APPROACHES FOR MODELLING THE INTERNATIONAL TRADE OF BIOMASS FOR BIOENERGY (TO EVALUATE ITS IMPACTS ON BIOENERGY MARKETS)

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ABSTRACT: Since biomass is of utmost importance for the future energy supply there will be an increase in the global and regional trade of biomass. The understanding of how this development is best organised and managed is still relatively poor. As a result there is the need for models to improve the understanding of biomass and bioenergy markets and its linkage to other sectors of the economy and to analyse the impacts of biomass utilisation and trade.
Therefore we carried out a literature survey on three different types of modelling approaches (basic modelling approaches for analysing macroeconomic effects of international trade, computable general equilibrium models and geographic information system (GIS) approaches) and analysed their ability to deal with biomass trade.
All of these approaches have strong and weak points and consequently the suitable approach depends on the particular research question and objective of the analysis. Up to now no customized models are available for incorporating global import/export potentials and international trade. A combination of GIS technology, basic transport modelling approaches and conventional energy modelling methods could be a reasonable approach for the modelling of bioenergy systems.
Keywords: analysis, bioenergy, biomass, commodity market, modelling, trade

1 INTRODUCTION

After years of an unsustainable consumption of fossil fuels and the related change of the climate and for fuel diversification for the securing of energy supply, there is a strengthened focus on the sustainable use of biomass for energy all over the world. In many countries there are large potentials for agricultural and forest biomass. However, these potentials are not distributed equally and the production costs vary in a certain extent. At the moment the trade of biomass for bioenergy is still in an initial phase. As biomass is of utmost importance for the future energy supply there will be an increase in the global and regional trade of biomass for balancing regional and international distinctions of supply and demand.

The understanding of how this development is best organized and managed is still relatively poor. This can be illustrated by the way how very well established and commonly applied energy models deal with bioenergy trade. Either exogenous assumptions and scenarios regarding international biomass trade are assumed or simple bubble-approaches (see below) are discussed or applied (e.g. POLES, Green-X).

The modelling of bioenergy markets could contribute to a better understanding of the international linkage of bioenergy markets.

1.1 Objective, methodology and structure of the paper

The main objective of this work is to assess possible approaches for the modelling of international trade of biomass for bioenergy to gain better understanding of the underlying dynamics of such complex systems.

Therefore in the beginning the general system of biomass markets will be characterized and relevant attributes for the modelling of biomass trade (e.g. biomass potentials, cost-resource curves, demand, transport routes, freight rates…) will be identified.

In the literature there are described two broad classes of models for the modelling of the economy, the energy sector and the environment: **top-down** and **bottom-up** models.

In the top-down approach you start with a highly detailed description of the (macro) economy and the macro-economic relations and then derive from there the demand for energy inputs in terms of the demand for various sectors' outputs through highly aggregate production or cost functions [1].

The bottom-up models propose a detailed description of the considered economic or energy system and place the emphasis on the correct description of energy options and their cost structure. Consequently in bottom-up models the base elements of a system (e.g. different energy technologies) are first specified in great detail. These elements are then linked together to simulate the whole system. Therefore bottom-up models have a high level of disaggregation. Because of the detailed specification of the technologies, newly developed or future technologies can be incorporated into the analysis.

These two strategies have their pros and cons and by now, a number of existing models are hybrid, providing simultaneously some details on the structure of the economic and technological sectors.

As there are an immense number of different approaches and strategies for the modelling of economies, markets and trade, we will focus on three types of models:

- basic trade models
- market equilibrium models
- GIS models

<u>Basic trade models</u>

We use the term "basic trade models" for approaches that are relatively transparent, simple and powerful models. Some of them have played an essential role in particular in the historical process of developing such methods. These types of models usually are developed by using a top-down strategy. These kinds of models will be analysed in chapter three.

<u>Market equilibrium models</u>

A lot of energy models are market equilibrium models. In general they are based on the idea that the clearance of a market is taking place with a specific set of price and quantities. The objective of these models is to determine this set of price and quantities. There are two types of these models: **partial equilibrium models and general equilibrium models**.

Partial equilibrium models are models where the clearance on the market of some specific goods is obtained independently from prices and quantities demanded and supplied in other markets. In other words the determination of the price of a good is simplified by just looking at the price of one good and assuming that the prices of all other goods outside the boundaries of the investigated system remain constant.

In the real economy the expansion of activity in one sector may have effects on other sectors. Such effects are not systematically accounted for by partial equilibrium models. Therefore general equilibrium models are used to analyse how equilibrium is simultaneously determined in the whole economy. By linking the prices and production of all goods, including the price of money and interest, this type of models tries to give an understanding of the whole economy with several markets.

As we are interested in the overall implications involved with increases in the use of bioenergy and in the trade of bioenergy products the focus of this paper will be on general equilibrium models, especially on **computable general equilibrium (CGE-) models**. These types of models are described in chapter four.

GIS models

Given the large difference in the availability of renewable biomass resources across the world the spatial dimension will play a key role in determining the optimal solution of the future energy system. GIS with its upcoming advanced technology could be a great asset to the modelling of biomass and bioenergy trade. The goal of this paper is to outline the rational basis for the linkage between GIS and the modelling of bioenergy trade. We will carry out a literature review on existing GIS-models for commodity markets, logistics and transport in chapter six.

Based on these appropriate assessments for the modelling of biomass trade we will derive conclusions regarding the strengths and weaknesses of various modelling concepts.

1.2 Relevant literature

With regards to the modelling of bioenergy trade a report by IEA Bioenergy Task 40 [2] is of great relevance. In this report several trade models (economic models of the forest sector, the agricultural sector and the energy sector) are evaluated to assess their strong and weak points for analysing international trade of biomass and bioenergy products. One conclusion of this report was that none of the existing models were capable of performing good analysis of trade of biomass and bioenergy products.

To get an overview about international trade theory the books "International Economics" by the two economists Obstman and Krugman [3] and "Understanding International Trade Theory and Policy" by Wolfgang Eibner [4] are recommended. They present an integrated treatment of basic trade models along with in-depth analysis of empirical evidence. Moreover they cover the effects and causes of trade policy, including strategic trade policy and the income-distribution effects of trade.

There is loads of literature on general and partial equilibrium models. The small listing of models in the following lines is only to show some examples for the application of market equilibrium to concrete energy models.

The partial equilibrium model CAPRI as one example for the modelling of the agricultural sector is described in [5]. EFI-GTM (European Forest Institute – Global Trade Model) is a partial equilibrium model of the global forest sector. The structure of this model is described in [6]. The general equilibrium approach and its concrete application to energy models are discussed in [7] for the TIMES model and in [1] for the GTAP-E model. In [8] there is a general survey of market equilibrium models and of the gravity approach, which will be described in chapter three of this paper. A critical discussion of computable general equilibrium models can be found in [9].

To get a good overview about the basics of GIS we would recommend [10]. Geographic information systems can be used for a wide range of problems. The "Encyclopaedia of GIS" [11] is a collection of well-written articles on the expanding field of GIS technology. Today there are many attempts to apply GIS technology for processing and solving problems with regards to energy supply and demand and energy potential. In [12] there is a discussion of several energy related projects in Europe where GIS approaches are utilized. They state that data will become available together with tools that allow experts to do their own analysis and to communicate their results in ways which policy makers and public can readily understand.

Since large sources of biomass are not often found where they are needed, for the modelling of international trade of bioenergy products it is crucial to have a comprehensive understanding of logistics, especially of maritime shipping. Two books that give deep insight into the shipping business and shipping markets are [13] and [14]. With regards to the characteristics of maritime shipping of biomass and biofuels [15] would highly be recommended.

2 CHARACTERISATION OF BIOMASS MARKETS AND BIOENERGY TRADE

Given the various types of biomass resources and the plenty of options for the conversion and the energetic use of biomass, the bioenergy system is very complex. As a first step in the modelling of international bioenergy trade it is of great importance to take a look at the whole bioenergy system and further on to its linkage to the overall economy.

In a simplified way the bioenergy system can be characterised as follows: The system begins with the areas of land where the biomass grows. The supply chain (harvesting, transport, processing) links the biomass resources to the energy products and services at the end of the system.

Based on a wide variety of resources, there are numerous technologies to provide energy services with biomass. Biomass resources can be used for heat and power generation as well as for the production of biofuels for transport. The following figure (see Fig. 1) illustrates the diversity of bioenergy systems. Each utilization path is characterized by specific costs and energy and greenhouse gas (GHG) balances.

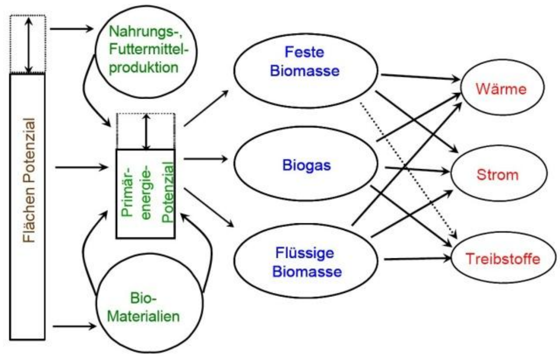

Figure 1: The bioenergy system: Symbolic illustration of the subject. Source: [16]

Biomass markets cannot be to observed separated from the environment because they are linked to the world economy at several stages.

First of all the **available area for biomass production is limited**. Therefore the production of bioenergy products has to compete to some extent with the production of food and fodder. In the recent past the increase in the production of biofuels together with rising prices for food has led to the "food vs. fuel" debate. Moreover the production of biomass for energy can also have negative ecological (e.g. land use change) and social impacts when sustainability criteria are not taken into account.

Transport capacities again are limited and used in other markets and sectors of the economy as well. Transport costs are linked to prices of fossil fuels and the development in the respective transport sectors. Freight rates of maritime shipping are a good example for these couplings. As the historical development of freight rates shows, the charter market is highly competitive. Freight rates can change dramatically over a short period of time. When there is a shortage of transport capacity freight rates rise, and when there is an oversupply of ships freight rates can plummet. From 2006 to 2008 the shipping shortage caused prices to rise considerably. For example, the Capesize rate rose from $4000 per day in 2004 to $20,000 per day in 2008. As a result in the period of peak prices the shipping of bioenergy products was not economical feasible in this period. During 2008 the current world financial crisis, which has lead to the common recessionary factors of falling demand and over-supply of inventories, as well as collapsing oil-prices, has caused a free-fall in shipping prices [15].

Finally bioenergy products have to compete against conventional fossil fuels or other renewable energy technologies and moreover in some cases there is demand for the same raw materials in other sectors of the economy. To give an example:

Pellets have traditionally been manufactured from sawmill and pulp mill residues that are a by-product of lumber and pulp manufacture, and could be acquired at virtually no cost. In the last 2-3 years increases in bioenergy development, and major reductions in lumber and pulp production in many regions, such as Canada, the US, and South Africa, have resulted in formerly free residue becoming a rare commodity commanding significant prices.

For the modelling of international biomass trade these linkages and a lot of other issues (tariffs, taxes, etc...) have to be considered.

3 INTERNATIONAL TRADE THEORY AND BASIC TRADE MODELS

International trade describes the exchange of raw materials, manufactured goods services or money across national borders. International trade theory is a subarea of macroeconomics that describes the practical economic contexts of trade across national borders.

Many people are sceptical about importing goods that a country could produce for itself. International trade theory describes areas such as incentives for the involvement of countries in international trade and the economic impacts of trade.

According to [4] the four main reasons for international trade relations are:

- non availability of certain goods and/or resources in the domestic market
    - climatical reasons
    - geological reasons
    - technical reasons
- inter-industrial trade - different conditions of production of certain goods in various countries and therefore different prices
    - absolute advantages
    - relative advantages – theory of comparative advantages
- intra-industrial trade - subjective product differentiation - Lancaster approach (see also [17])
- transportation cost

Several Economists have proposed different models to predict patterns of trade and to analyse the effects of trade policies. The most important theories are the neoclassical trade theories that assume that firms produce under conditions of perfect competition. Examples for neoclassical models are the Ricardian model, the specific factors model and the Heckscher-Ohlin model. Most neoclassical basic trade approaches are illustrated as two country models and they also usually assume only two commodities in international trade. Neoclassical trade theory is particularly suitable for pointing out the links between different markets.

Other trade theories like the new trade theory or the gravity model have been established to address the shortcomings of standard trade theory by dealing with some of the realities of trade in a more complex and sophisticated manner.

Each of these trade theories has both strengths and weaknesses in describing and analysing the effects of trade. In the following these trade theories will be described in brief.

3.1 Ricardian model

The Ricardian model is a general equilibrium model. This means it describes a complete circular flow of money in exchange for goods and services. It's a simple, yet very important model (in particular from a historic point of view) that describes the reason for the development of foreign trade relations. According to Ricardo **comparative advantages** (relative price differences), not absolute price differences, are the main reason for the foreign trade of goods. Thus a country will produce those goods where it has comparative advantages compared to another country. The Ricardian model shows that as a reason the overall available supply of goods will rise and the welfare will be improved.

The Ricardian model makes several assumptions. It is assumed that labour is the only primary input to production, the amount of labour in the economy is limited, the productivity of labour is constant, labour is perfectly mobile among sectors but not internationally, there are constant returns of scale and there is perfect competition.

A detailed description of the Ricardian model and a discussion of the effects that can be derived from this model can be found in [3]. In [18] a Ricardian model of international trade was developed that incorporates a role for geography (distances, transport costs, tariffs and quotas, delays etc.).

3.2 Specific factors model

The Ricardian model shows, that foreign trade can be advantageous for all parties. As labour is the only primary input to production in the Ricardian model and labour is perfectly mobile among sectors, all individuals can benefit from foreign trade. In reality foreign trade can influence the distribution of income so that it involves disadvantages for some individuals.

In the specific factors model according to [3], two other factors are defined as factors of production in addition to labour: capital and land. Industry products require the input of the factors labour and capital, food is produced by using the factors labour and land. In this model, labour mobility between industries and the production of food is possible while capital only can be used specifically in industry and land only can be used for the production of food. The specific factors name refers to the given fact that in the short-run, specific factors of production such as physical capital are not easily transferable between industries.

As a result of the specific factors model foreign (free) trade is of additional use for the specific sector where a country already has advantages, but does damage to the specific sector that already is handicapped.

For a country with relatively much capital this result means that a movement to free trade will cause a redistribution of income. The owners of capital in the export industry will benefit from free trade. Owners of land in the import-competing production of food will lose from free trade. Workers, who are freely mobile between industries may gain or may lose since the real wage in terms of exports rises while the real wage in terms of imports falls. If workers preferences vary, then those individuals who have a relatively high demand for the export good will suffer a welfare loss, while those individuals who have a relatively strong demand for imports will experience a welfare gain [19].

3.3 Heckscher-Ohlin model

The Heckscher-Ohlin model is based on the Ricardian model. It is a theory to explain why countries trade goods and services with each other. As in the Ricardian model, absolute and relative advantages are the causal factors for the origin of international trade. Heckscher and Ohlin trace the rise of foreign trade to differences in the endowment of various nations with the factors of production, in this case labour and capital. According to Heckscher and Ohlin those countries that are relatively well-endowed with capital will produce and export capital intensive goods and will import labour intensive goods. Vice versa countries that are relatively well-endowed with the production factor labour will export labour intensive goods and import capital intensive goods [4].

According to this theory, specialization in production and trade between countries generates a higher standard-of-living for the countries involved.

3.4 New Trade Theory

New trade theory has been established to address the shortcomings of standard trade theory by dealing with some of the realities of trade in a more complex and sophisticated manner by incorporating a fuller range of factors. However, they provide few unambiguous conclusions.

New trade models incorporate innovations within neoclassical economics: market imperfections, strategic behaviour, new industrial economics and new growth theory (e.g. learning by doing) and political economy arguments [3]. One kind that has gotten a lot of attention in the past is the theory of economies of scale. This theory assumes increasing returns to scale, which means that large producers are more efficient than smaller producers.

Many of the models based on market imperfections and strategic behaviour justify interventionist trade policy. Although much of the literature linking trade and new growth theory favours trade liberalisation (mainly on the grounds of knowledge spillovers), in the case of new trade theory the possibility that free trade may be detrimental to economic growth is taken into account. Overall, however, interventionist trade policies are rejected even by those at the forefront of these theories, mainly on the grounds of political economy arguments [20].

3.5 Gravity model of trade

Compared to the more theoretical models discussed above the Gravity model of trade presents a more empirical analysis of trade. Gravity models are suitable for the modelling of systems where certain behaviours that mimic gravitational interaction as described in Newton's law of gravity can be observed. Since international trade contains elements of mass and distance, gravity models are particularly suitable for the modelling of such systems. In the context of international trade flows, the gravity model states that the size of trade flows between two countries is determined by supply conditions at the origin, demand conditions at the destination and stimulating or restraining forces related to the trade flows. Other factors such as income level, diplomatic relationships between countries, and trade policies are also included in expanded versions of the model.

According to [21] the early empirical use of the gravity model was criticized because of its weak theoretical foundation. With the work of [22] it was recognized that the prediction of the gravity model could be derived from different structural models such as Ricardian models, Heckscher–Ohlin models and increasing returns to scale models of the New Trade Theory.

3.6 Advanced Heckscher-Ohlin approach

Basic trade models like the Ricardian model, the Heckscher-Ohlin model or the gravity model of trade are suited very well to analyse patterns such as the gains from trade or the effects of taxes and tariffs.

Another approach described in [23] incorporates the energy environment and the agricultural sector to the classic Heckscher-Ohlin model. This modelling approach has been developed by Hochman and Zilberman at the Energy Biosciences Institute of the UC Berkeley to address the issues of an increase in the importance of bioenergy (e.g. food versus fuel and environmental consequences). It is described in detail in [23].

To model the consequences of the introduction of biofuels to the energy market that is dominated by fossil fuels this approach incorporates household production, introduces energy as a factor in production and defines utility over an untraded convenience characteristic and an environmental commodity.

Therefore they assume a two-country model, a world comprised of Home and Foreign countries. The countries are endowed with three factors for production: labour, land and capital. These factors can be used to produce four (intermediate) goods: food (agricultural product), manufactured goods (capital products), fossil fuels and crops for biofuels. It is assumed that people derive utility from food, convenience (produced in the household function by manufactured goods and energy) and environment. The environment offers benefits in the form of recreational opportunities and biodiversity.

Food and manufactured goods are produced by using labour, land, capital and energy. Energy is produced by using two technologies. Fossil energy is produced by using the factors labour and capital (drill and pump oil) and bioenergy is produced by using the factors labour and land.

Both the production of biofuels and the consumption of fossil fuels result in externalities. Using land for the production of biofuels on the one hand reduces the utility that can be derived by the environment. On the other hand biofuels reduce carbon emissions compared to the consumption of fossil fuels. To internalise these externalities the countries may use carbon taxes and land taxes.

With this conceptual framework the impacts of globalisation, capital inflows and technical changes on the energy demand and the availability of land are analysed. By assuming that land is allocated to maximise firm profits and all markets are competitive the equilibrium prices and resource allocations and moreover the socially optimal equilibrium and the trade pattern are derived and in addition the effects of suboptimal policies are discussed.

In the following the main results and the conclusions of this work will be described in brief.

The results of this modelling approach suggest that globalization and capital flows result in new demand for energy and in rising energy prices. Therefore more land is needed for the production of biofuels. As a result the land allocated to food production decreases and consequently the prices of food increase.

Under certain conditions improvements in technology could lessen the competition between food and biofuels. Technical changes and improvements that concentrate exclusively on the production of conventional biofuel crops would improve the productivity of land. This model shows that as a reason of this the biofuel production and therefore the demand for land on biofuel would raise. Therefore it would be necessary to improve the overall agricultural biotechnology to reduce the competition between food and biofuels. By moving from conventional biofuels to second generation biofuels making use of cellulosic feedstocks the linkage and competition between food and biofuels could be reduced further.

Even though international trade of bioenergy is not the main objective of this approach, it is suited well for analysing macroeconomic issues concerning the increasing use of bioenergy. Maybe the most interesting result of this work is that carbon taxes or similar policies (e.g. gasoline taxes or subsidies for biofuels) as the only instrument for the internalisation of externalities will not lead to a social optimum. To achieve the **social optimum carbon taxes** would have to be **accompanied by land taxes** that internalise the social cost from loss of biodiversity and recreational areas.

4 CGE APPROACH FOR MODELLING OF TRADE

Computable general equilibrium (CGE) models are a class of economic models that allow endogenous interaction of all sectors in the economy. In general they are based on the idea that the **clearance of a market** is taking place with a specific set of price and quantities. The objective of these models is to determine this set of price and quantities. Thus they are generally based on a set of equations describing the model variables and on a (detailed) database regarding the characterisation of different economic sectors.

The set of equations represents the behaviour of the economic agents such as consumers, investors, government and the foreign market. They describe the input demand and output supply of the economy, in other words the equations characterise the economic link.

In the database the numerical data to specify the numerical relationships in the model is given. The database usually consists of the social accounting matrix and/or the input-output table. The social accounting matrix represents the income and expenditure accounts of various economic agents. The flow of goods and services between all the individual sectors of a national economy over a stated period of time is described in the input-output table.

In addition, estimates of a number of elasticity parameters and coefficients are needed in the database to capture behavioural response (e.g. elasticities of substitution between domestic and foreign goods, between primary factors, export demand elasticities and product-product transformation parameters).

By distinguishing a number of sectors, commodities and regions the whole economy of a country or even the world can be covered in a more disaggregated way. The level of disaggregation can vary depending on the issues being studied [24]. Therefore sometimes it’s not quite clear to classify whether a model is a pure top-down or a pure bottom-up model. According to [25] a number of existing models are hybrid, providing simultaneously some details on the structure of the economic and technological sectors.

Many CGE models rely on **neo-classical assumptions** like perfect competition, market clearing and production functions characterized by constant returns to scale. In such approaches the economic agents maximise their behaviour, subject to the relevant constraints, allowing for all markets to clear, and transactions are conducted at equilibrium prices. The quantity supplied must exactly match the quantity demanded for every factor of production and for all goods and services consumed [24].

These neo-classical assumptions of some CGE models (the classical general equilibrium paradigms like market clearing, perfect competition) have been matter of considerable debate. As a consequence of this today many CGE models allow for imperfect competition or non-market clearing. Nonetheless, CGE models are useful for estimating the effects of changes in one part of the economy upon the rest.

There are many CGE models that would be of interest for this study. Some examples for well known types of CGE models are: MERGE [26], GREEN [27], NEWAGE [28] and GEM-E3 [29].

In the following the **focus** will be **on a GTAP model**, because these models are used widely to analyse trade policy.

4.1 GTAP/GTAP-E model

The GTAP-E model [1] is a CGE model based on the GTAP (Global Trade Analysis Project) models and databases with a strong focus on energy. The standard GTAP model is a multi-region, multi-sector model, with perfect competition and constant returns to scale. Bilateral trade is handled via the Armington assumption [30] that states that final products traded internationally are differentiated on the basis of the location of production.

The GTAP model was initially documented in the GTAP Book [31] and recent changes in the model structure can be found in various papers on the GTAP homepage (www.gtap.agecon.purdue.edu).

The GTAP-E model incorporates energy substitution in production into the standard GTAP model by a simple top-down approach with allowing for capital and energy to be either substitutes or complements. According to [1] this measure was a crucial one in determining the direction of the adjustment of aggregate output following energy price changes. The degree of complementarity and substitutability between energy and capital is measured by the substitution elasticity between energy and capital. As discussed in [32] this is the key parameter that determines whether output produced goes up or down after an energy price increase.

In addition, GTAP-E incorporates carbon emissions from the combustion of fossil fuels and a newer version of GTAP-E [33] provides for a mechanism to trade these emissions internationally.

Most recently the GTAP model and data base have been extended to improve the treatment of biofuel by products and accurately represent global land use. In [34] **biofuel sectors are introduced** to the GTAP database the GTAP-E model has been extended to analyse the impact of the EU biofuel directive on agricultural markets.

The following discussion will refer to an adapted GTAP-E model that is described in [35]. In this approach the GTAP-E model is further modified to capture the implications of biofuels mandates for global agricultural markets and on land use change. Therefore ethanol and biodiesel are introduced to the production and consumption structures of the GTAP-E model. Ethanol is produced from feedstocks such as cereal grains (ethanol1), sugarcane and sugar beet (ethanol2) and biodiesel is produced mainly from vegetable oilseeds (rapeseed, soybeans) and oil fruits (oil palm). Biofuels are treated as a tradable sector and biofuels and petroleum sectors are treated as complementary inputs.

An increase in the substitution of fossil fuels by biofuels could result in a change in the use of land. Since there are great differences belonging to temperature, soil types, moisture, length of growing period and topography of different regions in the world, the GTAP-AEZ framework discussed in [36] and [37] has been adopted for this approach. As a result 18 agro-ecological zones (AEZs) are incorporated (as per U.N. Food and Agricultural Organisation) for analysing the impact of biofuels on land use change.

Land rents are disaggregated on the basis of prices and yields. It is assumed that land is mobile across uses within an AEZ, but immobile across the 18 AEZs and that land owners maximise total returns by optimal mix among crops.

The original version 6 of the GTAP database has 57 sectors and 87 regions. Based on the original version in this approach three additional biofuel sectors (2 ethanol, 1 biodiesel) are introduced. By using the aforementioned information on land rents, land endowment data is aggregated from 87 regions to 18 AEZs.

Summing up, this approach is useful in assessing the impacts of an increase in the production of biofuels on crop production, utilisation and prices, on changes in land cover and crop areas, on factor movements and on bilateral trade.

A big advantage of GTAP models is that they are very transparent and that there are many programmers working and further developing these models. Since the biofuel sector is very dynamic a weak point of the GTAP models is the refresh period of three to four years of the databases. The GTAP 6 database that has been utilized in the GTAP-E model uses the year 2001 as base year. The regular GTAP model is static and therefore does not provide trajectories of changes over time. To meet these limitations dynamic behaviour has been incorporated in the dynamic GTAP model [38].

5 GIS APPROACH

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of geographically referenced information [10]. Consequently the data is organized in a database and the GIS-software provides tools for the processing of the data.

GIS technology helps to organize geographic data so that a person reading a map can select data necessary for a specific project or task. GIS-software allows the user to add layers of information to a base map of real-world locations. For example, a social analyst might use the base map of Eugene, Oregon, and select datasets from the U.S. Census Bureau to add data layers to a map that shows residents education levels, ages, and employment status. With an ability to combine a variety of datasets in an infinite number of ways, GIS is a useful tool for nearly every field of knowledge from archaeology to zoology [39].

The combination of GIS technology and conventional energy modelling methods could be a reasonable approach for the modelling of bioenergy systems. In [40] and [41] GIS and geographic information are tied together with a conventional modelling approach of energy systems, the TIMES model. TIMES is an economic model generator for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. It is usually applied to the analysis of the entire energy sector, but may also be applied to study in detail single sectors (e.g. the electricity and district heat sector). In this approach GIS data serves as input for TIMES. Therefore spatially and temporally high disaggregated problems in the energy system can be treated. In an elaborated case study the practicability of this approach is shown. Especially sensibilities of an optimal system setup in dependency on assumptions on specific costs for energy transport or storage can be investigated in a very detailed manner. It enables the analysis of influences and sensibilities related to spatial and temporal deviations in our energy system either on the supply or the demand side. Given that the supply component of the TIMES model generator includes the identification of trading possibilities, where the amounts and prices of the traded commodities are determined endogenously [7] this approach could be suitable for the modelling of biomass trade as well.

GIS technology is increasingly being combined with decision support systems (DSS) to form a hybrid type of decision support tool known as a spatial decision support system (SDSS). Such systems combine the powerful spatial referencing and spatial analytic capabilities of a GIS with the data and logic of a DSS. These tools can be used to assist in making effective decisions for many kinds of problem sets and information domains, including natural resource management, business, health care, emergency management, and many others [11]. There is a lot of literature about the use of GIS for achieving effective, commercially appealing and environmentally sustainable strategies for biomass use for energy production. Up to now most of these approaches apply to small regions. In the following there will be a brief description of some of these systems.

In [42] a GIS-based Environmental Decision Support System (EDSS) for **improving the efficiency of** the whole **biomass supply-chain** is discussed. The EDSS is organized in three modules: GIS, data management system and optimization. It is used to define planning and management strategies for the optimal logistics for energy production from woody biomass, such as forest biomass, agricultural scraps and industrial and urban untreated wood residues. For a case study, this EDSS is applied to a small region in Italy (the Val Bormida, Savona Province). For this region an optimal solution has been derived in terms of plant technology, capacity and harvesting.

As harvesting costs are largely determined by geographic factors GIS tools are well suited for the optimizing of harvesting costs. In [43] operational costs for different locations are calculated using GIS and matched with total demand in the subject region. In addition, locations with lower operational costs are identified and an investigation of a highly feasible use of forest biomass is carried out. In [44] they are presenting a GIS-based decision support system for selecting least-cost bioenergy locations. The methodology tackles the **resources competition problem** between energy facilities through a location-allocation model based on least-cost biomass quantities.

In [45] GIS tools have been used to analyse and map the demand for heat (domestic heating and hot water) in a certain region. In addition the potential of fuel has been determined by matching data of the annual increment of woody biomass (depending on age of the forest, altitude, region, etc.) with data on infrastructural constraints. This approach is useful for analysing the possible degree of self-sufficiency of a region.

Another study [46] used a GIS supported methodology to assess the bioenergy potential at a regional scale in Sicily. The methodology was based on the use of agricultural, economic, climatic, and infrastructural data in a GIS. Data about land use, transportation facilities, urban cartography, regional territorial planning, terrain digital model, climatic types, and civil and industrial users have been stored in the GIS to define potential areas for gathering the residues coming from the pruning of olive groves, vineyards, and other agricultural crops, and to assess biomass available for energy cultivation.

Because of the spatial fragmentation of different biomass sources in one or more regions the design and assessment of sustainable biomass delivery chains is rather complicated. In [47] a GIS tool is presented that supports the design and facilitates a sustainability assessment of biomass delivery chains at a regional level, in terms of the regional availability of biomass resources, costs, logistics and spatial and environmental implications. According to [48] GIS is well suited to this type of analysis.

Most assessments of biomass availability estimate the total amount of biomass within a given straight-line radius and assume average production costs for the area. In reality costs vary with biomass type, distance, and transportation infrastructure. When transportation costs are taken into account, more costly resources in close proximity may be economically competitive with cheaper resources farther away, and vice versa. In [48] an approach for GIS based generation of biomass supply curves, where transport costs are taken into account is described. The methods that were used in this approach are composed of the following three components: calculation of transportation costs and haul times, determination of physical availability and geographic distribution of biomass. Based on this data biomass resource supply curves were created.

Accurate and up-to-date global land cover data sets are necessary for all the GIS approaches mentioned above. One way for achieving data is the integration of satellite data. In recent years, substantial advancement has been achieved in generating such data products. Two examples for global datasets are the Global Land Cover 2000 (GLC-2000) and MODerate resolution Imaging Spectrometer (MODIS) global land cover data [49]. These datasets contain several land cover classes. The major land cover classes are: forest, savannas/scrublands, grasslands, cropland, mosaic of cropland and natural vegetation, barren lands, urban, and wetlands. The more data you have and the higher the geographic resolution of the data material is the better can be the results achieved with such systems.

Particularly renewable energy resources depend on numerous additional datasets. The most important ones are topography, climate, soil types, humidity, population distribution and transport routes. Based on the fact that numerous aspects describing our energy system rely on spatial characteristics in [50] a geographical database has been implemented. Based on these datasets the theoretical and furthermore useable global potentials of renewable energy carriers were estimated. Even though in this paper the computation of wind power was shown exemplarily, the same approach could be used for estimating biomass potentials. According to [50] when modelling renewable energy potentials special attention has to be paid to the fact that renewable energy potentials are often not additive, what means that the land surface is only available once and therefore several potentials exclude the option to yield another potential on the same area. For the estimation of the highest possible energy potential on a certain area, a competition analysis regarding the utilization of the land surface was carried out in the study described above.

6 CONCLUSIONS

In this paper three different types of modelling approaches have been analysed. Basic trade models, general equilibrium models (especially CGE-models) and GIS approaches and their ability to assess trade.

The **basic trade models are suited very well for evaluating the macro-economic impacts of trade.** The Ricardian model and the Heckscher-Ohlin model show that the specialisation in production and trade between countries in general lead to an increase in the available supply of goods and to an overall improvement of welfare, at least under certain (neoclassical) conditions. Nevertheless basic trade models are appropriate tools for analysing the macroeconomic gains of trade and the effects of taxes and tariffs. These **neoclassical assumptions** (e.g. perfect competition), often **are subject of discussion**. As a matter of fact **some models allow for non-market clearing, imperfect competition or other conditions that are closer to reality**, for example the New Trade theory.

By incorporating other sectors to basic trade models, the **functionality** of such models **can be expanded** and new **or other issues** (e.g. food vs. fuel) **can be addressed.** One example for the extension of basic trade models is the advanced Heckscher-Ohlin approach described above which incorporates energy, environment and agriculture to the basic Heckscher-Ohlin model. This approach allows addressing the issues of an increase in the use of bioenergy and bioenergy trade (e.g. land use change). With this conceptual framework the impacts of globalisation, capital inflows and new technologies can be evaluated.

The gravity model, which differs slightly from the other basic approaches, is an attractive analytical tool for researchers in the international trade area. Gravity equations can be utilized to evaluate market access, border effects, trading potentials, the impact of regional agreements, and so forth [8].

The **CGE-models** we have analysed in this paper are **more complex** compared to the basic approaches and therefore **allow for a more detailed analysis** of energy systems. Multi-country multi-sector CGE-models are **appropriate to evaluate the consequences of changes and developments in dedicated sectors on national incomes, trade, and production.** Static models are inapplicable for the modelling of the long-run development process of economies is. This requires the development of dynamic CGE models as discussed in [38].

As described above CGE models are based on equations describing the model variables and on databases for characterising the whole economy. One critical point of CGE models is that these databases are **depending on proper data** which **often** are **not available in the required extent**, especially in developing countries. Sometimes it is criticised that most of the parameter values (e.g. elasticities) are at best guesses and are not based on appropriate econometric studies. According to [24] some of these issues are being addressed by the development of social accounting matrices in least developed countries and when there are no econometric estimates for parameter values, the plausibility of these guesses can be determined through sensitivity analysis. Another **critical issue** in this context is the **actuality and the refresh rate of the databases**. With regards to highly **dynamic developments** (e.g. the increase in the production of ethanol and biodiesel in the recent past) or **technological changes** (e.g. second generation biofuels) these issues have to be considered.

There was not enough time for us to address partial equilibrium models in this paper in detail. According to [8] partial equilibrium models are useful when the objective is to analyse the consequences on trade flows in the world market of a specific commodity that is characterized by a great diversity of production systems (such as sugar or rice). Concerning the high complexity of bioenergy markets and the strong linkages and connections to other sectors, CGE models may be better suited to deal with issues like land use change or food versus fuel.

The last types of modelling approaches we analysed in this paper are geographic information systems (GIS). These systems can be used for capturing, managing, analysing, and displaying all forms of geographically referenced information. As biomass potentials are distributed heterogeneously, GIS-software provides convenient tools for determining the regional spread of energy for analysing and optimising the whole supply chain (harvesting, storage and transport).

So GIS-tools can be used for many kinds of problem sets and information domains, including natural resource management, improving the efficiency of the whole biomass supply-chain, optimizing of harvesting costs, analysing the possible degree of self-sufficiency of a region by matching data of supply and demand and even for the automated generation of biomass supply curves (taking transport costs into account). By **combining GIS technology with decision support systems** and by linking energy and environment policies across time and space GIS are well suited for policy analysis.

Up to now most GIS approaches only apply to small regions. For incorporating international trade of bioenergy it would be **important to expand these approaches to a global dimension.** Therefore the **availability of high resolution spatial satellite data has to be improved** and the technology of remote sensing (automated capturing, analysing and referencing) in areas in which few data from in situ analysis are present, has to be improved and **proper algorithms have to be developed for data analysis** (see [41]). With high resolution data and better algorithms being available, **GIS-data** would adapt easily to serve as **proper input for conventional energy models.**

According to [49] by learning from past experience and building on the existing regional frameworks, the consistency and accuracy of global land cover data are expected to improve in the future.

As stated in [8] the world of international trade is infinitely complex. For a better understanding of such complex systems the abstraction of critical elements is necessary.

Up to now no absolutely superior methodology for analysing international trade exists and no customized models for incorporating global import/export potentials are available. Nevertheless there are a lot of different approaches that are suited for answering questions related to international bioenergy trade. Each method has both strong and weak points which have to be kept in mind.

A simple approach for incorporating international bioenergy potentials to existing energy models (e.g. GREEN-X [51] or POLES [52]) could be a **"bubble approach"** where roughly estimated international potentials of bioenergy products are pooled in a "bubble". All countries recognized in this model could access this pool and import biomass from there. In this approach costs would be depending on average distances and on the infrastructure (availability of harbours, rail...).

As described above the **combination of GIS technology, basic transport modelling approaches with a conventional energy model** can be very useful for answering questions related to the international trade of bioenergy. After all, with a better availability of high resolution spatial satellite data the combination of GIS technology and conventional energy modelling methods could be further improved.

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