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Analysing Bioenergy and Land Use Competition in a Coupled Modelling System: The Role of Bioenergy in Renewable Energy Policy in Germany*

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Abstract: In the context of energy security and climate protection, biomass is given high importance. Nevertheless, land-use conflicts resulting from the cultivation of biomass and their economy-wide effects are yet to be fully understood. To shed light on this issue we link three distinctive models; a global, multi-regional general equilibrium model (DART), a regionalised agricultural sector model for Germany (RAUMIS) and a location model for biogas plants. The DART model allows capturing international and national feedback effects of an increased use of bioenergy such as increased agricultural prices. The interaction of DART and RAUMIS links global markets and connects them to the detailed specification of agricultural land use in Germany. Finally, we link this system to the newly developed location model ReSI-M that accounts for the location choices of biogas plants in Germany and the resulting regional markets for energy crop demand. As a first application of the modelling system we analyse the effects of the German Renewable Energy Source Act on German biogas production and of the EU 10%-biofuel target on German agriculture and world agricultural prices. A main result of the simulations is that accounting for existing land-use restrictions and land-use competition has a significant effect on model results.

Keywords: Bioenergy, land use, renewable energy policy, coupled models, agricultural-sector models, CGE

JEL classification: C61, C68, Q15, Q42, Q48

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1. Introduction

In the context of energy security and climate protection, biomass is given high importance. Especially biofuels have received increased attention since they are able to replace fossil energy in the transport sector. They are therefore seen as a special option since the transport sector is contributing an increasing share to global carbon emissions and since other renewable energy sources mostly replace fossil fuels in the electricity (wind, hydro, photovoltaics) and heat (wood pellets, geothermal energy, solar thermal energy) sectors. Currently, only Brazil is able to produce bioethanol from sugar cane at sufficiently low costs to be competitive with conventional fuels. But as a result of different kinds of support policies such as quotas, tax exemptions or direct production subsidies the production and consumption of biofuels has risen worldwide in the past years. Figure 1 displays the growth in production over the period 1992-2008 for three major biofuel-producing regions.

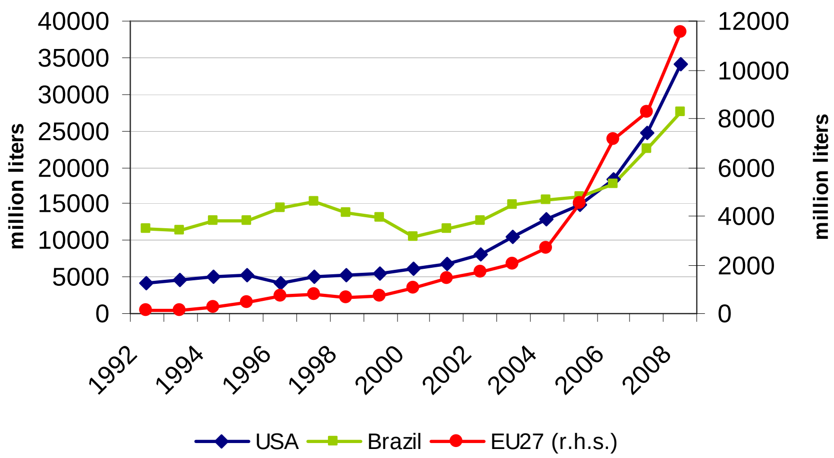

Figure 1: Historical production of ethanol in USA and Brazil and of total biofuels in EU27, r.h.s. (Sources: RFA, 2009; UNICA, 2009; Biofuels Platform, 2009)

With rising food prices biofuels have fallen into disrepute and are accused of potentially aggravating poverty and hunger in developing countries. Though a variety of factors inter alia crop failures were responsible for the recent rises in food prices, it has become clear that bioenergy feedstocks compete with other uses for the scarce factor land. With an extension of biofuel production in the future – and current legislation such as the EU's directive on the use of energy from renewable sources (European Union, 2009) and the US Energy Independence and Security Act (United States. Cong. Senate, 2007) that set ambitious targets for the consumption of biofuels point in this direction – there will surely be an effect on food prices. In order to adequately capture the interlinkages between energy and agricultural markets, it is essential to account for land-use competition and land scarcity.

Capturing land-use conflicts resulting from the cultivation of biomass and their economy-wide and international effects is our main motivation for setting up a harmonised modelling framework. Kretschmer & Peterson (2010) give an extensive overview about the current status quo of modelling bioenergy. One finding is that existing modelling frameworks all represent the world economy disaggregated into countries and regions. Furthermore, the frequently employed general equilibrium models do not only model agricultural and energy sectors but represent a complete sectoral structure for each economy. With countries and regions being linked via bilateral trade, the effects of sectoral policies, such as those supporting biofuels, are not only felt across sectors within one economy but also internationally. The existing model refinements with respect to land use also take on a global dimension and aim to better capture land use competition globally. This has to go at the expense of sectoral detail. In our modelling framework we choose a different approach: Our aim is to look more closely at land-use competition within one economy in order to better understand the repercussions of international (agricultural) market developments as well as national bioenergy support policies on the local agricultural sector. While we here focus on Germany, we believe that this modelling approach could be adopted for other countries as well.

In order to take into account international developments and study their regional and local impacts, we chose the approach of linking three different models that work on different scales to analyse the role of bioenergy and land-use competition in Germany. The advantage of coupling different models is that interdependencies between different systems can be addressed without loosing a good representation of the details. The three models are the global multi-regional, multi-sectoral CGE model DART, which was developed for the economy-wide analysis of questions related to climate policy, the regionalised agricultural and environmental information system RAUMIS, which maps in detail the German agricultural sector and its land use, and a newly developed location model ReSI-M for the location choices of biogas plants that provides regionalised demand functions for maize. In this paper we show two different applications where we compare unadjusted simulations of DART and RAUMS to simulations of the adjusted models in the integrated framework. One application deals with effects of German biogas production on land use in Germany under different policy scenarios. Taking international energy and agricultural markets into account, the second application adds the effects of the EU 10%-biofuel quota that is to be achieved until the year 2020. A third application of the modelling framework analyses international effects of bioenergy policies with respect to the food versus fuel debate in a global context. All applications show that accounting for existing land use rigidities and restrictions has a significant impact on modelling results and thus also on policy recommendations that could be derived from such results.

The paper proceeds as follows: In the next section we briefly present the modelling framework and its components. Section 3 shows the two applications. Section 4 concludes.

2 The modelling system

The modelling framework consists of three models. The first model, DART, is a CGE model of the world economy with different world regions and sectors that is able to account for the relevant national and international feedback effects, including effects on agricultural and energy markets. DART is also able to model European and international biofuel policies. The second model, RAUMIS, is an agricultural sector model for Germany that models the regional impacts of bioenergy policies on agricultural land use, production and income as well as on the environment in great detail. The third component of the modelling framework is the newly developed model ReSI-M for the choice of location of biogas plants in Germany. Below we briefly present each of the models and the approach for harmonising them.

2.1 The DART model

The DART (Dynamic Applied Regional Trade) model is a multi-region, multi-sector recursive dynamic CGE-model of the world economy. For the analysis of bioenergy policies, it is calibrated to an aggregation of 19 regions that include major current and potential future bioenergy-producing regions (e.g. Brazil, Malaysia and Indonesia) as well as the main bioenergy-consuming regions (in particular the USA and different EU countries and regions including Germany). Each regional economy comprises seven energy sectors, eleven agricultural sectors that include the most important energy crops (wheat, maize, oil seeds, sugar cane and sugar beet) and three industrial production sectors (see table 1). Motor gasoline, motor diesel and natural gas can either be produced conventionally based on fossil resources or based on different energy crops. Bioethanol is produced from wheat, sugar cane, sugar beet and maize. Biodiesel is produced from oil seeds and vegetable oils.

The economy in each region is modelled as a competitive economy with flexible prices and market clearing. Three types of agents exist: a representative producer in each sector, a representative consumer in each region, and regional governments. All industry sectors operate at constant returns to scale. Output is produced by the combination of energy, non-energy intermediate inputs, and the primary factors labour and capital (and land in the agricultural sectors). Producer goods are directly demanded by regional households, governments, the investment sector, other industries, and the export sector. The representative household receives all income generated by providing primary factors to the production process. Disposable income is used for maximising utility by purchasing goods. The consumer saves a fixed share of income in each time period which is invested in production. The third agent, the government, provides a public good financed by tax revenues. All regions are linked by bilateral trade flows where domestic and foreign goods are imperfect substitutes, and distinguished by country of origin (Armington assumption). Factor markets are perfectly competitive and full employment of all factors is assumed. Labour and capital are assumed to be homogeneous goods, mobile across industries within regions but internationally immobile. The primary factor land is only used in agriculture and exogenously given. The DART model is recursive-dynamic, solving a sequence of static one-period equilibria connected through capital accumulation. The model horizon for this study is 2020. The major exogenous drivers of the model dynamics are changes in the labour force, the rate of labour productivity growth, changes in human capital, the savings rate, the gross rate of return on capital, and thus the endogenous rate of capital accumulation. Concerning the representation of the energy sector, the elasticities of substitution for the energy goods coal, gas, and crude oil are calibrated in such a way as to reproduce the emission projections of the EIA (EIA 2002).

Table 1: DART Regions and Sectors

Countries and regions			
EU and other Annex B		**Non-Annex B**	
DEU	Germany	BRA	Brazil
GBR	UK, Ireland	LAM	Rest Latin America
FRA	France	IND	India
SCA	Denmark, Sweden, Finland	CPA	China, Hong-Kong
BEN	Belgium, Netherlands, Luxemburg	MAI	Indonesia, Malaysia
MED	Greece, Italy, Portugal, Spain, Malta	PAS	Rest of Pacific Asia
REU	Rest of EU27	CPA	China, Hong-Kong
USA	United States of America	MEA	Middle East & North Africa
OECD	Rest industrialised OECD	AFR	Sub-Saharan Africa
FSU	Former Soviet Union		
Production sectors/commodities			
Energy Sectors		**Agricultural Sectors**	
COL	Coal Extraction	WHT	Wheat
GAS	Natural Gas Production & Distribution	COR*	Maize
CRU	Crude Oil	GRO	Other cereal Grains
GSL*	Motor Gasoline	OSD	Oil Seeds
DIS*	Motor Diesel	VOL	Vegetable oils and fats
OIL	Other Refined Oil Products	C_B	Sugar cane, sugar beet
ELY	Electricity	SGR	Sugar
		MLK	Raw Milk
Other production sectors		MET	Meat
ETS	Energy intensive sectors covered by EU ETS	AGR	Rest of agriculture & food products
CRP	Chemical products	FRS	Forestry
OTH	Other Manufactures & Services		

* These sectors where disaggregated from the original GTAP database

The current version of the static model is calibrated to the GTAP7 database that represents production and trade data for 2004 (Narayanan and Walmsley, 2008). To explicitly model motor gasoline and diesel (to be substituted by bioethanol and biodiesel) as well as maize (input for ethanol), their production was split from the more aggregated GTAP sectors 'refined oil products' and 'other grains', respectively. Bioenergy production is modelled as a latent technology that is not active in the base year because it is associated with a price mark-up relative to the fuel it substitutes for. This means that biofuels are only produced once relative input and/or output prices change or once policies are introduced that make them competitive with fossil fuels. The only country where bioethanol is already competitive is Brazil. Biofuel production in all other countries relies on support policies such as quotas or different forms of subsidies including tax exemptions or direct production subsidies. We introduce bioenergy production technologies from 2005 onwards. For bioethanol and biodiesel relevant feedstocks, labour, capital and electricity enter a nested CES-function and data from the Biofuels Platform (2009) are used to calibrate biofuel consumption shares (table 2).

Table 2: Shares of biofuel in total fuel consumption in 2007

	Biodiesel (oil seeds and vegetable oils)	Bioethanol			
		sum	Wheat	sugar beet/cane	maize
Germany	6.9	0.47	0.31	0.15	0.01
France	2.0	1.0	0.25	0.5	0.25
Great Britain	0.6	0.04	0.04	-	-
Scandinavia	1.05	0.4	-	0.4	-
Benelux	0.3	0.08	0.04	-	0.04
Mediterranean	0.8	0.48	0.24	-	0.24
Rest-EU	1.2	0.43	0.43	0.00	-
USA	1.2	3.2	-	-	3.2
Brazil	3.2	40.0	-	40.0	-
Rest OECD	0.02	0.34	-	0.17	0.17
Malaysia/Indonesia	4.7	-	-	-	-
China	0.4	1.0	1.0	-	-
India	0.38	0.48	-	0.48	-

Source: calibration based on Biofuels Platform (2009) and personal communication with meó Consulting Team

We assume in the reference scenario that the share of biofuel in total fuel consumption in each region stays at its 2007 level until the end of the projection period. DART endogenously calculates the implicit subsidies that are necessary to reach the imposed benchmark shares. Calibrating an export structure for a latent technology is difficult and data on biofuel trade flows are scarce. We assume that only Brazil exports bioethanol and only Malaysia/Indonesia export biodiesel. Both are imported by all industrialised countries. For a more detailed description of the introduction of biofuels into DART we refer to Kretschmer et al. (2008). For biogas, it is not maize that enters the production function, but instead all the intermediate inputs and the factors of production, including land, in the same shares as in conventional maize production. We then calibrate the amount of land that enters biogas production to correspond to the land used for energy maize production in RAUMIS (see also section 2.4).

2.2 RAUMIS

The Regional Agricultural and Environmental Information System RAUMIS developed by Henrichsmeyer et al. (1996) is a mathematical programming model covering German agriculture in line with sectoral data on the Economic Accounts for Agriculture (EAA). It is used for medium and long-term impact of agricultural and environmental policies in particular on regional agricultural land use, production, income and environment. The production is currently represented by 31 plant and 16 livestock activities that use about 40 inputs and produce 50 agricultural products. In addition to the variables land use and production the model comprises indicators such as fertiliser surplus (nitrogen, phosphorus and potassium), pesticides expenditures, a biodiversity index, and greenhouse gas emissions.

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

Adjustments caused by changes in general conditions e.g. agricultural and environmental policies are determined endogenously in RAUMIS using a positive non-linear mathematical programming approach (Howitt, 1995; Cypris, 2000). RAUMIS comprises a set of technical, political and economic constraints e.g. land availability, set-aside obligations, and production quotas. In outlook and impact analyses of alternative policies and framework conditions a comparative static approach is applied that proceeds in two stages. In the first stage, optimal variable input coefficients per hectare or animal are determined. In the second stage, profit maximising cropping patterns and animal herds are determined simultaneously with a cost minimising feed and fertiliser mix. Hence, activity levels and agricultural income on regional and aggregate level are endogenous variables. The specification of non-endogenous variables is based on trend extrapolations of yields, input coefficients, capacities as well as exogenous information e. g. prices and price indices from other models. In this context

RAUMIS is closely linked to the partial equilibrium model AGMEMOD (2007), both being part of the network of agricultural economic models at the von Thünen-Institute (Offermann et al., 2009).

Renewable raw materials for biofuel production are provided by traditional crops e.g. rape seed for biodiesel, and cereals and sugar beet for ethanol. In practice, there is no activity differentiation with regard to the use of the produce as feed, food or raw material for biofuels production. Hence, activities for biofuel production are not explicitly modelled.

In Germany, the amendment of the Renewable Energy Source Act[1] – (EEG) in 2004 has established an attractive support of using renewable resources for energy production, which since then has fuelled a rapid expansion of biomass crops. Green maize has proven to be the most competitive crop among the available traditional and non-traditional biomass crops for power generation in biogas plants. Against this background the new activity "energy maize" referring to green maize used for biogas production was implemented into RAUMIS (Gömann, Kreins & Breuer, 2007). The specification is based on the functional relationships that determine the input use e.g. seed, fertiliser, plant protection and machinery of the comparable activity "fodder (green) maize". The integration of activities that were not observed in the base year requires an appropriate modelling of the adjustment behaviour. Since no information especially on PMP (Positive Mathematical Programming)-Terms is available from ex-post analyses and base year calibrations, weighted PMP-terms of comparable activities are used to simulate an expectable activity level.

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

Support of biomass production for power generation mainly occurs through a guaranteed price for electricity generated from biomass. So far a sectoral producer price for biomass i.e. energy maize substrate has been derived based on the support scheme and used in simulations. It has been assumed that biomass demand is totally elastic at the given price and biogas plants will be built accordingly in Germany. The objective of the coupling of RAUMIS with ReSI-M and DART is to establish an endogenous price formation both for energy maize and the prices of other traditional crops that are so far taken from agricultural outlooks (e.g. FAPRI/USDA/OECD) or from results of market models such as AGMEMOD.

[1] *Erneuerbare Energien Gesetz* (EEG)

2.3 The location model ReSI-M

RAUMIS assumes completely elastic demand for biomass at given producer prices and opportunity cost. However, due to a variety of factors biogas plants might not be constructed everywhere. Thus, a regionally differentiated modelling of the demand for biomass is required which is especially important for crops with high transport costs as is the case for green maize.

The optimal location and size of biogas plants depend on a variety of interdependent factors: legislation, the availability of raw materials and resulting transportation costs, production costs, and the possibilities to use the produced crude biogas. In order to pre-select locations for biogas plants in Germany as well as to gain input data on land use characteristics and infrastructure a Geographical Information System (GIS) is used. In a first step we classify counties by their selling opportunities for heat produced by biogas plants and the possibility to induct gas into a natural gas pipeline. The second part of the GIS-analysis determines counties with a high population density and finally variances and mean shares of agricultural land are calculated for each county to account for differences in land distribution as well as rising transport costs with the amount of used maize. For more detail see Delzeit et al. (2009).

The thus collected information enters ReSI-M, which is formulated as a modified Capacitated Facility Location Problem (CFLP) with the objective to maximise return of investments. CFLP are classified as Mixed-integer programming models which start with a given set of potential facilities (Klose & Dexel 2005, p.11). The objective of the CFLP is to minimise costs considering the trade-off between fixed operating and variable delivery cost. Assuming a single-stage model (=simple plant location problem) it has to be decided whether to establish facilities (binary variable) and which quantities to transport from the field to a facility such that total costs (including fixed and variable costs) are minimised. In the model at hand, revenues from heat and electricity sales are reduced by fixed and variable crude biogas production costs, transportation costs, and processing costs which vary according to the size of a plant and the characteristics of the NUTS 3 regions.

To reduce variables, ReSI-M works at German NUTS 2 level with average sizes of ~900 km² and optimises location and size of biogas plants within its NUTS 3 regions (counties). The model could not be solved using Cplex version 10.1 in GAMS due to the high number of variables and binarity of one decision variable turning the problem into a NP-hard problem. Thus, a sequential methodology was applied to iteratively locate facilities, which allows the binary variable to be dismissed. This does not give an optimal but a reasonable solution. In each sequence profits are maximised by selecting the optimal size of a plant at different price levels of maize, given the differing characteristics of the counties. Thus, in each sequence, the optimal size of a plant is calculated and realised. Given the restriction that the sum of all transported maize cannot be higher than the available maize in all NUTS 3 regions, the used amount of maize for the current capacity is subtracted from the available amount of maize of the former sequence for the next step. The model allocates plants in the different NUTS 3 regions in each sequence as long as their profit is positive. Running sequences for different price levels a demand function for maize for each NUTS 3 region can be gained. A detailed description of ReSI-M can be found in Delzeit et al. (2009). Based on the simulations for different prices, demand functions for maize for each NUTS 3 region are generated. Additionally, numbers and sizes of biogas plants as well as regionally differing transport distances from maize transport are displayed.

2.4 The harmonised modelling system

Figure 2 below presents the modelling system of all three components. DART as the general equilibrium model passes on changes in world market prices to RAUMIS. RAUMIS calculates agricultural output in Germany based on these price changes. The thus derived supply elasticities for the German agricultural sector are used to recalibrate DART so that it produces comparable output responses in the German agricultural sectors. The output responses in the energy maize sector are crucial for the linkage between RAUMIS and ReSI-M. As an example, higher wheat prices trigger increased wheat production in RAUMIS, which due to restricted land availability will crowd out energy maize production. A reduced supply in energy maize enters the location model ReSI-M that will yield different market equilibria for the energy maize sector depending on the supply derived from RAUMIS and the demand function generated within ReSI-M.

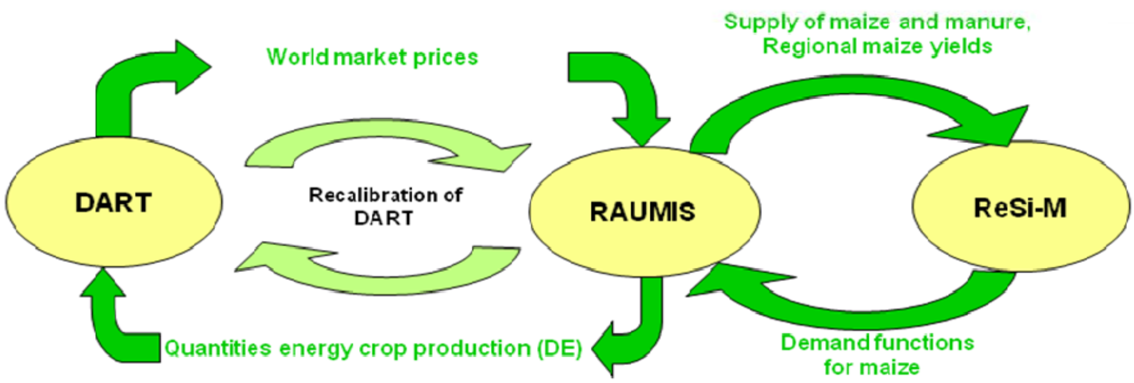

Figure 2: The harmonised modelling system

Linking DART and RAUMIS

As has become evident in the description of the individual models, DART and RAUMIS operate on very different scales and have very distinct comparative advantages. Linking them allows for the translation of national and global policy effects on the regional level in Germany. At the same time it is hard to reconcile models of such different methodologies and scales. The general idea is that we assume that RAUMIS correctly represents the German agricultural sector and correctly models the adjustment and structural change over time as well as the reaction to different external factors. RAUMIS provides a much more disaggregated representation of the agricultural sectors than DART and relevant parameters in DART are adjusted to imitate reactions of RAUMIS. Furthermore, DART incorporates information on present and projection of future 2020 energy maize and thus biogas production derived from RAUMIS. DART, on the other hand, adequately captures the interdependencies on global energy and agricultural markets, which are reflected in the equilibrium prices obtained from DART. These equilibrium prices thus form the basis for the model harmonisation and are passed on to RAUMIS, where prices enter exogenously. A RAUMIS baseline is consequently shocked with these price changes. The information gained from RAUMIS are changes in agricultural production and land-use patterns in Germany as a consequence of biofuel policies.

To arrive exactly at the same baseline and policy reactions in DART and RAUMIS turned out to be very difficult for a number of reasons including that

- in DART all outputs and prices of all sectors and regions are linked so that it is difficult to calibrate to a given price AND output vector of a subset of sectors;
- rates of technical progress are difficult to harmonise across the agricultural sectors that are common in both models;
- some relevant linkages of agricultural sectors like by-products are included in RAUMIS but not in DART; and
- RAUMIS includes many policy details e.g. of the CAP that influence reactions in the different production processes which are not included in DART (milk quotas, set aside land, etc.).

Our chosen approach with interesting implications is thus to adjust DART in such a way to get as close as possible to the agricultural sector development as projected by RAUMIS for Germany and to produce comparable policy reactions without achieving a full base convergence of both models. Thus, after a comparable baseline is constructed the next step is to run a policy scenario with DART – in this paper a 10% EU biofuel target. We then use the two models DART and RAUMIS sequentially and pass on relevant price changes from DART to RAUMIS that then delivers the sectoral details for the German agricultural sector.

Since the sectoral disaggregation is different in the two models with eleven agricultural sectors in DART and 31 plant plus 16 livestock activities in RAUMIS we focus on sectors that are important feedstocks for bioenergy production or are likely to be diverted due to enhanced bioenergy production. These are wheat, maize, other cereal grains and oilseeds as well as the milk and meat sectors with important linkages to the crop sectors as the latter provide input in the form of cattle feed to the former.[2] To match price and output developments of the German agricultural sectors in DART with the developments in RAUMIS required extensive adjustments in DART. First, we model the EU Eastern enlargement of 2004 by abolishing all import tariffs between all EU countries. We then adjusted the elasticity of substitution between land and other primary factors for the EU in order to approach agricultural technical progress rates as provided by FAPRI (2009) that also underlie the simulations of RAUMIS. Our initial progress rates derived from DART were too high so that we adjusted the mentioned elasticity downwards (from the original default value of 0.25 to 0.15). We furthermore performed sector-specific adjustments of the substitution elasticity for Germany in order to mimic the sectoral development derived from the *vTI model network*. Further adjustments were needed in the milk and meat sector where we exogenously scaled up output, mimicking a higher degree of technical progress in these sectors. We finally changed policy parameters, specifically abolished the subsidy rates on the intermediate use of maize, meat and milk in all EU regions. The rationale for these changes lies in the largely decoupled support of EU agriculture as part of the CAP. In the milk sector, the underlying policy change is the phasing out of the milk quota.

Further adjustments were necessary as first iterations between DART and RAUMIS based on a 10% biofuel scenario revealed the very distinct responses in a general equilibrium and a pure supply-side model. This became most apparent in the oilseeds sector: While German oilseeds production according to DART increased considerably (up to 20%) as a result of biofuel policy, the corresponding producer price effects were much more modest (up to 4%). When these modest price effects were phased into RAUMIS, the resulting supply elasticities turned out to be less than one, meaning that the elasticities produced by the two models diverged tremendously. The reason is found in the unlimited transformability of land use between agricultural sectors implied by DART. We therefore introduced a two-level nested constant elasticity of transformation (CET) function in order to describe natural and economic constraints farmers face when deciding between different land uses. In the first level land is distributed to either crops (wheat, other grains, maize, oil seeds) or non-crops (milk, meat, sugar beet, other agricultural products) production. In the second level cropland is distributed to the different crops. Elasticities of transformation are taken from the OECD-PEM model[3] and adjusted to mimic the vTi baseline (see Offermann et al. 2010). The introduction of the

[2] We do investigate the sugar sectors in both models in detail since this sector is strongly regulated by the EU's Common Agricultural Policy (CAP), which is represented in RAUMIS but not in DART.
[3] http://www.oecd.org/dataoecd/11/27/37076349.xls, last accessed 29.6.2010.

CET framework made DART react very consistently with RAUMIS, mimicking thus the existing land use restrictions.

Coupling RAUMIS and ReSI-M

In order to derive regional green (energy) maize markets, RAUMIS and ReSI-M are coupled in an iterative approach. First, RAUMIS simulates price-quantity relations for different maize prices based on the political framework considered in the baseline scenario of RAUMIS. This allows deriving supply functions for every NUTS 3 region in Germany. In a second step, by intersecting these supply functions with demand functions generated by ReSI-M, market clearing price and quantities are derived. Finally, these regional market prices exogenously enter RAUMIS and reaction within the agricultural sector can be simulated. In this case, the two models RAUMIS and ReSI-M are thus completely coupled.

3 Application of the model framework: bioenergy policies and land use restrictions

In this section we present a first application of the model framework in which we show the effects of the linking and harmonisation of the models and the implications of the German EEG on German biogas production as well as of the EU target of a 10% biofuel quota on land use change in Germany.

3.1 Scenario design

The starting point for the simulations is a baseline or reference scemario (Acronym: *Reference*) that rests upon the vTI-baseline (Offermann et al. 2010) which, however, required some modifications due to the harmonisation of DART and RAUMIS mentioned in the previous section. The reference represents the expected development of the German agricultural sector until 2020 and builds on the EU common agricultural policy as decided in the Health Check reform. The phasing out of the milk quota and the obligatory set aside are of major importance regarding agricultural land use. Producer prices are expected to increase by 41% for wheat and 39% for rapeseeds from 2004 until the target year 2020. The producer price for energy maize is derived on the basis of the support scheme stated in the EEG 2004, however a uniform sectoral price of 27 Euros per ton (28 per cent dry matter; free at biogas plant) is assumed.

ReSI-M then introduces two different scenarios. The EEG 2004 scenario applies feed-in tariffs which biogas plants receive for inducting electricity into the grid according to EEG 2004. Under a second scenario the amendment of EEG 2008 is considered. Here, the basic feed-in tariffs per unit inducted electricity is increased compared to EEG 2004 and an additional bonus is paid to small scale plants for using a minimum share of 30% manure (the so called "manure bonus"). RAUMIS is then run with the two sets of regional demand curves of ReSI-M's EEG 2004 and EEG 2008 scenarios (Acronyms: *EEG-2004* and *EEG-2008*). The results show how a better representation of maize demand changes the RAUMIS results and how EEG 2004 and EEG 2008 compare to each other.

To analyse the 10% EU biofuel target accounting for the intersectoral and international linkages different scenarios with DART are run. In the DART reference scenario it is assumed that the share of biofuels in total fuel consumption stays at the level of 2007 (see table 2). This is achieved by a subsidy on domestic production of biofuels. DART then introduces a policy scenario of a 10% biofuel target in all EU model regions by the year 2020. We first run a DART baseline that tries to mimic the RAUMIS baseline including the demand curves of the EEG 2004 of ReSI-M. This DART baseline includes all the adjustments mentioned in section 2.4. Then we run the policy scenario with a 10% biofuel quota on top of this baseline. The resulting price changes are passed on to RAUMIS as described above which then shows the implications of the EU biofuel target for German agriculture. A further iteration step follows as the imposition of the biofuel quota crowds out energy maize production in Germany. DART is thus rerun with the 10% quota while targeting a lower 2020 energy maize production as projected by RAUMIS. The resulting scenario is referenced as *EEG-2004-BF*. To assess the implications of the harmonised modelling framework the thus derived results are compared to a set of reference/policy runs excluding the adjustments made to mimic the RAUMIS baseline and behaviour. In addition to these scenarios RAUMIS and ReSI-M are coupled given the political framework inherent in EEG 2008 and the effects of the 10% target imposed on top (Acronym: *EEG-2008-BF*).

In the following section we first present results for the EEG scenarios and then in section 3.3 for the EU biofuel targets.

3.2 Effects of the EEG on biogas production and the agricultural sector in Germany

Table 3 gives an overview about relevant outputs in the different EEG scenarios when RAUMIS is coupled to ReSI-M. One important result is that the coupling with a better representation of demand for maize clearly makes a difference. This is especially true for the *EEG-2008* scenario which can be seen in sizeable percentage changes of the variables shown. Concerning energy maize production, RAUMIS simulates an energy maize area for biogas production of about 1.5 million hectares in the reference scenario (see table 3). Energy maize production and its value amount to about 95 million tons and 2.6 billion Euros, respectively. According to simulations with ReSI-M energy maize is mainly demanded by medium size plants using an input of 10% manure and 90% energy maize under the *EEG-*

2004 scenario. Including the regional energy maize demand curves from ReSI-M into the RAUMIS analysis shows that under the *EEG-2004* scenario, the average of the regional producer prices for energy almost equals the uniform sector price assumed in the reference run (see table 3). While the total energy maize area does not change the regional allocation of energy maize area deviates from the reference scenario (see figure 3).

Table 3: Producer prices and land use under various scenario settings

	Refe-rence	EEG 2004	EEG 2008	EEG 2008-BF	EEG 2004	EEG 2008	EEG 2008-BF
	absolute values				% versus reference.		
Producer prices (Euro / t)							
Wheat	155	155	155	181	0.0	0.0	17.4
Rapeseeds	309	309	309	400	0.0	0.0	29.7
Energy Maize (biogas)	27.6	27.6	32.3	33.4	-0.1	16.8	21.0
Land use (1,000 hectare)							
Cereals	5,813	5,845	5,516	5,372	0.5	-5.1	-7.6
Wheat	2,747	2,765	2,647	2,797	0.7	-3.6	1.8
Maize	317	318	303	319	0.5	-4.4	0.6
Other cereals	2,750	2,762	2,566	2,256	0.4	-6.7	-17.9
Oilseeds	1,745	1,767	1,615	2,335	1.2	-7.5	33.8
Legumes and root crops	681	683	671	649	0.4	-1.4	-4.6
Green maize	901	900	882	846	-0.1	-2.1	-6.1
Other Green Fodder	521	519	481	348	-0.3	-7.6	-33.2
Energy maize (biogas)	1,532	1,483	2,118	1,834	-3.2	38.3	19.8
Set aside	90	92	64	11	2.7	-29.1	-88.2
Production (million metric tons)							
Cereals	44.4	44.7	42.3	41.9	0.6	-4.8	-5.8
Oil seeds	7.2	7.3	6.7	10.2	1.3	-7.3	41.9
Energy maize (biogas)	94.7	91.8	129.9	112.8	-3.1	37.1	19.1
Agricultural income (billion Euro)	12.2	12.2	12.5	14.3	-0.1	2.4	17.6

Source: Own calculations with RAUMIS, ReSI-M and DART.

Applying the *EEG-2008 scenario*, small scale plants using 30% manure and 70% of energy maize as inputs become the most profitable plant type. As a consequence of the introduction of the manure bonus under the EEG 2008 operators of these types of biogas plants are able to produce at higher energy maize prices making energy maize more competitive against other crops. According to the results of coupling RAUMIS and ReSI-M model, the average regional maize price increases by about 17 per cent. Due to its high competitiveness energy maize area increases by about 38% (see table 3) and the production value even by 62% compared to the reference scenario. The increase occurs mostly at the expense of other cereals and oilseeds that together decline by about 350,000 hectares. Due to the implementation of the so called “manure bonus” the total agricultural income increases by about 2% in comparison to the reference scenario (see table 3).

Furthermore, the results show that these changes vary regionally (see figure 3). As ReSI-M incorporates regional factors such as availability of manure or transport costs into the simulation of demand functions, regionally differentiated maize markets emerge under the *EEG-2008* scenario (see figure 3). The share of maize on arable land is particularly high in regions with a sufficient availability of manure and at the same time low opportunity costs of energy maize production (e.g. in some regions of Lower Saxony, Bavaria, Mecklenburg-West Pomerania). The next section adds a discussion of the consequences of imposing a 10% biofuel quota.

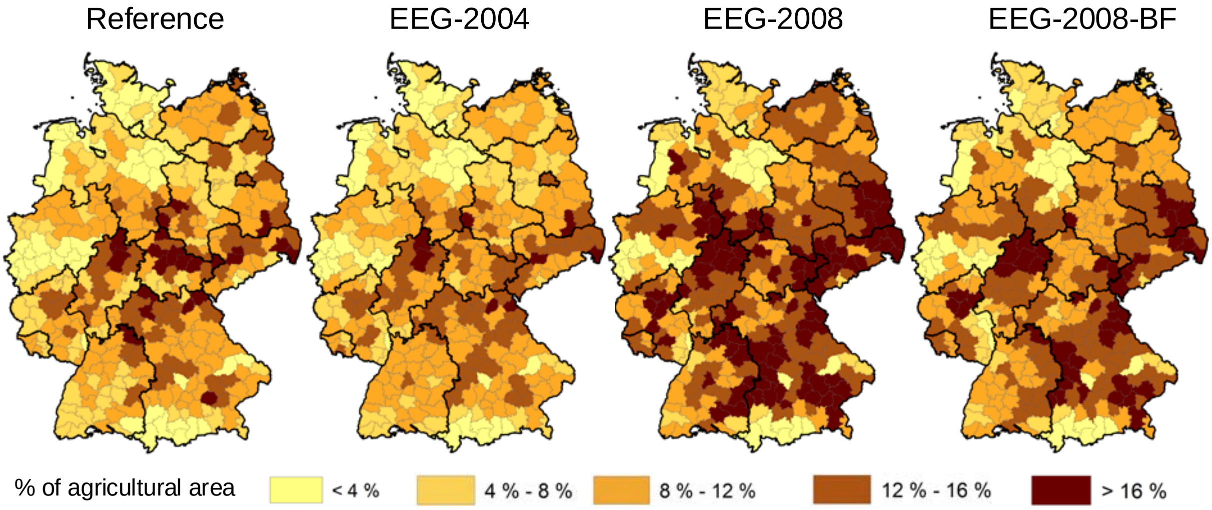

Figure 3: Share of maize on arable land in 2020 at different scenarios

3.3 Effects of the EU 10% biofuel quota in Germany

In the next step we run the DART model imposing a 10% biofuel target and pass on the resulting price changes for bioenergy feedstocks (wheat, maize, and oil seeds) and other relevant agricultural outputs to RAUMIS as has been described above. The results for Germany are included in table 3 and figure 3 (scenario *EEG-2008-BF*). Due to the additional demand for cereals and oilseeds to fulfil the biofuel target the prices for wheat and rapeseed increase compared to the reference scenario by 17% and 30% respectively.

Of course higher prices for the traditional crops in the *EEG-2008-BF* scenario in comparison to the *EEG-2008* scenario result in higher opportunity costs of energy maize production. Consequently, land used in particular for oilseed production is increased by 34% compared to the reference scenario and even by 45% compared to the *EEG-2008* scenario. The expansion of maize cultivation for biogas production is lower when adding the 10% target, but the production of other cereals and other green fodder is reduced considerably due to changes in relative prices. Because of the biofuel driven higher price level in the *EEG-2008-BF* scenario agricultural income is about 18% above the income in the reference scenario.

Regional impacts on the biogas maize area are illustrated in the right map of figure 3. The share of biogas maize on arable land is reduced mainly in regions that feature an increase in cereal and oilseed production. After running the *EEG-2008-BF* scenario, we performed a further iteration run in DART by including the increase in energy maize production of 19.8% compared to the reference triggered by the more generous EEG 2008 policy support. The results show that the price and quantity changes of relevant agricultural outputs in DART did not qualitatively alter with the change in energy maize production.

3.4. International effects of the EU 10% biofuel target

In this section we show selected results of the DART model focussing in particular on the European and international implications of the EU 10% biofuel quota. And here, it is important to note the implications that land use restrictions have on model results.

Figure 4 depicts biodiesel and ethanol production in the DART European model regions in the year 2020. Production in the two policy scenarios *no adjustment* and *mimic RAUMIS* is compared to production in the *no adjustment* reference scenario.[4] It should be noted that while we introduced CET-functions to better represent sectoral land use shifts in all DART regions, further adjustments to the agricultural sector were targeted at Germany in order to harmonise DART and RAUMIS. Introducing the CET approach has considerable consequences for production patterns in all regions producing bioenergy. One thing to note is that European imports of Brazilian ethanol drop by 46% in *mimic RAUMIS 10Q* compared to *no adjustment 10Q*. Since land-use restrictions differ to some extent across model regions, there are shifts in relative biofuel production prices and the cost advantages especially of Brazilian imports are reduced. This in turn has implications for European production with most notably Scandinavia and Great Britain and Ireland increasing their production. In *Rest of EU27*, it becomes cheaper to fulfil the quota by increasing ethanol at the expense of biodiesel production.

[4] There were only minor changes between the two reference scenarios *no adjustment* and *mimic RAUMIS* which is why only one reference is shown for better visibility.

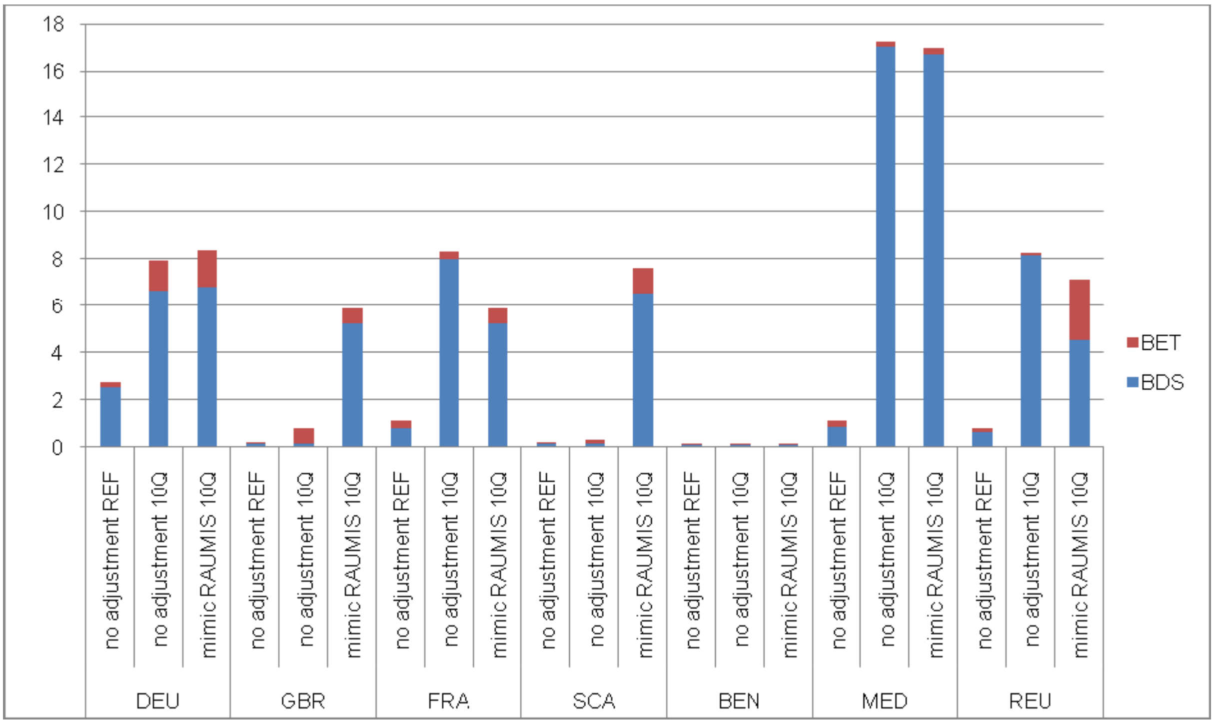

Figure 4: Biodiesel (BDS) and bioethanol (BET) production in the EU in 2020 (in mtoe).

In the context of the “food versus fuel” debate, the question is to what degree European biofuel production affects world agricultural markets and leads to spillovers on food prices. Figure 5 shows price effects of the EU 10% target in DART with and without the adjustments that were necessary to mimic RAUMIS baseline and behaviour for selected crops. The different bars refer to the production-weighted EU and global average prices. The standard DART model without the adjustments to mimic RAUMIS shows relatively small price reactions of 2.2–3.6% in the EU average and -1.3–1.1% in the world average. These results are also in line with other modelling studies based on similar approaches (see Kretschmer and Peterson 2010) and past simulations with standard DART (see Kretschmer et al. 2009) and follow from the very flexible adjustment possibilities in the agricultural sector. Also note that price changes are rather similar across different crops even though some of them are used as bioenergy feedstocks and others are not. Through RAUMIS we obtain information on more realistic elasticities of different land uses. Thus, when DART tries to mimic the reactions of RAUMIS the picture changes significantly. Now the price reactions for bioenergy feedstocks are much larger, reaching a maximum of 52% for the average European oil seeds price while the second highest increase is 16% for wheat. Also the price reactions of world markets reach 15 to 19% for maize and oilseeds and 5 to 7% for wheat, other grains and sugar beet/cane. Furthermore, there are larger price differentials across different agricultural goods. In particular, now the price effects for non-feedstocks (other grains) are much lower than for bioenergy feedstocks. Biofuel promotion is not only costly in terms of higher agricultural prices, but also in terms of overall welfare. For the EU as a whole, welfare in 2020 decreases by 5% in the *mimic RAUMIS* policy scenario compared to its baseline. In comparison, the more flexible land-use adjustment implies that welfare decreases by merely 0.02% in the corresponding *no adjustment* scenarios. For Germany, the focus of the model system, welfare reduces by 3.9% in the *mimic RAUMIS* policy scenario compared to minus 0.06% in the *no adjustment* scenario.

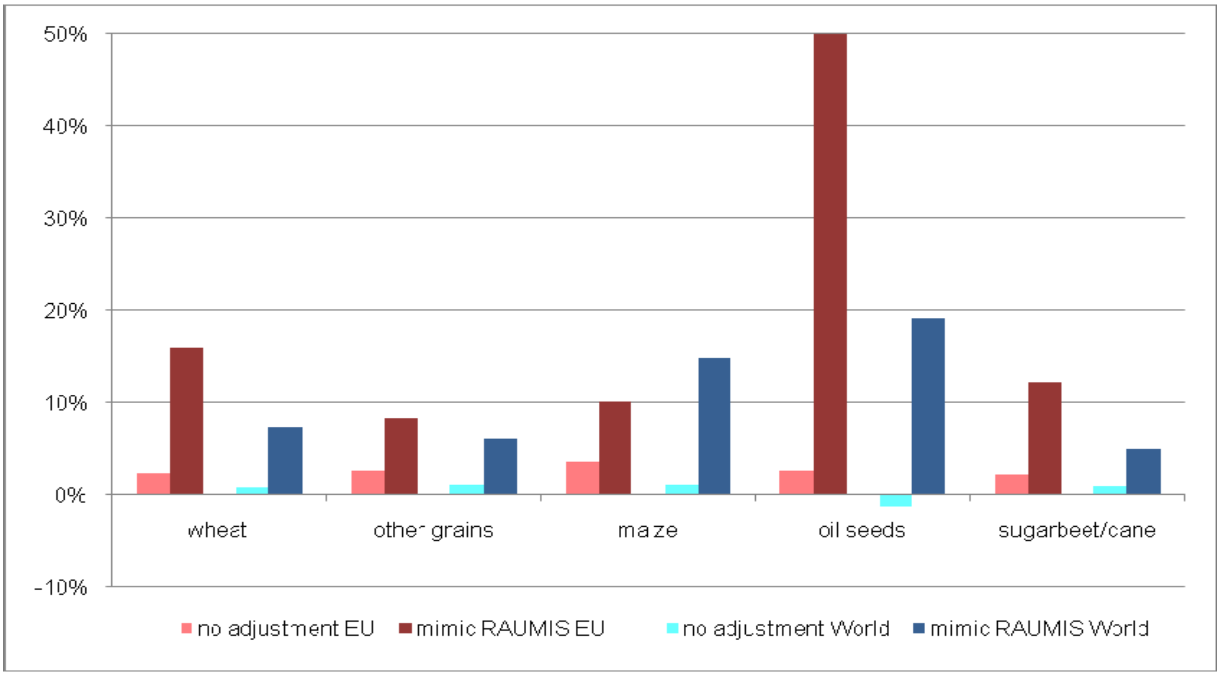

Figure 5: Changes in agricultural prices under a 10% EU biofuel quota compared to the baseline in 2020 in the EU and the world.

Overall, the simulations imply that the “food versus fuel” debate becomes in fact relevant when accounting for land use restrictions. To give an idea of the impact on food security in developing countries, figure 6 shows the effects on household consumption of the different crops in Latin America (LAM) and Sub-Saharan Africa (AFR). We see that consumption reductions are as high as minus 4% for oil seeds in AFR and even up to minus 7.5% in Latin America. While micro models are needed to study detailed effects on poverty and income distribution, these results can be read as pointing out a concrete danger of increased food shortage in developing countries as a response to biofuel promotion in the industrialised world. Of course it should be kept in mind, though, that agricultural sector development in developing countries for either food or bioenergy production could alter the picture in the sense that higher agricultural prices would then at least benefit farmers.

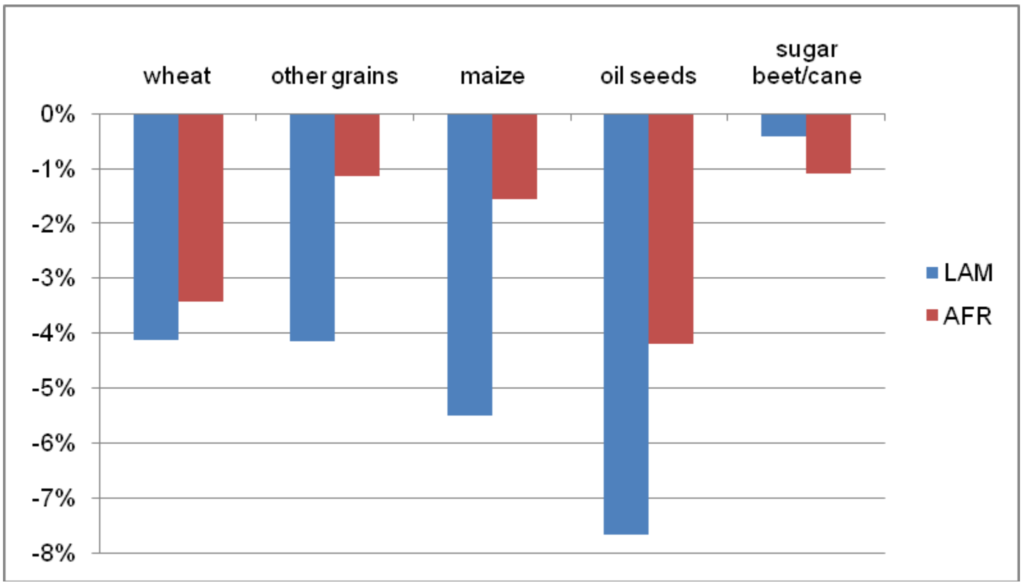

Figure 6: Changes in household consumption under a 10% EU biofuel quota compared to the baseline in 2020 in Sub-Sahara Africa and Latin America

4 Summary and conclusions

For analysing the implications of an increased production of bioenergy in Germany, the EU but also worldwide it is important to account for the linkages especially with the agricultural and the energy sector. In particular, one needs to account for the competing uses of agricultural land where the most important is clearly the competition between feedstocks for biofuel production and food production which is the basis for the "food versus fuel" debate. In addition, it is also important to account for the rigidities of agricultural production and the limitation to move land between different uses. Others have already stressed that an adequate representation of land-use competition and land-use restrictions is decisive for the implications of bioenergy production and while early studies where mostly only focusing on biofuel production itself, there is now a steadily growing number of modelling studies that account for the relevant linkages and also include details on land use (see Kretschmer and Peterson 2010 for an overview). Most of the models in this respect aim to better capture land use competition globally, which goes at the expense of sectoral detail. In the modelling framework presented in this paper we aim to look more closely at land-use competition within one economy. While we here focus on Germany, we believe that this modelling approach could be adopted for other countries as well.

The models of the presented modelling framework consist of the global regionally disaggregated general equilibrium model (DART), the regionalised agricultural land use model (RAUMIS) for Germany and a location model for biogas plants (ReSI-M) also for Germany. The DART model, which is extended by technologies that produce biogas, biodiesel and bioethanol, allows capturing international and national feedback effects of an increased use of bioenergy such as increased food prices. Harmonising DART and RAUMIS links global energy markets with the rest of the economies and connects this global dimension to the detailed specification of land use in Germany. Finally, we link this system to the newly developed location model ReSI-M that accounts for the location choices of large scale bioenergy plants in Germany and the resulting limitations for bioenergy demand.

In this paper the model system is used to simulate two different types of bioenergy support. Coupling ReSI-M and RAUMIS, the effects of the German Renewable Energy Source Act in its previous and reformed version (EEG 2004 and EEG 2008) on German agricultural and in particular biogas production are analysed. Linking furthermore DART to RAUMIS, the effects of the EU 10% biofuel quota on German agriculture and international agricultural prices are analysed. DART simulates the EU policy, mimicking land-use restrictions that are captured in RAUMIS and passes on the resulting price changes in major agricultural outputs to RAUMIS.

The first result is that the EEG leads to massive increases in maize prices and cultivation area, especially under the *EEG-2008* scenario. Coupling RAUMIS to ReSI-M leads to a proper representation of regional parameters such as manure availability and transport costs and significantly changes the baseline of RAUMIS. The results taking these parameters into account and running the *EEG-2008* scenario show a clear pattern of high manure availability and high crop production coinciding with high shares of maize cultivation area. The importance of manure availability is in line with the incentives set by the EEG 2008 that grants a bonus for small scale plants that use at least 30% of manure as input. Introducing the effects of the 10% biofuel target dampens the increase in maize cultivation area and leads to expansion of oil seed cultivation while set-aside area is reduced further.

For the simulations with DART the most important result is that the adjustments that were necessary in DART to adequately capture the land-use restrictions modelled in RAUMIS have significant implications on the effects of the 10% bioenergy target on German, EU and world agricultural markets. Price increases for crops, which are an indicator for the relevance of the “food versus fuel” debate were only in the range of 2% in Germany, 2.2–3.6% in the EU average and -1.3–1.1% in the world average (always relative to the baseline in 2020) before harmonising DART and RAUMIS. Also, there was no price differentiation between crops used as bioenergy feedstocks and crops only used for food production. After the adjustments price changes where substantially higher and now mostly in the order of 10–20% increases. Furthermore, effects for bioenergy feedstocks where significantly larger than for other crops, reaching even a 50% increase of European oilseed prices. This shows that land-use restrictions do matter and that current estimates of low price changes may not be realistic. Furthermore, effects will become even larger when accounting also for the bioenergy targets of other countries like the US or when more countries like China and India agree on such targets.

Altogether, the main conclusion that one can draw from this paper is that an adequate representation of land-use restrictions is important for assessing the implications of increased bioenergy production. At the same time, coupling different models with very different set-ups and model philosophies is indeed difficult and we did not yet arrive at a fully coupled and integrated system. Yet, our existing results have shown that it is worthwhile to invest in future research in this direction.

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