050, while the current application analyses the period 2000-2030. The output is provided per decade.

Dynamic features

The model is driven by energy demands and policy targets in combination with changing costs of fossil fuel determine technology choices and increasing share of biomass in the energy system. Fossil fuel costs and energy demands are set exogenously. Also costs and potentials of biomass supply change over time and are set exogenously.

Supply potentials of renewable energy production are implementation potentials, i.e. they are assumed lower than technical potentials but represent the amount that is ‘possible to reach’ within the given time period. Energy conversion technologies are assumed to operate with future performance (costs and efficiency). Also biomass yields increase due to learning, but also for biomass supplies additional restriction on the growth of biomass production are set. These restrictions cover the assumption that adoption rates by farmers will be a limiting factor.

Capital investments in the energy system take place if they reduce the overall energy system costs, but technological change is limited by using constraints on maximum growth potentials and maximum expansion rates of capital stock per technology (energy conversion). The basic

assumption behind this maximum expansion is the fact that a complete system turnover would take 50 years.
Main exogenous variables are:

- Biomass supplies
- Fossil fuel supplies
- Fuel costs
- Performance of energy conversion technologies
- Energy demands
- Policy targets (CO_2, biofuels)
- Initial energy system in the starting year

Main endogenous variables are:

- Share of energy conversion technologies in the energy system
- Trade of biomass and biofuels

Several policy instruments to promote biofuels can be included, e.g. using carbon dioxide targets and sectoral constraints for the introduction of biofuels.

3.8.3 Level of detail of the model

Forestry and forest industries

Biomass supplies including starch, oil and sugar crops as well as lignocellulosic energy crops and residues from forestry and agriculture, are set exogenously based on biomass potential analysis in the VIEWLS and REFUELS project. In the PEEP model, however, forestry and forestry industries are not explicitly included.

Bioenergy

The energy sector is divided into three end-use sectors, i.e. electricity, transportation, and heat and other fuel use. Exogenous biomass supplies consist of lignocellulose, starch crops, oil crops and sugar crops. Technological options that are considered are heat plants, power plants, CHP plants, transport fuel production, combined heat and transport fuel production and co-firing of biomass.

Other sectors

The main part of the model is the energy sector modelling the use of energy conversion technologies from an exogenous supply of primary energy carriers and a demand of heat, electricity and transport fuels.

3.8.4 Model and data availability

Data

The model starts in the year 2000 using data on the existing European energy system. Data on energy conversion technologies are given in the PEEP database that is available from the authors. Assumption on primary energy demands and supply are based on scenario studies (e.g. VIEWLS, see Wakker et al., 2005) but other scenario sets could also be used.

Most uncertain are the data on energy demands, supply and related cost as they depend on scenario analysis and many underlying assumptions, such as the agricultural system or

economic developments. Also the performance data of energy conversion technologies that are not yet commercialised are to be considered highly uncertain.

Model availability
The model is currently operational and is used in the European REFUEL project (Refuel: Planning the road ahead for biofuels, http://www.refuel.eu.). Datasets for the PEEP model will be adapted according to the results of this project.

The model is a linear programming model using GAMS. It has not been validated but uses the initial European energy system as a starting point.

3.8.5 Other factors

Model and data improvement
Datasets for the PEEP model will be adapted according to the results of the REFUEL project (see 4.2).

The model currently includes bio-energy trade in Europe. In order to include global bioenergy trade, data sets with global biomass supplies (amounts and productions costs) as well as transportation costs would have to be included.

3.8.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

The PEEP model is weak on all criteria except C5. The model analyses bioenergy uses from a demand-driven point of view. Its main advantage is that it uses a more detailed database on energy conversion technologies than general equilibrium models and as such the results are more technology and country specific. However, trade is not modelled from an actor perspective, i.e. maximising consumer and producer surplus, but serves the minimisation of overall energy system costs. As a consequence, actual trade flows are not modelled. Global trade would have to be included in order to use the model to investigate the development for bio-energy uses and trade for Europe.

3.9 TIMER/IMAGE

3.9.1 Introduction

TIMER (Targets-Image Energy Regional Model) is the energy submodel in IMAGE 2.2 (Integrated Model to Assess the Global Environment). IMAGE is an integrated assessment model that has been developed by the Netherlands Environmental Assessment Agency to analyse the long-term dynamics of global change. This is done by modelling the interactions in the society-biosphere-climate system. IMAGE is a model family that consists of many submodels that model economic and demographic developments, the energy-industry system, the terrestrial environment system and the atmospheric ocean system. TIMER is the energy submodel that deals with the assessment of energy supply and demand.

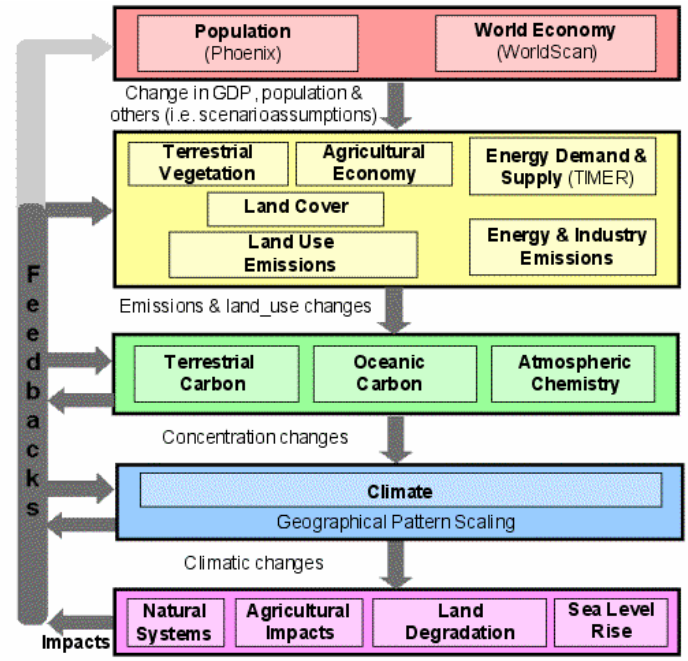

Figure 1: Model flow diagram: Models used for the IMAGE 2.2 scenarios (Source: MNP)

The main output of IMAGE 2.2 are long term dynamics of global change under various scenario assumptions that gives improved insights into the impacts of global change and a quantitative basis for analyzing the relative effectiveness of various policy options to address global change. TIMER analyses development over time of energy demand and supply in the different regions for the primary and secondary energy carriers as well as feedstocks.

The IMAGE model is and has been used to analyse scenarios in global environmental assessments such as the Special Report of the Intergovernmental Panel on Climate Change on emission scenarios, the Global Environment Outlook of UNEP, and the Second Environmental Outlook of the OECD. It has also been used for a scenario analysis of biomass potentials (Hoogwijk et al. 2005).

3.9.2 Model structure

Agent behaviour assumed in the model

IMAGE is an integrated assessment model driven by economic development and population in which bottom-up information (e.g. crop yields, energy efficiency) is combined with a maximisation of utility. Modelling of agent behaviour differs in the various sub models:

- In the global economic model that calculates GDP and other data, it is assumed that consumers maximise their lifetime utility, while firms maximise their profits under perfect competition. The economic model is a global applied general equilibrium (AGE) model, and is only loosely coupled to the rest of the IMAGE framework (only income and economic structure outputs are picked up and translated as inputs in the other models).
- The demand for food is modelled by optimising regional utility which is expressed in land budgets. This utility function is described by 'preference levels' of food intake and weighing constants. Currently, this task is often replaced by cooperating with specific food models such as LEI/GTAP and IMPACT (IFPRI).
- The demand for wood products is modelled as a direct function of price, population and income.
- In TIMER, the energy demands for fuels and electricity in five sectors are determined per fuel (solid fuels, heavy liquid fuels, light liquid fuels, gaseous fuels, traditional biomass,

modern biomass, electricity, and secondary heat) from prices and preferences. For the energy supply, TIMER does not optimise on the basis of perfect foresight, but simulates year-to-year investment decisions using recursive optimisation. These investment decisions are based on a combination of bottom-up engineering information, investment behaviour, fuel substitution and technology.

Spatial aspects and time horizon

In the economic sub model that determines GDP and value added, trade is included using short-term and long-term Armington trade elasticities that describe the preference for domestic over foreign commodities. For the energy supply, regional trade depends on the ratio between the production costs plus transport costs in the exporting region and the production costs in the importing region is assumed. Food trade is modelled using regional self-sufficiency ratios.

IMAGE describes 24 world regions (energy, trade, emissions), i.e. (1) Canada, (2) United States, (3) Central America, (4) South America, (5) Northern Africa, (6) Western Africa, (7) Eastern Africa, (8) Southern Africa, (9) OECD Europe, (10) Eastern Europe, (11) Former USSR, (12) Middle East, (13) South Asia, (14) East Asia, (15) South East Asia, (16) Oceania, (17) Japan, (18) Greenland, (19) Antarctica. The terrestrial system that includes land cover and agricultural production, is modelled using a 0.5 by 0.5 degree grid. The time horizon for model simulations is the period of 1970-2100.

Dynamic features

The different submodels of IMAGE are driven by dynamic factors that often result from other parts of IMAGE. Economic developments are driven by population changes. Agricultural and forestry production are mainly driven by the income per capita, the value added of the industry sector and the resulting demand of food, feed, biofuels and timber. Finally, in TIMER the energy supply and demand is steered by the regional population and regional macro-economic parameters (GDP, value added in industry and services, private consumption).

Technological change and learning are incorporated in various ways in IMAGE. Technology development using learning curves and progress ratios is assumed, e.g. for the exploration and exploitation dynamics of fossil fuels, the penetration of biomass fuels, production of biofuels, nuclear and renewable biomass generations. In TIMER, penetration of biomass fuels and energy intensity are time-dependent, too. The energy intensity developments result from autonomous energy efficiency improvement and as a response to prices. Furthermore, time dependent time dependent management factors that influence food and feed production efficiency are assumed.

For most submodels in IMAGE, economics are relatively unimportant. IMAGE provides a system-dynamic description of the world instead of an economic description. Except for a very small subcomponent related to food demand, utility does not play a role. Economics are mostly brought in by cooperation with others (e.g. LEI/IFPRI). The exception here is TIMER, which gives a price-driven description of he world energy system. TIMER, simulates year-to-year investment decisions. These decisions are based on production costs in combination with premium factors influencing the resulting costs. Premium factors include non-costs based considerations such as e.g. preferences, environmental policies and strategic considerations A certain construction time is assumed before production from new investments takes place.

IMAGE uses the AGE model WorldScan to investigate the whole world economy. This is a global model based on the GTAP data base. Starting from population growth and influenced by exogenous parameters such as time-dependent Armington elasticity, productivity in developing countries, etc., World Scan generates regional GDP and value-added projections. These projections are used as exogenous variables for other parts of the model. However, it should be emphasized that WorldScan is only loosely coupled to the rest of the IMAGE framework. The agricultural and forestry sector is modelled starting from food, feed, timber and biomass demands that are derived from macro-economic parameters. Main exogenous factors in this sector are land use intensities, preference levels of food consumption, agricultural management factors and feed efficiencies. The energy demand and supply of the whole economy is modelled in TIMER, starting from regional population and regional macro-economic activity. Other exogenous parameters in the energy sector are e.g. autonomous energy intensity developments, resource availability and fuel preferences.

IMAGE has been constructed in order to analyse various scenarios to understand the interactions between the socio-economic systems and the biosphere and to analyse the effect of various policy options to address global change. As such IMAGE has been used to analyse greenhouse gas emissions using the SRES scenarios of the IPCC's special assessment report on emissions scenarios.

3.9.3 Level of detail of the model

Forestry

The area covered with forests that is suitable for timber production (i.e. excluding regrowth forest and protected reserves) is harvested driven by the demand of timber, based on historical FAO data. Forest growth is modelled on a grid cell level (0.5 by 0.5 degree, in Europe this corresponds to about 20 by 20 km) with regional harvests in preference areas that are close to infrastructure, agricultural land, etc.

Forest industries

Forest harvest and production of wood products are based on historical FAO data, population growth, industrial value added and the availability of forests. Wood products are divided into the following GTAP categories:

- Pulp and paper products
- Sawnwood, veneer and board products
- Roundwood

Bioenergy

Bioenergy production is modelled as demand for modern and traditional biofuels. The demand for modern biofuels is modelled taking into account the use of biomass for solid fuels, for electricity generation and for liquid biofuels. This demand is influenced by prices and premium values that reflect non-price factors such as preferences, environmental policies, strategic considerations, etc. The share of biomass for electricity and of biomass-derived liquid fuels is calculated from a comparison of production costs and is subject to fossil fuel depletion dynamics. Finally, the market share of traditional biomass is determined by per capita income. IMAGE includes an analysis of land cover and biomass production. The biomass supply to meet bioenergy demands is modelled on a grid cell level including forestry, agricultural and other land areas.

Other sectors

The IMAGE model starts from the development in the global economy as modelled in the submodel WorldScan. Also, the agricultural production and the related demand for food and feed demand are included as well as the industrial sector. The complete energy supply is modelled quite detailed within TIMER (see also 2.1).

3.9.4 Model and data availability

Data

Data for the carbon cycle start from the 1765 period, while for the human system data is available from 1970. IMAGE and TIMER include an extended database for variables of which many are bottom-up information on the technological system modelled, e.g. the efficiency of crop production or electricity generation. If the model is to be extended with more detailed information on a specific subject, research on these bottom-up parameters will be needed.

Main uncertainties in data are in the interactions with the climate system, e.g. the changed productivity of crops and forests and regional patterns of climate change. Uncertainties in population and economic developments are analysed by means of scenario analysis.

Model availability

IMAGE 2.2 is operational and is used by the Netherland Environment Assessment Agency to contribute to various environmental assessments, see Section 1. The model has been calibrated with historical data on the climate system from 1765-1995 and on the human economic system from 1960-1995. The latter is used to calibrate the energy-industry system and the terrestrial environment system. TIMER, which represents a large part of the energy-industry system, is calibrated to reproduce the world energy demands from 1971-1995

3.9.5 Other factors

Model and data improvement

Currently, many improvements of the model as well as the databases are just finalized or underway, among others:

- Inclusion of agro-economic modelling from GTAP to improve demand, supply and trade scenarios for agricultural products (just finalized)
- Improved modelling of animal husbandry including extensive grazing systems and intensive mixed/landless systems (just finalized).
- Improved crop modelling at grid cell level (of 0.5° x 0.5°) linking crop growth to climate, soil, water nutrients and management parameters.
- Inclusion of the WaterGAP model to include water stress (just finalized)
- Linking a climate model to capture implications of climate variation, e.g. on agricultural production.
- Integration of GLOBIO biodiversity model into the IMAGE framework (just finalized)

3.9.6 Overall evaluation of strong and weak points related to analysing international trade of bio-energy

IMAGE and especially TIMER are well suited to analyse the energy demand for different types of bioenergy under specific scenario assumptions. Biomass production is modelled on a grid-cell level and data improvement is underway. Potential for maize and sugar production

are included, although other (potential) energy crops are not differentiated (for example short rotation forestry). Important environmental issues (carbon cycles, land degradation, climate change) are included. All in all, IMAGE is strong on criterion C4.

Competition for land is not explicitly modelled in IMAGE. The potential for biomass is only considered on low-productive land that is never used for food production, and on abandoned land (i.e. land that is not needed any more for food production). In this way the competition for land is avoided. That is a weak point on criterion C1. Another related weak C1 point is that the link to economic theory is limited.

The spatial aggregation in the economic parts of the model, with for example Europe modelled as two regions only, is a weak point in relation to criterion C2. Also, the aggregation of forest industry products and agriculture products is high.

The model as it is could be used to analyse regional demands and supplies of bio-energy including regional trade. A more detailed representation of different types of energy uses and crops and residues linked to these uses in TIMER and the agricultural economy model, as well as a more realistic representation of the forest sector, would then be preferable. For this purpose more bottom-up data on energy conversion and energy crops would be needed. Also modelling biomass and energy trade in a more detailed way could be a desirable feature which the current development of including agro-economic modelling from GTAP may provide.

3.10 GRACE (GTAP model)

3.10.1 Introduction

The **GRACE** (Global Response to Anthropogenic Changes in the Environment) model is a GTAP-based CGE (Computable General Equilibrium) or AGE (Applied General Equilibrium) model. As GTAP models are increasingly used in applied trade analyses, we give in Appendix 1 a brief overview of these model types.

GRACE is developed at CICERO, Norway, with the main aim to analyse environmental issues related to energy, environment and GHG emission (Aaheim and Rive 2005). It is one of the GTAP models which include forestry as separate sector, and is therefore of special interest in relation to trade of biomass.

The main outputs of the model are production quantities (including forest harvest), prices and trade for all products and regions included in the model for each period which the analysis covers. It has recently been used to analyse how increased forest growth (caused by climate change) effects forest harvests, production and trade pattern of roundwood and forest industry products (Aaheim, Rive and Hauge 2006).

3.10.2 Model structure

Agent behaviour assumed in the model

The model assumes perfect competition, and impacts are modelled as differences between two or more equilibrium solutions.

Spatial aspects and time horizon

Trade is included endogenously in the model, so that export/import take place whenever it is profitable - for each product and between each of the regions included in the model.

The present model includes 9 regions: China, India, Rest of Asia (incl. Oceania), EU-25, Norway, NAFTA, Central and South America, Russian Federation, and Rest of the world.

The model can in principle be run in 5-years step for as many years (periods) one wants, and in Aaheim et al. (2006) it is run for 100 years.

Dynamic features
The dynamic of GRACE is based on the GTAP-Dyn model. A fixed saving rate determines the total investments in each period, which accrue to a global bank. Investments are then allocated across regions such that the expected deviation from the "normal" rate of return is equalized across all regions. The expected rate of return in one period becomes the actual rate of return in the next period – i.e. the investment decision is "backward looking". Economic growth rates and technological change are set exogenously for each region. The equilibrium solutions in each period are modelled by recursive programming. That is, the long run spatial market equilibrium problem is broken up into a sequence of short run problems, one for each period. Hence, the model assumes that the decision makers in the economy have imperfect foresight. After each period, the data on market demand, supply and changes in production costs and technologies are updated. Thereafter, a new equilibrium is computed subject to the new demand and supply conditions, new technologies, and new capacities.

Technological change is set exogenously. For each products, new capacities enter whenever that gives higher surplus in the objective function.

Main endogenous variables are:

- Prices and produced quantities (for each period and region) for the timber (wood fibre), forest products, and recycled papers
- Transport quantities from/to each region and total use per year of production inputs (labour, electricity, bioenergy, fossil fuel) for each region

Main exogenous variables are:

- Economic growth in each region (driving the demand for final forest products)
- Initial production technologies and production structure/capacity in each region for ach industry
- Initial forest structure and roundwood supply elasticities in each region
- Foreign exchange rates
- Future land availability for forestry and fibre production
- Future forest growth changes due to climate change

In principle, any scenario should be possible to link to the model if the scenario can be specified consistently by using the exogenous variables described above.

3.10.3 Level of detail of the model

Forestry
At present the forestry submodel in each region consists of a standing stock module, a growth module which increases the standing stock a certain (exogenously defined) % per period, and

a harvest module which endogenously determines the harvest volume per period. The growing stock in subsequent period therefore equal growing stock in previous period + net growth – harvested volume. The forest model is not age-structured.

The fibre supply in each region is determined through fulfilling the demand from the forest industries, and has only one type of assortment.

Forest industries
The model today incorporates for each region 2 forest industry products: sawmilling (lumber) and the pulp and paper industries. These are the only ones available in the GTAP data base.

Bioenergy
Bioenergy is today not included in the model.

Other sectors
The model uses as input the data in the GTAP data base, which means that 9 sectors are included (among these 3 energy sectors, one agriculture). No bioenergy sector is included.

3.10.4 Model and data availability

Data
Base year for the existing model is 2000, the latest in the GTAP data base. Forestry is probably one of the most uncertain sectors in this data base, as it is hard to define properly and may have varying definitions in various countries.

Model availability
The model is operational at present at CICERO, Oslo. The program language used is GAMS. The model has not been validated except for the base year 2000, for which it also is calibrated.

3.10.5 Other factors

Model and data improvement
No plans exist for major improvement of the model. To incorporate bioenergy it is necessary to have production costs, production capacities, transport costs and demand in each region and for each bioenergy alternative.

3.10.6 Overall evaluation of strong and weak points related to analysing international trade of bioenergy

GRACE is strong on criterion C1., as the main advantage with CGE models are that they secure consistency between economic sectors.

The model has few regions and is weak on criterion C2.

Several GTAP models exist, but GRACE is probably the one which incorporates forestry and forest industries best. However, the link to agriculture and environment is weak, and before bioenergy is included, the model is of limited interest regarding analysis of biomass trade if used alone. The model therefore is weak on criterion C4. But used together with a more realistic forest sector model like the EFI-GTM, GRACE could be of considerable interest, as

it secures consistency with the rest of the economy. However, one should also have in mind the rather high uncertainty involved in the GTAP models like e.g. deciding exogenously the saving rate.

4 FINAL DISCUSSION AND CONCLUSIONS

Future bioenergy production will be based on a number of biomass resources, like residues from agriculture and forestry, secondary and tertiary wastes, dedicated energy crops and traditional forest fiber resources. As bioenergy in the past has been a relatively small share of the total energy production and the resource potential, model approaches which integrate bioenergy activities with other energy and non-energy sectors did not play a major role in the past. Recently, this picture has been changing, because of the need to reduce net GHG emissions, to increase the security of energy supply, and to find new production activities and employment in rural areas. Moreover, technological change has been a main driving force for the development of bioenergy. An example is the production of biofuels for which the present import and agricultural products supply meet the current demand, but where increased demand and expected second generation biofuel based on lignocellulose require different biomass supplies and imports. To determine the possibilities and costs of these supplies, a combined analysis of the forestry and agricultural sector is important.

In a European setting at least, value chains of traditional wood use (sawmilling, pulp and paper making) must be included in analyses of bioenergy trade, since woody biomass represents a major potential for increased bioenergy use. Models without a forest sector module have a major drawback with regards to incorporating the competition for forest based fibre. Also, the food production chain (agricultural crops for food and fodder) needs to be included, as energy crops that may be partly grown on agricultural land are the other major potential for increased bioenergy use.

When focussing more on a global level, certainly also the trade in liquid biofuels (e.g. ethanol, vegetable oils, biodiesel, and possibly pyrolysis oil), as well as other solid biomass, such as wood pellets and agricultural residues (e.g. palm kernel shells, rice husks, olive press cake etc.) would have to be taken into account.

Biomass trade has in the past (and at present to a certain degree) been rather immature, implying that assumptions of competitive markets are not necessarily fulfilled – especially with regard to full information and free market access. In the long run, with presumably increasing trade volumes, this issue is likely to reduce in importance.

The question of model suitability depends heavily on the type of problem to be analysed (e.g. it is a great difference between trade of sugar biomass or trade of softwood chips, or impacts of CAP policy reforms), time horizon of interest, market behaviour assumed, future development of bioenergy technologies assumed (bio-heat, bio-power or liquid biofuel for transport), etc. A consistent analysis of the likely mix of these commodities and the underlying trade of biomass resources and bioenergy carriers requires substantial modelling efforts, especially linking the supply and demand side on a local/regional basis.

Table 1 presents a summary comparison of the models included in this study, based on the five criteria described in chapter 2 and the findings reported in chapter 3.

Table 1: A comparison of the described models related to criteria C1-C5

Model	**C1** ***Link to economic theory***	**C2** ***Spatial aspects***	**C3** ***Dynamic factors***	**C4** ***Sectors included***	**C5** ***Model & data availability***	**Summary Strong points**	**Summary Weak points**
CAPRI	Competitive markets Imperfect foresight	For Europe: NUTS 1 & 2 For rest of the world: 24 regions	• Static optimisation. Yearly solutions • 10-20 years horizon • Technology change included in several ways	Agriculture Environment (GHG emissions)	Operational	C1 C2 (Europe) C5	C3 C2 (Rest of the World) C4
AGLINK COSIMO	Competitive markets Imperfect foresight	Country in Europe + 30 other world regions	• Recursive dynamic model • 10 years time horizon • Technology change included in crop yields	Agriculture	Operational	C1 C2 C5	C3 C4
EFI-GTM	Competitive markets Imperfect foresight	Country in Europe, 30 other world regions	• Static optimisation. Yearly solutions • Time horizon 20-30 years. • Technology change included in several ways	Forestry, forest industries and wood bioenergy	Operational	C1 C2 C3 C5	C4
EU-FASOM	Competitive markets Perfect foresight	In Europe: NUTS 1 on agric., and country on forestry/forest industries 6 other global regions(?)	• Dynamic optimisation. 5 years solutions • Time horizon 100 years + • Technology change included in several ways	Agriculture, forestry, and forest industries. Environment (GHG emission, bioenergy)	Not fully operational	C1 C2 (Europe) C3	C2 (rest of the World) C4 C5
ENFA	Like EU-FASOM	Like EU-FASOM	Like EU-FASOM	Like EU-FASOM, more biobased materials & more bioenergy chains included	Like EU-FASOM	Like EU-FASOM	Like EU-FASOM
BIO TRANS	Cost minimization for given demand of transport fuel energy	31 countries (EU 27, Switzerland, Norway, Belarus, and Ukraine), all on NUTS2 level	• Network flow optimization. • Time horizon 30 years • Technology learning included endogenously	Energy in the transport sector.	Operational	C3 C5	C1 C2 C4
PEEP	Cost efficiency for given demand of energy (share of biomass in energy sectors heat, electricity and transport fuels)	European countries (E25). Trade if cost efficient. No trade outside Europe.	• Linear program optimization. Solution per decade 2000-2050. • Technology change included as available technological options	Energy	Operational	C5	C1 C2 C3 C4

IMAGE/ TIMER	Framework of coupled models, econ. links from global GTAP model to agr. model & price-driven energy model TIMER. Otherwise weak links to economic theory.	24 World regions: (for Europe only 2 regions: OECD region and Eastern Europe), Agricultural output on grid cell level	• Simulation model • Technology change included in several ways	Environment sectors included 1 forestry, 2 forest industry sectors and agric. included	Operational	C3 C4 C5	C1 C2 (C4 – bioenergy)
GRACE	Competitive markets Imperfect foresight	Global- 9 regions	• Nonlinear programming. • Static optimization. • Solutions each 5 year. • Technology change set exogenously	Included are: 1 forestry sector and 2 forest industry sectors. Land for forestry included as environmental issue	Operational	C1 C3 C5	C2 C4

It is seen that none of the existing models are capable of performing good analyses of international trade of biomass and bioenergy products. Each of the models has strong and weak points here. TIMER, included in the IMAGE model group set up, represents probably the most complete (set of) models of those investigated in this study, but it is seen that also this family of models has severe weak points related to biomass trade – particularly regarding few European regions (only 2) and the inclusion of rather few forest industry and agricultural sectors.

ENFA and EU-FASOM seem to be promising models, but have several weak points like only partial inclusion of other sectors outside agriculture, forestry and forest industries, operating on 5-years time intervals, and not being fully operational yet. In addition, it might be argued that the objective function (maximising discounted utility) is questionable, particularly for simulating biomass trade.

The other models have as main drawback that they include only one or a maximum of two sectors, or have a too short time horizon.

It seems therefore that a <u>combination</u> of models is best for analysing the complex issue of biomass trade including various biomass resources, bioenergy carriers and regions. Here, several combinations exist – like combining EU-FASOM with a suitable CGE model, or combining TIMER/IMAGE with a more detailed agricultural and forest sector model.

It has not been possible for us to go into very detailed analysis here as it would require discussions with persons who know in details each of the models in questions, and also a specification of what types of biomass trade to be analysed (e.g. sugar crops globally or wood products regionally, in reaction to CAP policy reforms). However, based on our present understanding, the following combination of models seems most promising: CAPRI covering the agriculture sector rather detailed, EFI-GTM covering the forest sector rather detailed, a global CGE model having both agriculture, forestry, forest industries and energy, and a global land-use change model. As such a combination of CAPRI, EFI-GTM, GRACE and IMAGE seems promising (it might be that GRACE is unnecessary as IMAGE could cover the GTAP global economic modelling through WorldScan).

In addition, it would be a strong advantage if the technology and demand information provided by the detailed energy model PEEP and BIOTRANS could be made available for top-down sector models such as CAPRI and EFI-GTM. Instead of CAPRI one could use the AGLINK/COSIMO model. The main advantage of CAPRI here would be its availability and the detailed description of the European agriculture at NUTS 2 level, making it highly suitable for modelling impacts of e.g. CAP reforms. On the other hand, AGLINK/COSIMO has a better global coverage.

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APPENDIX I: BRIEF DESCRIPTION OF GTAP MODELS[1]

Computable general equilibrium **(CGE)** models - also referred to as **AGE** (applied general equilibrium) models - are a class of economic model that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. These models consist of (a) equations describing model variales and (b) a database (usually very detailed) consistent with the model equations.

The model equations tend to be neo-classical in spirit, often assuming cost-minimizing behaviour by producers, average-cost pricing, and household demands based on optimizing behaviour. However, most CGE models conform only loosely to the theoretical general equilibrium paradigm. For example, they may allow for:

1. non-market clearing, especially for labour (unemployment) or for commodities (inventories)
2. imperfect competition (e.g. monopoly pricing)
3. demands not influenced by price (e.g. government demands)
4. a range of taxes
5. externalities, such as pollution

A CGE model database consists of:

1. tables of transaction values, showing, for example, the value of coal used by the iron industry. Usually the database is presented as an input-output table or as a social accounting matrix. In either case, it covers the whole economy of a country (or even the whole world), and distinguished a number of sectors, commodities, privary factors and perhaps types of household.
2. elasticities: dimensionless parameters that capture behavioural response. For example, export demand elasticities specify by how much export volumes might fall if export prices went up.

CGE models are descended from the input-output models pioneered by Wassily Leontief, but assign a more important role to prices. Thus where Leontief assumed that, say, a fixed amount of labour was required to produce a ton of iron, a CGE model would normally allow wage levels to (negatively) affect labour demands.

CGE modelling of richer economies descends from Leif Johansen's 1960 MSG model of Norway, and the model developed by the Cambridge Growth Project in the UK. Both models were pragmatic in flavour, and were dynamic (traced variables through time). The Australian MONASH model is a modern representative of this class.

CGE models are useful whenever we wish to estimate the effect of changes in one part of the economy upon the rest. For example, a tax on flour might affect bread prices, the CPI, and hence perhaps wages and employment. They have been used widely to analyse trade policy. More recently, CGE has been a popular way to estimate the economic effects of measures to reduce greenhouse gas emissions.

[1] This description is basically taken from Wikipedia

CGE models always contain more variables than equations – so more variables must be set outside the model. These variables are termed exogenous; the remainder, determined by the model, are called endogenous. The choice of **which** variables are to be exogenous is called the model **closure**, and may give rise to controversy. For example, some modellers hold employment and the trade balance fixed; others allow these to vary. Variables defining technology, consumers' tastes, and government instruments (such as tax rates) are usually exogenous.

Today there are many CGE models of different countries. One of the most well-known CGE models is global: the GTAP model of world trade.

CGE models are also very common in development economics as they allow to run simulations for countries that have just changed their type of government and for which is no time series-data available. CGE is used to project policy changes or analyse future development if a historical analysis is not possible.