**Paper prepared for the 19th Annual Conference on Global Economic Analysis**
**"Analytical Foundations for Cooperation in a Multipolar World"**
**Washington DC, June 15-17, 2016**

# Modelling the Bioeconomy: Linkages between Agricultural, Wood and Energy Markets

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# 1 Introduction

In light of finite fossil resources and negative environmental impacts of their use, policy makers have initiated strategies for a transition from a fossil-based economy to an economy based on biological resources, referred to as ´bioeconomy´. Agriculture and food, forest as well as pulp and paper producing sectors constitute the most important sectors of the bioeconomy in terms of turnover and employment (EUROPEAN COMMISSION 2012).

These sectors are strongly interconnected. The linkage is obvious between agriculture and food industries and between forestry, forest products and pulp and paper. Agriculture and forestry production compete for natural resources, in particular land and water use.

The interlinked nature of the bioeconomy requires a holistic approach to any impact assessment. To cover the full range of effects on the overall economy, the agricultural and forest sectors in particular, farms and regions, a combination of models with different characteristics is required. The objective of the paper is to show how a combination of the general equilibrium model MAGNET (WOLTJER ET AL. 2014) with partial equilibrium modelling tools as well as programming models are applied for a comprehensive analysis of the bioeconomy sectors. To illustrate our approach, we deploy stylized scenarios that show the impact of varying energy prices on agriculture and forest industries. These sectors need energy in their production processes and at the same time provide inputs for energy production. The simulations will reflect that changes in energy prices may be driven by different causes, in our case varying economic growth rates versus a limited availability of energy resources.

Starting point of the simulation is the MAGNET model, which is based on the GTAP database and structure. The chosen aggregation will give detailed information on European countries and on the agri-food sectors, forestry, pulp, paper and lumber as well as on energy sectors. Simulated changes in selected variables concerning these markets will be either passed to the agricultural market model AGMEMOD (AGMEMOD 2013) or to the global forest product model GFPM (BUONGIORNO ET AL. 2003). AGMEMOD will give insight into effects across agri-food markets in European countries and will provide a price vector for agricultural products to both the farm model FARMIS (DEPPERMANN ET AL. 2014) and the regional model RAUMIS (GÖMANN ET AL. 2011). GFPM will focus on forest products markets, especially changes in production, trade and demand for wood used for energy production. From GFPM, the price for fuel wood will be used as a proxy for wood from short rotation plantations, and will be fed back into the agricultural sector model RAUMIS. On this basis, the impact of the scenario shocks on regional (European NUTS III level) production, sector income, land use as well as the associated environmental impacts will be estimated with RAUMIS. Farm-level effects such as adjustments of production intensity and technology in response to changes in energy prices, as well as impacts on income levels and distribution will be covered through the linkage with FARMIS.

The paper lays out the methodological approach in a detailed manner along with some illustrative results. Expected results will describe the impact of the varying energy prices on land use, farm incomes, feed, food fuel and fibre consumption and production, changes in trade patterns and factor markets.

# 2 Quantitative Approach

This paper explicitly examines the joint effect of obligatory biofuel mandates in the EU, the US, Canada, Brazil, Rest of South America, India, and South-East Asia on land, food production, total GHG balance, trade and prices of agricultural commodities.

## 2.1 *Database*

The analysis is based on version 7 of the GTAP data, Dimaranan (2008). The GTAP database contains detailed bilateral trade, transport and protection data characterizing economic linkages among regions, linked together with individual country input-output databases which account for intersectoral linkages. All monetary values of the data are in $US millions and the base year for version 7 is 2004. This version of the database divides the world into 88 regions. The database distinguishes 57 sectors in each of the regions. That is, for each of the 88 regions there are input-output tables with 57 sectors that depict the backward and forward linkages amongst activities.

The initial data base was aggregated and adjusted to implement two new sectors – ethanol and biodiesel – representing biofuel policy in the model. These new sectors produce two products each; the main product and byproduct. The ethanol byproduct is Dried Distillers Grains with Solubles (DDGS) and biodiesel byproduct - oilseed meals (BDBP).

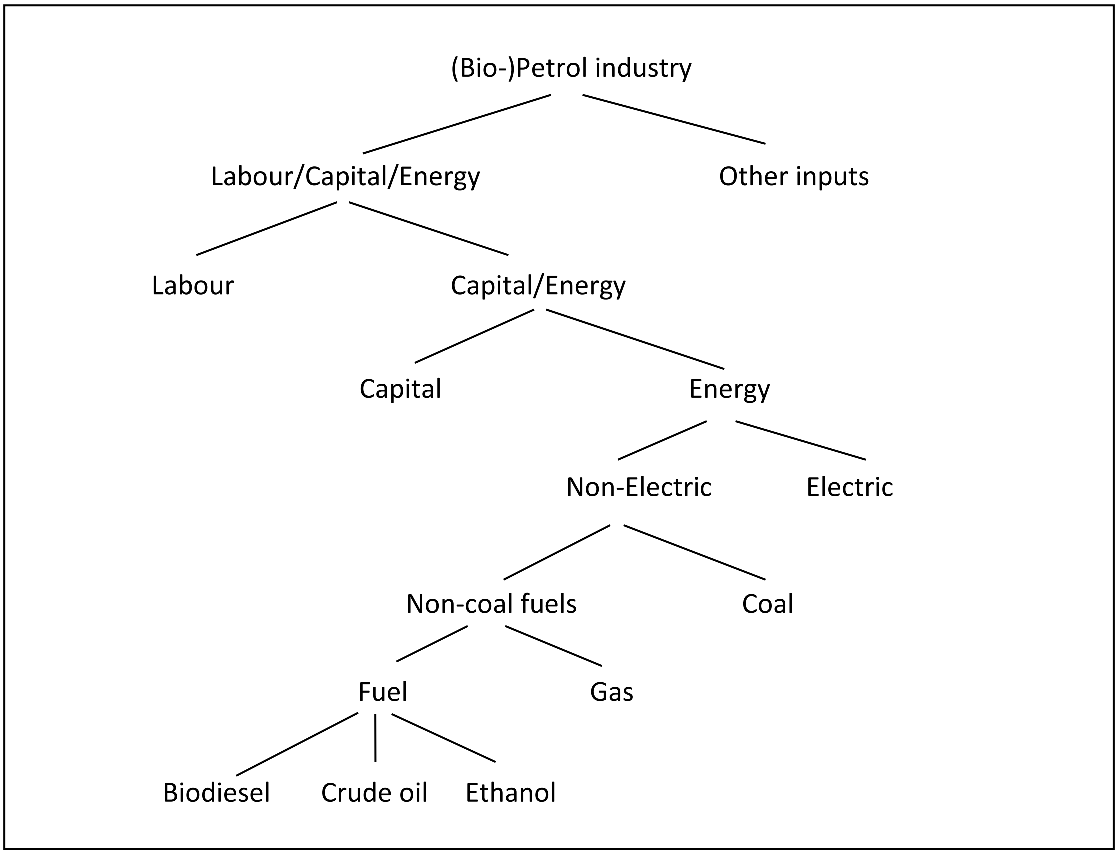
Finally, we distinguish 45 regions, 26 sectors and 28 products. The sectoral aggregation includes, among others, agricultural sectors that use land (e.g., rice, grains, wheat, oilseed, sugar, horticulture, other crops, cattle, pork and poultry, and milk), the petrol sector that demands fossil (crude oil, gas and coal), and bioenergy inputs (ethanol and biodiesel) and biofuel production byproducts. The regional aggregation includes all EU-15 countries (with Belgium and Luxembourg as one region) and all EU-12 countries individually except for the Baltic countries which aggregated to a single region, with Malta and Cyprus included in one region, and Bulgaria and Romania aggregated to a single region. Outside the EU the analysis covers all important countries and regions from an agricultural production and demand point of view.

## 2.2 *MAGNET model*

The economic model is the MAGNET model which is a multi-regional, multi-sectoral, static, applied general equilibrium model based on neo-classical microeconomic theory; see (WOLTJER ET AL. 2014). It is an extended version of the standard GTAP model, Hertel (1997). The core of GTAP and MAGNET models is an input–output model, which links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. Extensions incorporated in MAGNET model includes an improved treatment of agricultural sector (like various imperfectly substitutable types of land, the land use allocation structure, land supply function, substitution between various animal feed components), agricultural policy (like production quotas and different land related payments) and biofuel policy (capital-energy substitution, fossil fuel - biofuel substitution). On the consumption side, dynamic CDE expenditure function was implemented which allows for changes in income elasticities when purchasing power parity (PPP)-corrected real GDP per capita changes. In the area of factor markets modeling, the segmentation and imperfect mobility between agriculture and non-agriculture labor and capital was introduced.

To model biofuel use in the fuel production, the nested CES function of the GTAP-E model, Burniaux and Truong (2002) had been extended it for the petrol sector (Figure 1). To introduce the substitution possibility between crude oil, ethanol and biodiesel, we model different intermediate input nets in the petrol. The nested CES structure implies that biofuel demand is determined by the relative prices of crude oil versus ethanol and biodiesel including taxes and subsidies.

**Figure 1: The (bio-) petrol industry nested production structure**




Source: Own compilation.

The feed byproducts of biofuel production (DDGS and BDBP) are demanded only by livestock sectors in MAGNET. This demand is generated through the substitution process in the feed nest in the livestock sector. In order to model substitution between different feed components and feed byproducts of biofuel production, we use two-level CES nest describing the substitution between different inputs in the animal feed mixture production. The top level describes the substitution possibility between concentrated feed and its components and grassland (i.e., roughage). The lower level intermediate describes the composition of different types of feed commodities (cereal, oilseeds, byproducts and other compound feed).

## *2.3 The AGMEMOD model*

The partial equilibrium model AGMEMOD (Agricultural Member States Modelling) focuses on a detailed representation of the agri-food markets described by quantities and prices while the other economic sectors are not covered. It is a modelling tool designed to analyze agri-food markets and related policies, originally, covering all EU Member States with the exception of Malta, Cyprus and Luxembourg which are integrated in other countries. Candidates and potential candidates to EU accession are represented, like the Former Yugoslav Republic of Macedonia or Turkey (Erjavec et al., 2007; Van Leeuwen et al., 2007a; Van Leeuwen et al., 2007b; Salputra et al., 2008; Chantreuil et al. 2011, AGMEMOD partnership, 2010), and neighboring countries like Russia (AGMEMOD partnership, 2012) and Ukraine (AGMEMOD partnership, 2012) as well.

In AGMEMOD, a flexible, modular bottom up approach is used. Econometric based, recursive-dynamic country specific modules have been developed to reflect details of agriculture at country level and at the same time allow for combining these individual country models into an overall aggregate model. Such an approach is to capture the inherent heterogeneity of the different agricultural systems existing while the analytical consistency across the country models will be obtained via a close adherence to templates. Various domestic commodity markets are linked by substitution or complementary conditions in supply and demand, covering differentiated types like demand for food, feed, energy use or further processing. All supply and utilization of a distinct commodity are balanced via a closure variable. These sub-models also include a detailed set of agricultural, trade policy or other policy instruments in each MS.

Equilibrium for each commodity market at the MS, the EU and the global levels are described by equation for market clearing implying that on each market production plus beginning stocks plus imports will be equal to domestic use plus ending stocks plus exports. Given that the countries integrated do not represent a closed economy, the Rest of the World has important impacts on the price formation of all countries so a module for the Rest of the World (RoW) capture this relation in stylized form as neither detailed policies are implemented nor model parameters are econometrically estimated, but derived from the literature. Supply and demand in the RoW sub-model allow closing of markets for each tradable by forming the respective world market price. To account for the impacts between the world market price level and the regional respectively the EU price level, price linkage equations are used.

For each commodity market and for each country, the functional representation can vary and should capture distinct market features at country level. Where data limitations exist, the final functional forms are adjusted in response to the statistical and economic validation of the models. For country details see e.g. Chantreuil et al. (2005), Esposti and Bianco (2005), Leeuwen and Tabeau (2005). In the validation process multidisciplinary teams and a network of market experts in the countries considered are involved to build and to verify the country models. Based on this concept, projections for each commodity, in each year out to a ten year horizon, for each country, and for aggregate regions are produced which, in turn, also serve as a counterfactual baseline for the impact analyses of policy changes.

AGMEMOD covers a wide range of products, either primary or processed. Hence, due to the modular structure specific products may not be captured in all countries due to their limited importance or unavailability of data. In principle, cereals (soft wheat, durum wheat, barley, maize, rye, oat, triticale and other grain), rice, oilseeds (rape seed, sunflower seed and soybeans including their respective oils and meals), protein crops, potatoes, industrial crops (cotton, tobacco) are represented in the crop sector as well as milk and dairy products (drinking milk, other fresh products, cream, butter, cheese, skimmed milk powder, whole milk powder and other products), cattle and beef, pigs and pork, poultry, sheep and goat and meat hereof in the animal sectors. Also bio-fuels are implemented driven by targets based on required feedstuffs. Production, supply and use items are driven by exogenous variables like productivity, technical coefficients, prices, macro-economic variables, policy variables and further endogenous variables.

Within the Thünen model platform AGMEMOD uses a set of macro-economic and policy variables harmonized across all other models of the platform. AGMEMOD provides a price vector of agricultural products especially to the farm and regional models which themselves deliver a production volumes. In an iterative process production within AGMEMOD is adjusted to the outcomes of the farm and regional models while adapting prices used as input for the other models.

## *2.4 The FARMIS Modelling System*

FARMIS is a comparative-static programming model for farm groups (Bertelsmeier, 2005; Offermann et al., 2005; Deppermann et al., 2014). It provides sector-consistent modelling of policy impacts taking into account farm characteristics as well as ownership and prices of quotas and land for income assessments. The model specification is based on information from the German Farm Accountancy Data Network (FADN), supplemented by data from farm management manuals. Data from three consecutive accounting years is averaged to reduce the influence of yearly variations common in agriculture (e.g., due to weather conditions) on model specification and income levels. Production is differentiated for 27 crop and 15 livestock activities. The matrix restrictions cover the areas of feeding (energy and nutrient requirements, calibrated feed rations), intermediate use of young livestock, fertilizer use (organic and mineral), labor (seasonally differentiated), crop rotations and political instruments (e.g., set-aside and quotas). The model is calibrated to observed production decisions and elasticities using a positive mathematical programming approach. For this study, the model specification is based on data from the accounting years 2009/10, 2010/11 and 2011/12. The farm sample was stratified by region, type, system and size, resulting in 646 farm group models. Results are aggregated to the sector using farm group specific weighting factors. Competition of farms on important factor markets (e. g., land) is modelled endogenously.

## *2.5 The RAUMIS Modelling System*

RAUMIS was developed for continuous usage in the scope of medium and long-term agricultural and environmental policy impact analyses. It comprises more than 50 agricultural products, 40 inputs with exogenously determined prices, and reflects the whole German agricultural sector with its sector linkages. The model consolidates various agricultural data sources and generates base model data with the national agricultural accounts as a framework of consistency. (Kreins et al. 2007)

The spatial differentiation is based on administrative bodies on NUTS III level, which is due to data availability. Some 326 regions are treated as single *region farms* that so far autonomously reach their production decisions. Hence, adjustments of production at the national level are based on aggregated responses of region farms. Adjustments caused by changes in general conditions e.g. agricultural policies are determined using a positive mathematical programming approach (Howitt, 1995) with the following non-linear objective function for each region:

$$\begin{aligned} \max_x \quad & \Pi = \sum_i z_i(x_i)\, x_i \\ s.t. \quad & b_i \geq \sum_i a_i x_i \end{aligned} \tag{1}$$

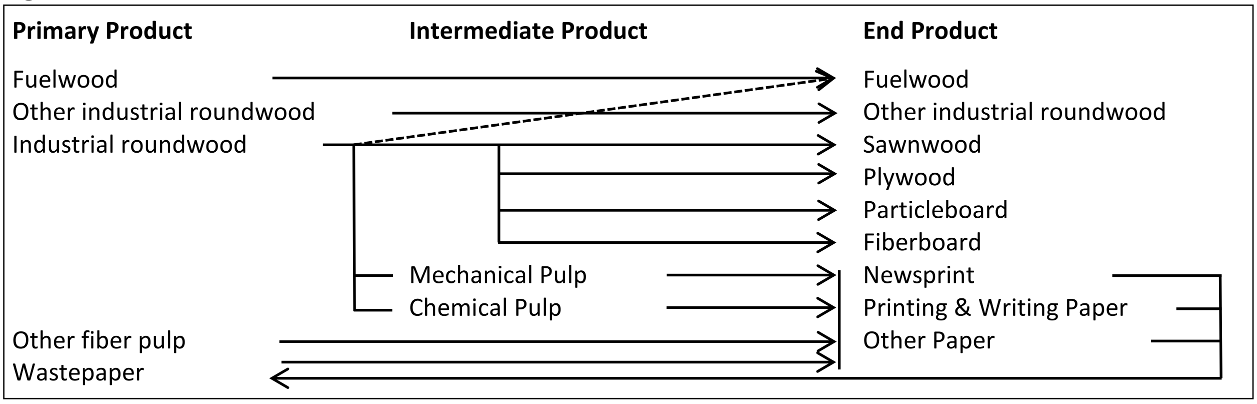
The objective function is a regional agricultural profit ($\prod$) function maximizing the product of per unit margins $z_i$ between the price and the costs of the ith netput where positive elements of $x_i$ denote outputs while negative elements denote inputs or intermediate inputs such as farmyard manure and the level of each netput $x_i$. The objective function is non-linear since $z_i$'s are functions of their realized netput level $x_i$. The problem is solved subject to a set of technical, political and economic constraints ($b_i \geq \sum_i a_i x_i$), e.g. land availability, set-aside obligations etc. and proceeds in two stages. In the first stage, optimal variable input coefficients per hectare or animal are determined. In the second stage, profit maximizing cropping patterns and animal herds are determined simultaneously with a cost minimizing feed and fertilizer mix.

A set of agri-environmental indicators implemented in RAUMIS is linked to agricultural production. Currently, the model comprises indicators such as nutrient surplus (nitrogen, phosphorus and potassium) (Kreins et al. 2007, Kuhr et al. 2013), pesticides expenditures (Sieber et al. 2010), a biodiversity index, and corrosive gas emissions (Röder et al. 2015).

## *2.6 The Global Forest Products Model (GFPM)*

The Global Forest Products Model (GFPM) is a dynamic partial equilibrium model of the forest sector. It covers wood markets in 180 countries and it comprises of 14 different primary, intermediate and end products, (e.g.) fuelwood, industrial round-wood, sawn-wood, wood-based panels, pulp, waste paper and paper and paperboards. The GFPM calculates the consumption, production, imports and export quantities in physical units in the market equilibrium of 180 countries for the given products. Hence it provides equilibrium prices as well (Buongiorno et al. 2003).

**Figure 2: Product transformation in GFPM**




Source: Buongiorno et al. (2003), own adjustment for the manufacturing of fuelwood out of industrial round-wood.

The GFPM derives the spatial global equilibrium solution for one point in time (static phase) by maximizing consumer and producer surplus. For the next time period (dynamic phase) demand and supply curves shift according to various variables; e.g. gross domestic product per capita or forest growth dynamics. Then a new equilibrium is calculated (static phase). For every simulation period numerous exogenous changes can by implemented to account for changes in e.g. economic growth, manufacturing technologies or tariff systems. The most detailed model description can be found in Buongiorno et al. (2003). For our calculations we use the 2016 GFPM version (Buongiorno und Zhu 2016, 2015) as our base model.

For calculating primary product supply the GFPM includes data on forest stock, forest area and forest growth dynamics on a national level, see Figure 2. The GFPM uses the FAOSTAT forestry database (FAO 2016a) for historical production, import and export quantities. Of this it derives consumption levels and prices. Data on forest area and forest stock are taken from the Global Forest Resources Assessments (FAO 2016b). Input output coefficients as well as manufacturing cost are calibrated for the base period based on historical data. Elasticities are taken from literature.

In our general approach for modelling the bioeconomy we will link the partial model GFPM with MAGNET as the general economic model. This will be done by using country specific GDP developments as well as demand changes in respective forest related sectors and changes in other selected variables simulated by MAGNET.

# 3 Scenario results

## *3.1 Scenario description*

The analysis of economic effect of varying fuel prices is based on a combined economic which covers different layers of regional and sectoral coverage, using the general equilibrium model MAGNET, the partial equilibrium model AGMEMOD, the farm-type model FARMIS, the regional agricultural model RAUMIS and the Global Forest Products Model (GFPM). The scenario setting is built on a reference scenario (BASE) which assumes the continuation of current agricultural policies as well as the current levels of biofuel mandates in Europe and other parts of the world. In addition, we run a policy scenario experiment ENERGY+ which assumes higher prices for fossil energy as under the scenario Base. Other policy measures such as import tariffs or agricultural support are kept unchanged compared with the scenario BASE.

Based on this setting we analyze the impact of changing energy prices and agricultural and forestry production, consumption and trade in an integrated modeling approach.

## *3.2 Scenario setup*

The scenario is constructed through recursive updating of the database for three consecutive time steps, 2013-15, 2015-2020 and 2020-2025. The first period is distinguished to update the database to 2015 situation by implementing policies introduced in 2013-2015 period, together with the macro-economic development of the world economy. Also, the EU biofuel shares in transport were targeted.

In the first stage, exogenous GDP targets are met and given the exogenous estimates on factor endowments - skilled labor, capital and natural resources - and population. The procedure implies that an additional country level technological change is endogenously determined within the model, Hertel et al. (2004). In the final stage, this technological change is, in turn, exogenous in the remaining simulation experiments. The sectoral total factor productivities (TFP) are a linear function of country level technological change. Following the Central Planning Bureau, CPB (2003), we assumed different technological development by sector and common trends for relative sectoral TFP growth.

The macro-economic development assumption concerning real GDP and population growth are taken from AGMEMOD model database, AGMEMOD Partnership (2008) for EU countries and from

USDA (2016) for the rest of the World. Based on stylized facts of long-term economic growth we assume that capital is growing at the same rate as the GDP and employment at the same rate as the population.

The crude oil price development, which also determines the relative competitiveness of biofuel vis-a-vis fossil energy, is modeled endogenously in the model. However, it is significantly driven by assumed future crude oil production derived from IEA Data. In the first stage, we translate the macroeconomic growth and crude oil production targets to the country specific efficiency of natural resources utilization in crude oil sector. The technological assumptions obtained in this way were used in the simulation experiments. They show decreasing productivity of natural resources in crude oil sector for almost all regions, which is generally consistent with observed and expected decline of output from oilfields, IEA (2008).

When the policy is concerned, we assume the continuation of all policies legislated in 2015 throughout the projection period. In particular, this includes agricultural policies as well as policies related to bioenergy. In the biofuel mandate scenarios, we fixed the share of biofuels in fuel used in transportation in 2020. To achieve this policy target, a subsidy on bioenergy inputs in the petrol sector increases endogenously to make bioenergy inputs competitive with crude oil inputs. Since this policy instrument is assumed to be 'budget-neutral', these input subsidies are financed by an endogenous user tax on petrol consumption which generates the required funds for the biofuel input subsidies. The following section will present the results for the BASE scenario which assumes the continuation of currently applied mandatory blending target.

## *3.3 Scenario results*

To conduct our joint analysis we were required to take on board a number of results depending on the other models, which were to be aligned in the Baseline scenario. For the Scenario ENERGY+ for the partial equilibrium model AGMEMOD some outcomes of MAGNET were applied as inputs such as

- Changes in evolvement of GDP in countries covered
- Adjustments in world market prices of agri-food products covered
- Changes in incidence of oil prices on production cost derived by changes in oil prices and changes in intermediate input of firm cost

Changes available for periods (2015-2020, 2020-2025 and 2025-2030) are interpolated to provide annual inputs for the simulation which is conducted a recursive dynamic manner. Depending on the path of the oil price within the scenario in the most cases highest changes occur between 2015 and 2020 and they are abating in later years, see Table 1.

**Table 1: Changes under the Scenario ENERGY+ compared to Scenario BASE**

| | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| | % change GDP compared to Baseline | | | |
| EU | 0 | -1.6 | -1.2 | -1.0 |
| Germany | 0 | -2.4 | -2.0 | -2.0 |
| France | 0 | -2.0 | -2.2 | -2.7 |
| United Kingdom | 0 | -2.0 | -1.4 | -1.1 |
| Poland | 0 | -1.3 | -1.1 | -1.0 |
| Rest of EU | 0 | -1.4 | -1.3 | -1.2 |
| | % change of cost compared to Baseline | | | |
| Wheat | 0 | 5.7 | 4.3 | 4.3 |
| Coarse grains | 0 | 5.9 | 4.5 | 4.5 |
| Corn | 0 | 5.0 | 3.8 | 3.8 |
| Soybeans | 0 | 3.4 | 2.6 | 2.6 |
| Rape seed | 0 | 6.8 | 5.2 | 5.2 |
| | % change of world prices compared to Baseline | | | |
| Wheat | 0 | 8.5 | 8.6 | 9.3 |
| Coarse grain | 0 | 8.4 | 7.8 | 7.7 |
| Corn | 0 | 7.9 | 7.8 | 8.3 |
| Rice | 0 | 2.5 | 2.5 | 2.8 |
| Soybean | 0 | 8.3 | 8.3 | 9.1 |
| Rapeseed | 0 | 8.1 | 7.7 | 7.8 |
| Beef, sheep meat | 0 | 3.1 | 3.3 | 3.7 |
| Pork, poultry meat | 0 | 4.1 | 4.3 | 5.0 |
| Dairy products | 0 | 3.8 | 4.2 | 4.9 |

Source: Own calculations based on MAGNET (2016)

**Results at agricultural and food markets**

Compared to BASE energy prices under the Scenario ENERGY+ increase between 30% in 2010 and 23% in 2030. As this is not due to increased economic growth but by limited resources GDP in the countries regarded is affected negatively while production cost increases.

With respect to Germany, effects on the GDP development are more pronounced than in the Rest of the EU on average with the exception of France where negative economic impacts will even intensify until 2030 while in Germany the impact will be somewhat mitigated. Such change will affect the demand side for agri-food products in addition to the increase of budget share to be used for energy purposes whereas rising energy prices induce cost increases in the production cost of agri-food products. At the same time higher prices will add to the negative demand impacts.

Results for Germany indicate that impacts on domestic prices for most products will be probably within the range of changes simulated for world market prices. But for a number of products simulated changes for domestic prices will be somewhat lower than on the world market. So, the projected price increase for wheat will be 9.0% compared to 4.3% for soybeans, see Table 2, as production of wheat will increase at the expense of other crops. At the same time domestic use of wheat is curbed slightly. Similar reactions can be observed with most other crops. Prices of corn and barley will react less markedly than on the world market.

**Table 2: Selected changes under ENERGY+ compared to BASE in German prices and use in the agri-food sector**

| | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| | % change in domestic prices | | | |
| Wheat soft | 0 | 8.2 | 8.4 | 9.0 |
| Barley | 0 | 8.5 | 7.2 | 6.8 |
| Maize | 0 | 6.8 | 6.7 | 7.2 |
| Rapeseed | 0 | 3.9 | 3.9 | 4.4 |
| Soybeans | 0 | 4.0 | 4.0 | 4.3 |
| Milk | 0 | 1.4 | 1.4 | 1.5 |
| Beef and veal | 0 | 2.5 | 2.5 | 2.9 |
| Pork meat | 0 | 2.8 | 2.2 | 2.0 |
| Poultry meat | 0 | 5.5 | 5.5 | 6.2 |
| Butter | 0 | 3.0 | 3.2 | 3.6 |
| Cheese | 0 | 2.0 | 2.1 | 2.4 |
| | % change in total use | | | |
| Wheat soft | 0 | -0.3 | -0.3 | -0.3 |
| Barley | 0 | -0.7 | -0.6 | -0.5 |
| Maize | 0 | -0.4 | -0.5 | -0.5 |
| Rapeseed | 0 | 4.0 | 4.5 | 4.8 |
| Soybeans | 0 | 0.4 | 0.4 | 0.4 |
| Beef and veal | 0 | -15.9 | -14.9 | -15.7 |
| Pork meat | 0 | -0.5 | -0.5 | -0.5 |
| Poultry meat | 0 | -0.4 | -0.4 | -0.4 |
| Butter | 0 | -0.4 | -0.4 | -0.5 |
| Cheese | 0 | -0.4 | -0.4 | -0.4 |

Source: Own calculations based on AGMEMOD (2016)

In general the simulated impacts on domestic prices of animal products are significantly lower than on crop products. Lowest effects will be likely to occur with respect to the dairy sector with simulated price changes between 1% and 2% for raw milk while impacts for dairy products themselves vary from 2.4% for cheese to +3.6% for butter. Those limited effects for raw have to be regarded with respect to significant shares of other cost. Price effects for meat products will depict higher price changes compared to milk, due to somewhat higher changes of world market prices. Stronger restrictions in the growth of poultry production will lead to higher price effects for poultry.

Demand may consist of human use, feed use, seed use and other uses either energy or further processing. Changes in the use of different products under the ENERGY+ scenario show significant variations. Except for products with low market shares decline in use quantities is very limited. In principle, smaller price increases in oilseeds compared to cereals due to limited further use as input for bioenergy will lead to some substitution of cereals by oilseeds which as a consequence will be reflected in an increase in the use of oilseeds. Use of meat products is shrinking a bit more pronounced than the use of crop products. In the dairy sector use of products is declining in the Scenario by lower GDP growth and higher prices on the world market and thus, leading to a lower production of dairy products in Germany.

**Farm Level Results**

At the farm level, rising product prices provide an incentive to increase the intensity of production, while higher energy and fertilizer prices have an opposing effect. These effects partially cancel each other out, and in total lead to a slight reduction in mineral fertilizer inputs (in physical terms), though the effect on yields is marginal. Overall, farm level income is reduced in the scenario ENERGY+, see Table 3. Farm net value added per work unit (FNVA/AWU) is lower by 2% compared to the Baseline, and there are few differences between farm types, with two notable exceptions: While arable farms can slightly increase their income due to higher prices for cereals and oilseeds, pig and poultry farms face a 9% decline in FNVA/AWU, as the small increase in meat prices cannot compensate the increase in input prices, especially the rise of prices of (imported) feedstuffs. Differences between farm types are more pronounced using the indicator Family Farm Income, which captures the decrease in land prices projected by the model for the scenario ENERGY+. Arable farms as well as other grazing livestock benefit most from the resulting decrease in rental expenditures, as these farm types are largest in terms of land size.

**Table 3: Income effects of an energy price increase at farm level, by farm type**

| | Farm net value added per work unit | Family Farm Income per family work unit |
|---|---|---|
| | %-change to Baseline | |
| **Average** | -3% | -2% |
| **Arable farms** | 1% | 5% |
| **Dairy farms** | -3% | -2% |
| **Other grazing livestock farms** | -3% | 2% |
| **Mixed farms** | -3% | -3% |
| **Pig and poultry farms** | -9% | -14% |
| **Permanent crop farms** | -2% | -4% |

Source: Own calculations based on FARMIS (2016)

**Results at Regional Level**

The almost 24 % increase in energy prices under the scenario ENERGY+ relative to BASE leads to an increasing product price level. Accordingly, the adjustments in the production structure areas show changing rates which are with generally low, one-digit percentages, quite minimal. Only wheat crops experience, with an increase of 6% relative in comparison the other arable crop processes, a strong extension. The extension takes place mostly at the expense of the comparable extensive cereal cultures such as, for example, barley or rye crops, see Table 4.

The changes in animal husbandry due to the changed product prices are, with a decline of 2% in cattle keeping and a small increase of 1% in poultry meat production, even less than in the plant production area. The slightly reduced beef husbandry causes an according reduction in arable feed production.

**Table 4: Development of production in German agriculture**

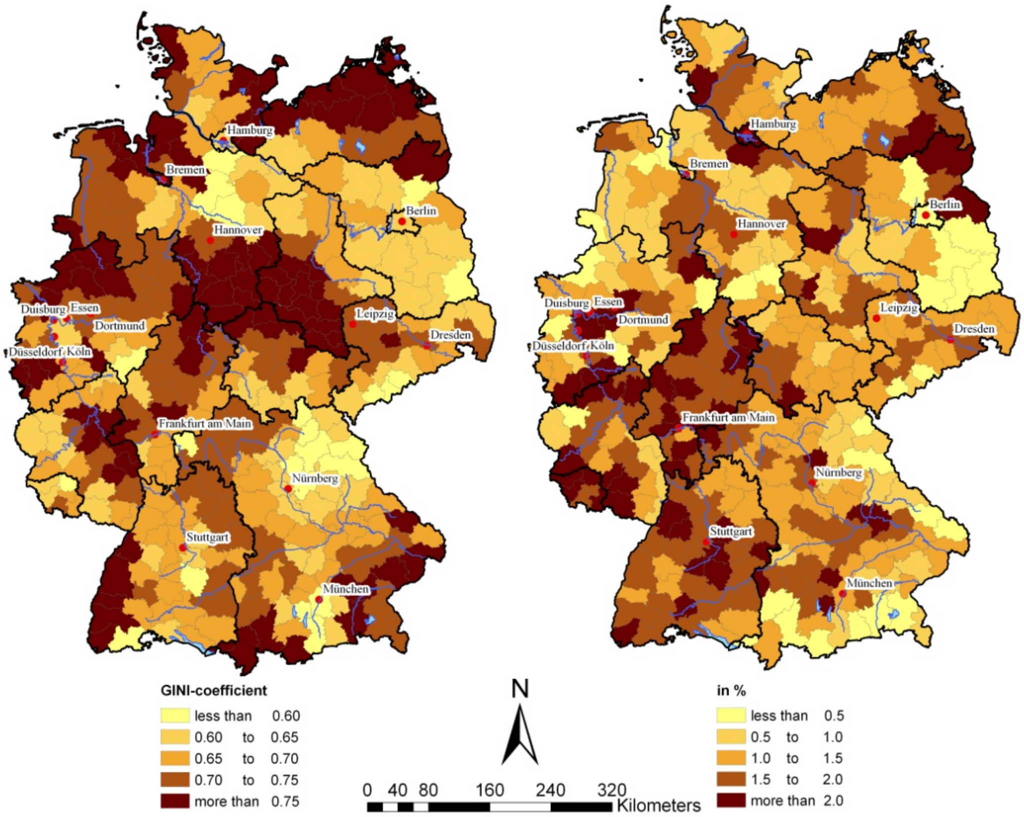
| | Unit | 1999[a)] | 2007[a)] | **2010[a)]** | **2025 Baseline** | **2025 Energy +** | *Baseline 2025 vs Energy + in %* |
|---|---|---|---|---|---|---|---|
| | | Absolute | | | | | |
| Landuse | | | | | | | |
| Cereals | 1,000 ha | 6 840 | 6 763 | **6 571** | **6 517** | **6 636** | *2* |
| Wheat | 1,000 ha | 2 706 | 3 098 | **3 298** | **3 535** | **3 750** | *6* |
| Barley | 1,000 ha | 2 196 | 1 968 | **1 641** | **1 408** | **1 368** | *- 3* |
| Rye | 1,000 ha | 851 | 649 | **627** | **589** | **579** | *- 2* |
| Oilseeds | 1,000 ha | 1 137 | 1 475 | **1 499** | **1 249** | **1 221** | *- 2* |
| Potatoes | 1,000 ha | 298 | 270 | **255** | **253** | **249** | *- 2* |
| Pulses | 1,000 ha | 112 | 119 | **91** | **171** | **87** | *- 2* |
| Root Crops | 1,000 ha | 804 | 651 | **633** | **624** | **608** | *- 3* |
| Silage maize | 1,000 ha | 1 203 | 1 017 | **1 050** | **973** | **962** | *- 1* |
| Other arable fodder | 1,000 ha | 469 | 599 | **750** | **706** | **665** | *- 6* |
| Energy maize | 1,000 ha | 51 | 444 | **809** | **1 075** | **1 056** | *- 2* |
| Set aside [b)] | 1,000 ha | 720 | 593 | **245** | **367** | **363** | *- 1* |
| Cattle | 1,000 head | 14 831 | 12 749 | **12 772** | **12 701** | **12 429** | *- 2* |
| of which: Dairy cows | 1,000 head | 4 765 | 4 123 | **4 191** | **4 443** | **4 396** | *- 1* |
| Milk produktion [c)] | 1,000 t | 26 768 | 28 057 | **30 051** | **37 040** | **36 654** | *- 1* |
| Beef and veal production | 1,000 t | 1 396 | 1 136 | **1 221** | **1 130** | **1 130** | *0* |
| Pork produktion | 1,000 t | 3 863 | 4 019 | **4 908** | **5 116** | **5 058** | *- 1* |
| Poultry production | 1,000 t | 799 | 959 | **1 588** | **1 909** | **1 920** | *1* |

*a) three-year period*
*b) Incl. unused grasslands.*
*c) Actual fat and protein content.*
Source: Own calculations based on RAUMIS (2016).

The higher energy prices in comparison to the baseline as seen in the Scenario ENERGY+, and the accompanying price increases, increase the competitive ability through the wheat production at the expense of comparatively extensive cereal types. In this manner, an overall a further narrowing of the crop sequence follows, whereby the regional form taken can vary greatly, see Figure 3. The left side of the map in Figure 3 shows the GINI coefficient as a measure for the crop diversity. The GINI coefficient can accept values between zero and one. Values near to zero show an equal distribution of the cropping practices, whereas a value of one shows a concentration of the arable crop structure to one practice. In the map on the right, changes of the GINI coefficients in the framework of the Energy+ Scenario is given. The GINI coefficient increases in all regions and thus indicates a general reduction of crop diversity. The narrowing of the crop sequence mostly takes place in regions that do not stand out as having an extremely narrow crop sequence in the baseline. Only in Hesse and northeastern Germany are counties found that increase this even more despite a very high concentration of crop systems.

**Figure 3:** Regional changes in crop rotation diversity

GINI-coefficient (2025; BASE) — Change of GINI-coefficient (2025; ENERGY+, in %)




Source: Own calculations based on RAUMIS (2016).

**Results for the forest products**

The goal of the application of the GFPM in our joint analysis is to see how (direction and quantity) wood and paper markets on a country specific commodity level react to higher oil prices. For example: Do German sawmills or panel producers have to reduce their production, because more round-wood is used as fuelwood? Or will they import more? How will prices change?

The GFPM is a partial equilibrium model. While the GFPM explicitly accounts for GDP growth rates as an exogenous variable it does not so for oil prices. In GFPM we want to account for four different effects due to higher oil prices in the scenario ENERGY+ compared to the BASE scenario.

- Growth Effect (GE): Higher oil prices influence GDP growth rates.
- Substitution Effect (SE): Higher oil prices may lead to substitution of fossil energy sources with fuelwood.

- Manufacturing Cost Effect (MCE): Higher crude oil prices may lead to rising costs for energy. As energy costs are not negligible in the manufacturing of wood and paper products manufacturing costs will presumably rise.
- Transport Cost Effect (TCE): With rising fuel cost transport cost rise as well and may change traded, produced and consummated quantities.

For the growth effect we use the region specific GDP and population developments of MAGNET to parameterize the GFPM. The MAGNET sector forestry (FRS) produces mainly two timber products – fuelwood and industrial round-wood. One can assume that fuelwood is directly consumed for energetic purposes while industrial round-wood is generally used for the further manufacture of wood products. Hence, when the sector electricity (ELY), private and governmental consumption are using the forestry output it can be assumed to be fuelwood. With this we derive growth rates of domestic fuelwood consumption from MAGNET and define fuelwood consumption paths in GFPM. GFPM will then calculate equilibrium prices and quantities for industrial round-wood and the other products that use industrial round-wood as an input. This represents the substitution effect. Parameters for the manufacturing cost effect are derived in a similar manner. Changes in input quantities in the sectors forestry (FRS), wood products (LUM), paper products, publishing (PPP) from the sectors ELY and PETRO are used in relation with their output quantities to calculate energy cost changes in manufacturing. To derive manufacturing cost growth rates we combine the energy cost changes with sector specific energy cost shares out of cost structure statistics, DESTATIS (2015). Commodity specific absolute changes in transport costs are derived by using an oil price elasticity of transport cost of 0.5[1] and the absolute values of transport costs in the GFPM.

Table 5 provides an example of data input in GFPM that are derived from the MAGNET results. It shows the annual growth rates of fuelwood consumption for some chosen countries in the baseline and the Energy+ scenario. A detailed look at the rates reveals rather small differences in the growth rates between the scenarios.

**Table 5: Example of data input of MAGNET in GFPM: Annual growth rate of fuelwood consumption for the substitution effect, in %**

| | Germany | France | UK | Canada | USA |
|---|---|---|---|---|---|
| Base | | | | | |
| 2013-2015 | 0.0132 | 0.0049 | 0.0096 | 0.0134 | 0.0276 |
| 2015-2020 | 0.0140 | 0.0087 | 0.0221 | 0.0187 | 0.0227 |
| 2020-2025 | 0.0121 | 0.0107 | 0.0175 | 0.0163 | 0.0204 |
| 2025-2030 | 0.0122 | 0.0111 | 0.0165 | 0.0145 | 0.0207 |
| Energy+ | | | | | |
| 2013-2015 | 0.0132 | 0.0049 | 0.0096 | 0.0134 | 0.0276 |
| 2015-2020 | 0.0136 | 0.0079 | 0.0223 | 0.0210 | 0.0214 |
| 2020-2025 | 0.0120 | 0.0105 | 0.0173 | 0.0157 | 0.0203 |
| 2025-2030 | 0.0121 | 0.0109 | 0.0163 | 0.0143 | 0.0205 |

Source: Own calculations

[1] This value is assumed as it balances the higher elasticities for transport by ship and lower elasticities for transports by trucks.

Accordingly to the scenario setup GFPM results show an increase in fuelwood consumption quantities in Germany from 2013 to 2030 of above 20% in the baseline scenario. The increase in fuelwood consumption levels is about the same in Europe. Generally, the scenario ENERGY+ does not increase the fuelwood consumption levels compared to the baseline. This is, again, in line with the scenario setup of MAGNET results, see Table 5. The small deviations for fuelwood consumption levels in European countries between the scenario BASE and ENERGY+ are on the one hand surprising and may indicate a need for further evaluation of model calibration and scenario setup of MAGNET and GFPM. On the other hand, when only modelling the wood and timber markets with GDP growth rates from MAGNET fuelwood consumption levels in Germany and Europe stay roughly on the same level. This indicates the benefit of interlocking MAGNET with GFPM beyond GDP growth rates, because it is a way to account for shifts in economic conditions and implement, for example, the substitution effect.

While in Germany and Europe the higher fuelwood demand does raise fuelwood prices. These increases seem not high enough to impact wood processing industries very negatively. But this is the case in some Asian countries: Higher fuelwood consumption and prices lead to less input quantities and higher prices for sawmills, panel manufacturers and the pulp and paper industries. Although demand of their products is rather stable, imports cannot fully compensate for higher input prices, increasing manufacturing costs and higher trade costs.

Overall are the changes between the results of the BASE and the scenario ENERGY+ are rather small. The present paper does not allow for an in depth analysis of the results for the 180 countries and 14 products or even for a decomposition of the overall effect in the four sub-effects mentioned in the scenario setup. But the latter method might be suitable to quantify the single impacts of higher oil prices on the wood and paper markets and gain more insight into their dynamics.

# 4 Conclusions

Several countries are determined to transform their economies from a fossil-based economy to an economy based on biological resources. In this process agriculture and food, forest as well as pulp and paper producing sectors become important sectors to provide biobased resources either from domestic production or from imports.

This paper illustrates and shed light on the degree of interconnectedness between the biobased sectors. The linkage is obvious between agriculture and food industries and between forestry, forest products and pulp and paper. Agriculture and forestry production compete for natural resources, in particular land and water use.

The interlinked nature of the bioeconomy requires a holistic approach to any impact assessment. To cover the full range of effects on the overall economy, the agricultural and forest sectors in particular, farms and regions, a combination of models with different characteristics is required. This paper applies several models to capture and cover potential general equilibrium as well as partial equilibrium effects to understand possible market implication of the transition process towards a bioeconomy. Programming models are applied for a comprehensive analysis at sectoral and regional level. This approach is presented in this paper under a stylized scenario that shows the impact of varying energy prices on agriculture and forest industries. The results indicate the different market effect induced by changing energy prices.

The scenario ENERGY+ with the current results of MAGNET and implemented effects have at first glance only very minor impacts on agricultural, wood and paper markets. This is somewhat surprising. On the one hand we have to check our assumptions about typical reactions on these markets and understand why these results might be correct. Maybe because assumed oil price developments are too small or effects are cancelling each other out. On the other hand we have to question ourselves if the similar scenario results in AGMEMOD, FARMIS, RAUMIS and GFPM are due to too small differences in the MAGNET outputs used for more sectoral models.

However, the approach of an integrated scenario analysis based on different models, presented here, enables us to analyze the complex and economy-wide impact of the transition process towards a biobased economy at the example of Germany.

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