Kiel
Working Papers

Kiel Institute
for the World Economy

An Economic Assessment of Biogas Production and Land Use under the German Renewable Energy Source Act 2012

by Ruth Delzeit, Wolfgang Britz and Peter Kreins

No. 1767 | April 2012, update November 2012

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

Kiel Working Paper No. 1767 | April 2012

An Economic Assessment of Biogas Production and Land Use under the German Renewable Energy Source Act

Ruth Delzeit, Wolfgang Britz and Peter Kreins

Abstract: The Renewable Energy Source Act (EEG) promotes German biogas production in order to substitute fossil fuels, protect the environment, and prevent climate change. As a consequence, green maize production has increased significantly over the last years, causing negative environmental effects on soil, water and biodiversity. In this paper we quantitatively analyse the EEG-reform in 2012 by applying the simulation tool ReSI-M (Regionalised Location Information System – Maize). Comparing the EEG 2012 with a former version of the legislation, results imply that the reform leads to reduction of biogas electricity generation compared to former versions, and thus to less substitution of fossil fuels. Furthermore, given a restriction in the share of green maize input, its production is reduced and the crop-mix is diversified. However, since maize provides the highest energy output per area, total land requirement for biogas production increases. An alternative analysis shows that an EEG with tariffs independent from plant-types would provide the highest subsidy efficiency, but slightly lower land efficiency compared to the EEG 2012.

Keywords: bioenergy, biogas, land use, policy analysis, simulation model

JEL classification: C61, Q16, Q42

Ruth Delzeit
Kiel Institute for the World Economy
D-24100 Kiel
E-mail: ruth.delzeit@ifw-kiel.de

Peter Kreins
Institute of Rural Studies, Federal Research Institute for Rural Areas, Forestry and Fisheries
D- 38116 Braunschweig

Wolfgang Britz
Institute for Food and Resource Economics
University of Bonn
D-53115
E-mail: wolfgang.britz@ilr.uni-bonn.de

1 Introduction

Based on the European Renewable Energy Road Map, which aims to increase the share of renewable energies for primary energy consumption to 20% by 2020 (European Commission 2007), Germany has subdivided the 20% target into a share of 14% in the heating sector, 17% for fuels and 27% in electricity production (BMU 2007). Within renewable energies, biomass has a share of 70% in Germany, and is used for heat, fuel and electricity production. In relation to the total end energy consumption, bioenergy accounted for about 7.7% in 2010 (BMU 2011, p.12), and is targeted for an increase to 10.9% in 2020 (BMU 2010, p.10). For the electricity sector, in addition to electricity from wind, water and solar energy, electricity from renewable energy is produced from biogas, which is mainly based on the fermentation of biomass. Due to current targets, the use of biomass is expected to grow in the future (SRU 2007, p.1).

One of the bioenergy options is production of biogas, considered in Germany as a promising candidate for a sustainable energy mix. Accordingly, Germany's Renewable Energy Source Act (EEG) promotes electricity production from biogas along with other renewable energies. The EEG provides producers of electricity from renewable energies with per unit feed-in tariffs (FITs) which are higher than the price paid for electricity from fossil fuels while forcing network operator to buy the electricity at the FITs. The higher costs raise the electricity bill of the final consumers. Thereby the EEG compensates the higher production costs of renewable energies and makes them competitive with electricity from conventional energy sources.

Green maize is the dominant feedstock used for biogas production in Germany, and with an increase in biogas production, its cultivation area has expanded significantly over the last years. The production of green maize on large scale comes along with negative environmental effects on soil, water and biodiversity (SRU 2007, p.2), seen by the German Advisory Council on the Environment (SRU) as a serious factor to harm the environment (SRU 2007, p.43).

While land use change under former versions of the EEG has been analysed by e.g. Gömann et al. (2011) and Delzeit et al. (2012b), the effects of the EEG 2012 have not been discussed in literature. Thus, the objective of this paper is to analyse impacts on land use and biogas production as well as costs to electricity consumers in Germany caused by the reform of the EEG in 2011 (came into force January 2012) by comparing biogas production under three policy scenarios. The paper is structured as follows: background on biogas production and German legislation is provided in section 2. In section 3, an extended version of the location model Regionalised Location Information System – Maize (ReSI-M2012), the underlying data and its parameterisation are presented. The applied scenarios and results on regional maize markets, land use, biogas plant structure and profitability are illustrated and discussed in section 4. The paper concludes with a summary of results and some suggestions for policy improvement.

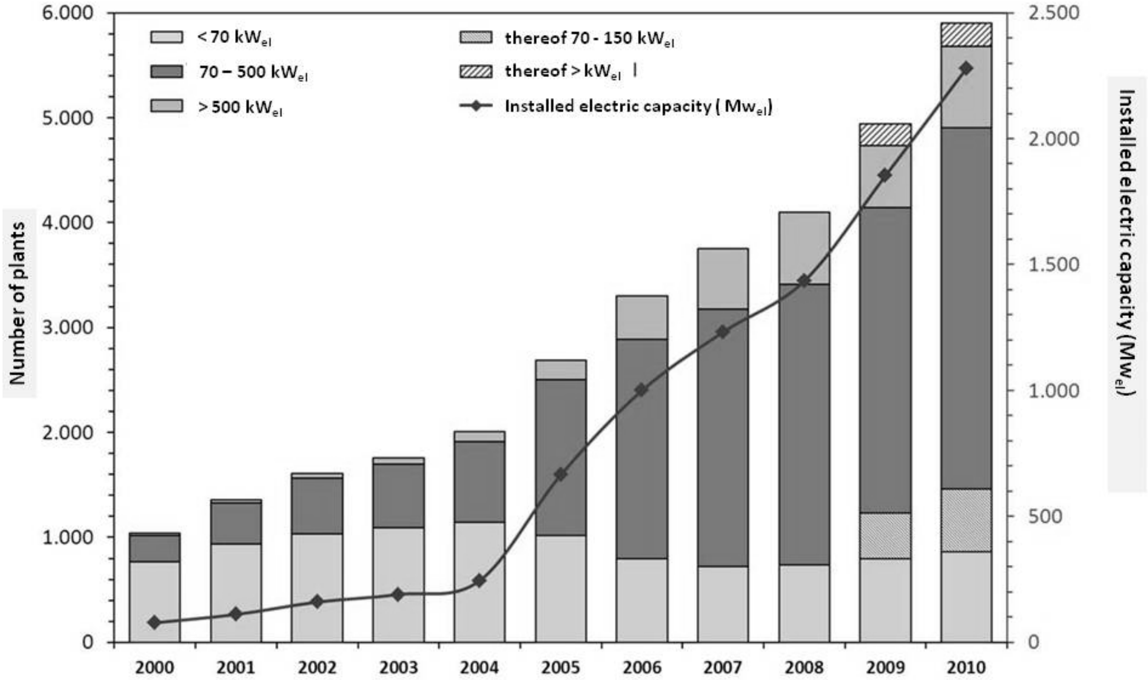
2 Biogas Production in Germany

Since 1990, the so-called (Stromeinspeisungsgesetz SEG, law on electricity feed-in) (BGBL 1990) regulated the feed-in of electricity produced from renewable energies into the public power grid in Germany. It was replaced in 2000 by the first version of the EEG (BGBL 2000) which was subsequently revised in 2004, 2008 and 2011 (BGBL, 2004, 2008, 2011). Already the SEG 1990 was assessed to be successful, since the share of renewable energies for electricity consumption increased from 5.2% in 1998 to 7.5% by the end of 2001 (German Federal Cabinet 2002, p.2). To further increase energy production from renewable energies, in 2004 the EEG was amended. Compared to the 1990 version, FITs are higher in the EEG 2004 and divided into a basic payment per kWh_{el} (Grundvergütung) and additional per unit subsidies adjusted depending on input, plant size and plant technology: an important bonus is the “NaWaRo” (renewable resources) bonus, which is restricted to electricity that is gained from plants or parts of plants which are produced in agricultural, silvicultural or horticultural farms and from manure (for more details on definitions see BGBl. 2004, § 8 (2)). In addition, producers receive a bonus for using heat according to the heat-and-power generation law. The combined heat and power generation (CHP) bonus depends on the actual amount of heat used and on the plant’s electricity efficiency. The efficiency as well as the share of heat used is generally lower in small plants (< 150 kW_{el}), which therefore benefit less from this bonus. A technology bonus is paid if CHP is applied and biomass is transformed by thermo-chemical gasification or dry fermentation, the biogas produced is processed to natural gas level quality or electricity is gained from fuel cells, gas turbines or other applications, which are defined in BGBL. 2004, § 8 (4).

As a consequence of the EEG 2004, installed electric power from biogas increased from 190 MW_{el} in 2003 to 1450 MW_{el} in 2008 (see Figure 1). Not only have more biogas plants been constructed, but their average plant size has also increased. Medium size plants with a capacity of 500kW_{el} using a high share of green maize (ensilaged maize where the whole plant is utilised) as input were the most favourable plant types.

.

Figure 1: Installed electric power and share of different plant sizes



Source: modified after DBFZ 2011, p. 37.

The version of the EEG 2004 aimed to achieve a 12.5% share of renewable energies for electricity production by 2010 and 20% by 2020. The 2020 target was even raised with the amendment of the EEG in 2008, taking effect in 2009 which aims to increase the share of renewable energies for total electricity production to at least 30% by 2020 (BGBl 2008). With rising prices for agricultural raw products and food in 2007-2008, in parts an effect of higher energy prices which increased variable costs in crop production (e.g. for diesel, fertiliser, plant protection), also competition for land between arable went up. Higher variable and opportunity costs let feedstock costs for biogas plants increase. As a response, in order to keep electricity production from biomass competitive, the EEG 2009 grants higher FITs with a focus on small scale plants. While for the use of CHG all plant sizes receive a higher bonus, the basic FIT was increased for the first 150kW$_{el}$ and the NaWaRo bonus for capacities up to 500kW$_{el}$. In addition, to provide an incentive to use a larger share of waste materials and thus to reduce competition for land, small scale plants (≤150kW$_{el}$) using 30% manure receive a special bonus. Table 1 illustrates that small-scale plants especially benefit from the amendment if they are able to claim all subsidies.

Table 1: Feed- in tariffs for EEG 2009

	≤ 150 kW_{el}	**≤500 kW_{el}**	**≤ 5 MW_{el}**	**5-20 MW_{el}**
Basic feed-in tariff	11.67	9.18	8.25	7.79
NaWaRo bonus	7	7	4	0
Manure bonus	4	1	0	0
Bonus CHG	3	3	3	3
Technology bonus	2	2	2	0
max. possible revenues from EEG (€ cent / kWh_{el})	**27.67**	**22.68**	**17.25**	**10.79**

Source: BGBL.2008

The observed increase of biogas production, at unchanged technology, was only feasible by higher feedstock use which in turn required devoting sizable amounts of arable land to feedstock production. It is assumed that in 2009, already 530,000 ha have been used for the cultivation of inputs for biogas production (FNR 2009), accounting for approximately 5% of total agricultural land in Germany, or about 1/4 of what the EU used to subsidise as renewable energy area EU wide. The regional distribution of biogas plants and related feedstock areas is very heterogeneous in Germany. Whereas in the most Northern German state Schleswig-Holstein, 26% of arable land were cultivated in 2010 with green maize for biogas production (MLUR 2011), in states such as Hessen or Saarland biogas production per arable land is very limited (DBFZ 2011, pp.39-40). We will discuss drivers of these differences in chapter 3.

Land use changes as consequence of the EEG 2009 are also simulated in economic models by Gömann et al. (2011) and Delzeit et al. (2012a, 2012b). Their results imply that the legislation meets its target of increased electricity production from biogas, but in total and also per produced unit of electricity, more land is used compared to the EEG 2004 (see Delzeit et al. 2012b). Especially the higher land demand per unit of electricity is surprising at first glance as the EEG 2009 introduced higher subsidies for manure use. The studies show indeed that newly erected plants use more manure, but highlight that the low energy efficiency of small-scale plants rendered economically attractive by the amendment (see table 1) offset the land saving effect of using manure which is anyhow small due the low energy content of manure.

A new amendment of the EEG came into force in 2012 and like the EEG 2009 it aims to *„(...) facilitate a sustainable development of energy supply, particularly for the sake of protecting our climate and the environment, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to conserve fossil fuels and to promote the further development of technologies for the generation of electricity from renewable energy sources" (*this English translation is taken from BGBl 2008 §1*).* While the EEG 2009 aims to achieve a 30% share of renewable energies for electricity production by

2020, this target is increased in the EEG 2012 to 35% in 2020 and up to 80% in 2050 (BGBl 2011 §1). In order to reduce the input of green maize, and to simplify the system of feed-in tariffs, substantial changes were introduced in the amendment. “NaWaRos” are divided into two classes with one class (substance tariff class II) containing ecological desirable substances (BGBl. 2011). Additionally, the combined feedstock share of maize and (coarse) grains is limited to maximal 60% on the mass content. In addition, plants are obliged to either use heat to a certain degree or reach a minimum share of manure in order to receive FITs.

Table 2: Feed- in tariffs for EEG 2012

	≤ 75 kW_{el}	**≤ 150 kW_{el}**	**≤500 kW_{el}**	**≤750 kW_{el}**	**≤ 5 MW_{el}**	**5-20 MW_{el}**
Basic feed-in tariff	14.3	14.3	12.3	11	11	6
Substance tariff class STC I	6	6	6	5	4	0
Substance tariff class STC II	8	8	8	8/6*	8/6*	0
Gas processing bonus	≤ 700Nm^3/h:3 ; ≤ 1000Nm^3/h: 2; ≤1400Nm^3/h: 1					0
Small manure installations*	25					

Source: BGBL.2011; *Over 500 kW and up to 5,000 kW only 6 ct/kwh for electricity from manure (BiomasseV).

The biogas produced can be used in different ways. The main technology is based on so-called heat-electricity plants (BHPPs), where electricity is produced by a combustion engine while the thermal energy emitted from the engine is used locally as a by-product. BHPPs thus need a suitable heat sink nearby such as buildings that require heating. Alternatively, the biogas can be upgraded locally and then fed into natural gas pipelines to transport it to gas based power stations with better opportunities to use heat. This increases the energy efficiency, but is only possible for large scale biogas plants due to high upgrading costs which can only be off-set if economies of scale are utilised.

3 Methods and Data

In this section, the standard location model ReSI-M and the Regional Agricultural and Environmental Information System RAUMIS are described as well as extensions to capture changes in potential inputs according to the EEG 2012 are explained. Furthermore, the underlying database and the model’s parameterisation are presented.

3.1 ReSI-M2012 Model Description

The optimal location and size of biogas plants depend on a variety of interdependent factors which are taken into account in the model: output prices according to legislation, the availability of raw materials and resulting transportation costs, production costs, and the possibilities to use the produced crude biogas and heat. In the following section, the standard ReSI-M model, which only considers green maize (we call green maize for biogas production “maize” in the following) and manure as feedstocks is described, since it forms the basis for the an extended version, which accounts for additional inputs.

3.1.1 The Standard Location Model ReSI-M

The regionalised location model ReSI-M was developed by Delzeit et al. (2012a) to simulate the number of biogas plants erected in regions based on independent, individual investments. The model takes into account the plant’s location in subregions and their type, characterised by size and feedstock mix, in a sequential process. This is done by iteratively maximising the return on investments (ROI) for biogas plants in NUTS 3 (Nomenclature of Territorial Units for Statistics)[1] regions inside each German NUTS 2 region. Given that the EEG guarantees output prices for 20 years after constructing a plant, this period is taken as the planning horizon and it is assumed that investments in plants are ranked and realised according to their net present ROI. In the model, two pathways of using the produced crude biogas are considered: 1) direct use in BHPPs and 2) upgrading biogas, inducting it into pipelines and finally use it in a BHPP (compare section 2). In the standard version, the model considers maize and manure as feedstock. Aggregated over all erected biogas plants, total feedstock demand at different prices for maize (21-53€/t) is determined for each NUTS 3 region from which by interpolation regional maize demand curves are derived.

The number of plants erected $n_{r,t}$ of a specific type t in a NUTS 3 region r at price w is assumed to depend on plants’ *ROIs.* The ROI is calculated from yearly operational profit $\pi_{r,t}$ and total net present value of investment costs I_t divided by the length of the planning horizon T:

$$(1) \quad ROI_{r,t}(w) = \frac{\pi_{r,t}}{I_t / T}$$

Yearly operational profit is the difference between revenues - output y_t times price p_t – and the sum of operational costs net of feedstock costs oc_t, and feedstock costs (see equation (2)). Feedstock costs are determined by the given input demand x_t multiplied by the sum of average per unit transport costs $\overline{tc_{r,t}}$ and feedstock price w.

$$(2) \quad \pi_{r,t} = y_t p_t - oc_t - x_t(\overline{tc_{r,t}} + w)$$

The substrate price w is exogenous for the individual agent taking the investment decision, but endogenous at regional market level in our overall simulation framework.

[1] For a description, see: http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html

Average per unit transport costs $\overline{tc_{r,t}}$ are the outcome of a transport cost minimisation problem which reflects inter alia regional availability of feedstock in the regions from where the feedstock is taken. Availability of feedstock depends on regionally differing “location factors”. These are feedstock yields as well as the share of arable land on total land, the spatial distribution of this share and the amount of feedstock that is already used. This spatial distribution determines the homogeneity of a region (see section 3.3). For a detailed description of the standard model, see Delzeit et al. (2012a).

3.1.2 Extending ReSI-M

In the former version of the model, four plant sizes (150, 500, 1000 and 2000 kW_{el}) and three manure shares (1%,10% and 30%) were considered. Based on the changes of the EEG 2012 described in section 1, the extended model now includes five plant sizes (75, 150, 500, 1000 and 2000 kW_{el}) and considers also grass silage, sugar beet and whole plant silage (WPS) from grains as possible inputs in different input shares and thus residue amounts. Note, that in opposite to maize, the input prices for these additional inputs are kept constant (see also section 3.2.2). It is presumed that biogas producers can choose between five different input mixes:

A) 40% manure (STC II)., 50% maize and 10% WPS grains (all STC I);
B) 20% manure (STC II)., 60% maize and 20% WPS grains (all STC I);
C) 10% manure (STC II)., 60% maize and 30% WPS grains (all STC I);
D) 40% manure (STC II).and 60% maize (STC I);
E) 80% manure and 20% maize

Whereas option 1) is only applicable for 75kW_{el}-plants which might claim the “small manure installations bonus” based on share of mass content (mass per cent) (see Table 2); options 2) and 3) are available to all plants and introduced to analyse the profitability of the differentiation in the two STCs.

In order to reduce the computing time unprofitable biogas plant types are not implemented in the model based on pre-calculations, which take plant size, input mix, and regional availability of gas pipelines and demand for heat for housing into account.

3.2 RAUMIS Model Description

The Regional Agricultural and Environmental Information System (RAUMIS) was developed for the regionally differentiated analysis of the agricultural sector of Germany (Henrichsmeyer et al. 1996). It allows quantifying economic (on production quantities, agricultural income, factor stocks) and environmental impacts (on nitrogen emissions into water and atmosphere) impacts of alternative agricultural policies.

3.2.1 Agricultural economic modeling

The methodological concept of RAUMIS is an activity based non-linear programming approach, designed for medium and long-term impact analysis. Production is represented by 50 agricultural outputs produced by 31 crops (including set-aside programmes) and 16 livestock activities, input use is disaggregated to about 40 inputs. The model data base, drawing on various agricultural data sources, is consistent to the Economic Accounts for Agriculture (EAA) and represents the whole output and inputs use of the German agricultural sector in monetary and physical terms, including intra-sectoral linkages.

Data base and model cover 326 administrative spatial units, the so-called NUTS 3 regions ("Landkreise"), for which data of sufficient quality are available. Each subregion is treated as an independent single farm, optimising its program at given prices for inputs and outputs. Changes are at national level are hence aggregated from adjustments of these regional farms to changes in drivers such as agricultural policies. These adjustments are determined by the interplay of a set of constraints and the objective function which uses a positive mathematical programming approach (Howitt, 1995, Cypris, 2000):

$$\begin{aligned} \max_x \quad & \Pi = \sum_i z_i(x_i)\, x_i \\ s.t. \quad & b_i \geq \sum_i a_i x_i \end{aligned} \tag{3}$$

The objective function represents regional agricultural profits (Π), i.e. the product of the level of each netput[2] x_i. multiplied by its per unit margin z_i, as the difference between revenues and variable costs. The objective function is non-linear since the z_i's are functions of the realised netput level x_i. The system is maximised subject to a set of technical, political and economic constraints ($b_i \geq \sum_i a_i x_i$),which are e.g. land availability, set-aside obligations, production quotas. The optimal program is determined in two decision stages process: 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 (Kreins et al. 2007). Hence, activity levels (production, feeding, and input factors) and agricultural income are endogenous variables. Exogenous elements are either based on trend extrapolation (yields, input coefficients, fixed factor endowments) or stem from other studies such as prices and price indices from other models.

3.2.2 Extending RAUMIS

In German agricultural the roughage is typically produced and used in the same farm unit, whereas trade between regions is restricted to small surplus quantities and mostly refers to

---

2 The notation netput stands for "net output" where positive elements of x_i denote outputs while negative elements denote inputs or intermediate inputs such as farmyard manure.

products with a low moisture content such as hay or straw. Fresh or ensilaged fodder (e.g. grass or maize silage) with higher moisture contents and thus higher per unit transport costs was so far rarely exchanged between regions. Therefore, in the former RAUMIS version, roughage produced had to be used as feed and only a small share of non-usable surplus quantities could be exported. Since the introduction and the amendment of the EEG, ensilaged maize cannot only be used as feed for animals, but also sold to biogas producers. Accordingly, a sales activity for silage maize was introduced. Due to the amendment of the EEG 2012 with the introduction of the two substrate classes, grass silage could become competitive for biogas production and also rendered tradable. Additionally to production costs of grass, the model accounts for the transformation process from fresh mass to silage, considering crop losses, the mass reduction from reducing the moisture content and the costs incurred by ensilage to derive total production costs including the opportunity costs of farm endowments. The profit function includes the sales revenues of grass silage. Sales will only occur if the assumed price paid by biogas plant operators for grass silage exceed production costs.

3.3 Data and Parameterisation

3.3.1 Production Costs and Revenues

Exogenous data to determine profits in ReSI-M π (used in equations (1) and (2)) are taken from literature: data on revenues are derived from feed-in-tariffs depending on applied scenario, augmented by heat sales depending on the plant size, and degree of combined heat generation.

Production and processing costs for three plant sizes are taken from Urban et al. (2008). The study displays results of a market survey on costs and technologies of biogas upgrading and induction into the gas grid. Underlying assumptions for these costs are described in detail in Urban et al. (2008, p. 84ff). Some crucial assumptions are:

The calculation of capital costs for the biogas plant is static and based on a recovery period of 15 years

- imputed interest rate: 6%
- labour costs are 35€/h
- electricity costs for technical plants are 15ct/kWh_{el}
- 8000 h/a operation hours
- 5250 h/a full load hours of BHPP (block heat power plants)
- electric degree of efficiencies of BHPP: 150 kW_{el} : 35%, 500 kW_{el}: 37,5% 1000kW_{el}: 39,5%, 2000 kW_{el} :41,7%

The assumed number of operation hours, full load hours of BHPPs and the electric efficiency determine the amount of annually produced energy in kWh_{el} per year: it is calculated by multiplying the plants' capacities (in normal cubic metre (Nm^3)) with the heat of combustion of biogas (kWh_{el}/Nm^3 of biogas), the assumed operating hours and electric degree of efficiency of BHPP. Given the large variability in annually produced energy observed in reality, this parameter is changed in sensitivity analysis (see section 3.3).

The study of Urban et al. (2008) does not provide all data for the 75 and $150kW_{el}$ plant sizes. Thus, we used data from the Association for Technology and Structures in Agriculture (KTBL) (Achilles 2005, p.942-944).

Assumptions on energy efficiency and maximum operating hours are varied for a sensitivity analysis.

3.3.2 Feedstock Availability and Prices

RAUMIS provides maize yields at NUTS 3 level. Additionally, information from RAUMIS on available manure per NUTS 3 region for the year 2020 is calculated from herd sizes and manure excretion per animal. A share of 10% pasture management for cattle was assumed, and subtracted from total amount of manure amount. In addition, it is assumed that use of manure in biogas plants is only profitable for farms with more than 30 milk cows or 50 other cattle or 200 pigs. Regarding chicken large mass production was presumed.

Transportation costs for maize are extracted from Toews and Kuhlmann (2007), while Kellner (2008) provided these for manure. Input prices biogas plants pay for sugar beet and WPS grain is taken from FNR (FNR 2010, p.174). These input prices are assumed to include transport costs, and there is no endogenous demand function generated in the model.

3.3.3 GIS-Analysis

NUTS 3 regions are classified according to their selling opportunities for heat produced by biogas plants and the possibility of inducting gas into a natural gas pipeline. A GIS-analysis excludes urbanised NUTS 3 regions as possible locations for biogas plants, assuming that zoning laws and low feedstock availability prevent installation of biogas plants in urbanised areas. The Federal Office for Building and Regional Planning (BBR) provided data on population density (BBR 2005). For the remaining NUTS 3 regions, variances and mean shares of agricultural land are calculated from data provided by Leip et al. (2008), who calibrated data from the European CORINE land cover (CLC) database to national and regional agricultural statistics. These data determine regionally different transport costs ($\overline{tc_{r,t}}$ (see section 3.1.1). Data are available for so-called "Homogenous Spatial Mapping Units" (HSMU) with a resolution of 1x1 km^2 which consider soil, slope, land cover and administrative boundaries as delineation features. For a detailed description of the GIS-analysis see Delzeit et al (2012a).

3.4 Incorporation of Uncertainties about Energy Efficiency

Data from existing plants suggests that energy efficiency can differ substantially from the mean energy efficiency levels reported in literature, with significantly impacts on demand for maize and other feedstocks. Since the exact efficiency level is not known, demand for every given price is computed as the average of three demand functions: one simulated for the mean efficiency level from literature (see section 3.2.1) and the two others for efficiency levels that are calculated by either reducing or increasing mean energy efficiency by 10%.

3.5 Simulating Market Clearing for Green Maize

In order to perform an impact analysis of biogas production on maize cultivation, market clearing prices and quantities are derived by intersecting the regional demand functions from ReSI-M with supply functions for maize derived from data provided by RAUMIS[i]. Simulations using RAUMIS provided supply of maize (net of regional feed use) for prices ranging from €20 to €53 per ton. Supply curves for maize derived from RAUMIS take into account production and opportunity costs, relating for example to competition for land between the different crop activities, as well as feeding and fertiliser substitution values. RAUMIS and ReSI-M do not deliver supply and demand curves, respectively, but only some simulated points. From these results alone, only lower and upper limit for the market clearing prices and quantities can be derived. It is therefore interpolated in the relevant range to determine the intersection.

The EEG amendment from 2012 increased the competitiveness of grass silage as a feedstock in biogas plants (see Table 2, differences in FTIs between STC II – manure and grass silage – and other feedstocks classified in STC I,). Sensitivity analysis with RAUMIS revealed minimum per unit production costs of 41€/ton of grass silage, considerably above those for silage maize. These findings are confirmed by farm cost data (DLG 2012) where grass silage was about 40% more expensive than silage maize, an outcome of the need to cut grass several times per year in combination with lower biomass yields on grasslands.

ReSI-M delivers demand curves for grass silage which drop towards zero at around 32 €/ton.

These results and the costs data suggest that relevant feedstock shares of grass silage under the EEG 2012 are rather unlikely. Grass silage is hence not considered as a feedstock in further analysis.

4 Results and Discussion

In the following, we discuss the scenarios applied before presenting results on plant sizes, which we compare to the trends observed in the construction of biogas plants. Furthermore, the total electricity production from biogas plants and related subsidies under the scenarios are discussed. Next, we compare regional demand curves for maize resulting from the modelling exercise and link them with supply from RAUMIS to derive market clearing prices and quantities. Finally, we present results on regional maize production under the scenario setting and compare the total land used for biogas production taking the state of Schleswig-Holstein as an example.

4.1 The Applied Scenarios

1) The scenario *"EEG 2004"* serves as a reference scenario and includes simulations from ReSI-M as well as simulations of the supply functions by RAUMIS for the target year 2020. In a joint yearly work encompassing several economic models for the agricultural sector, vTI Braunschweig develops a medium term baseline which captures the likely development in international and German markets for agricultural products. The baseline covers also regional German developments against which RAUMIS is calibrated ex-ante. The supply curves used in the current study are based on Gömann et al. (2011)[i] and derived from sensitivity analysis with different levels of exogenous given prices for maize for 2020. Supply curves for grass silage were constructed as well, but, for reasons discussed above, not used for further analysis.

In a similar fashion, ReSI-M contributes points on the regional feedstock demand curve at different price levels under the EEG 2004, while considering demand for feedstock of existing plants. The demand curve for feedstock is then constructed by interpolation. The details of the method are discussed in Delzeit et al. (2012a, p.79). The reference scenario is used to compare the EEG versions of 2009 and 2012 with each other.

2) In the scenario *"EEG 2009"* FITs according to the EEG 2009 are adopted and the demand for feedstock of existing plants is considered. It thus combines updated demand functions from ReSI-M with the same supply functions from RAUMIS.

3) Similar, the "*EEG 2012"* scenario comprises demand curves based on the FITs according to the EEG 2012 at unchanged supply curves. Again, feedstock demand by existing plants is taken into account.

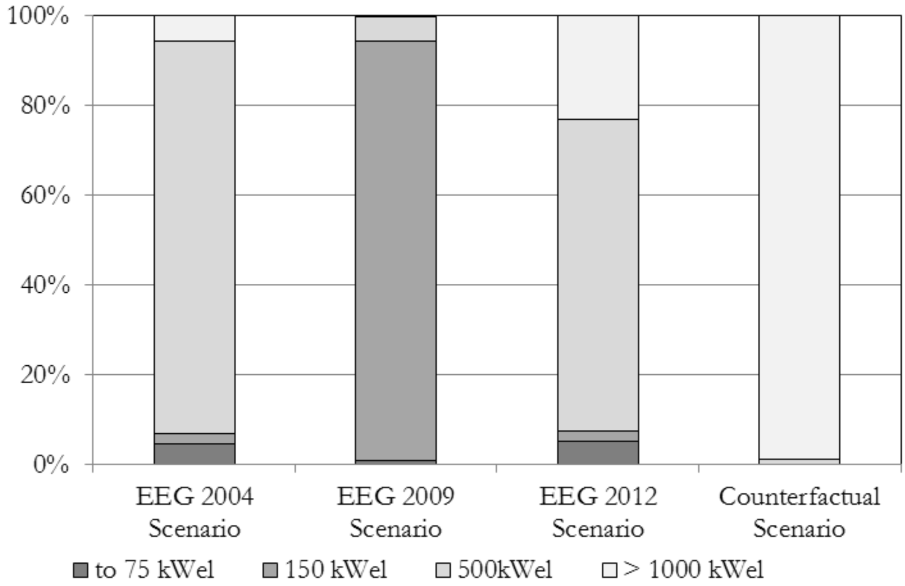
4) In our hypothetical "*Counterfactual Scenario"*, all plant sizes receive the same output price per kWh_{el} and no extra subsidies for using specific inputs or particular techniques. In order to make results comparable, a subsidy rate of 18.3 cent/kWh_{el} was derived by sensitivity

analysis such that approximately the same amount of electricity is produced as in the scenario “EEG 2012”. Existing plants are not considered, all plants are built from scratch. This scenario provides a comparison point with a cost-minimal plant structure where investors take solely a uniform subsidy per unit of output into account, and not, as in past and current legislation, differentiated subsidies which impact the choice of plant size and technology.

4.2 Profitable Plant Types and Electricity Production under the Scenarios

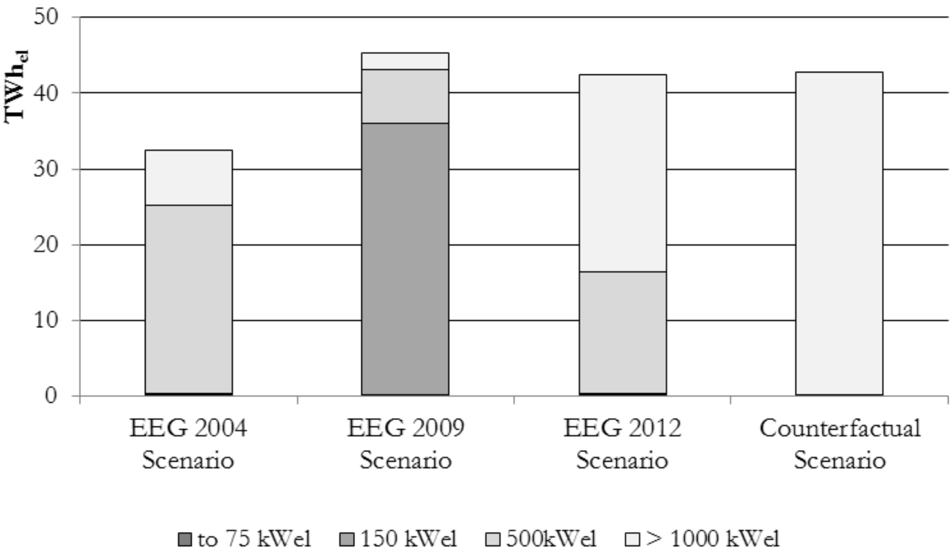
Figure 2 illustrates the plant structure under the different scenarios. Plant sizes of 500kW$_{el}$ are most profitable under the EEG 2004 scenario, while also a small share of large scale plants (>1000kW$_{el}$) are constructed. It thus reproduces the observed trends discussed in section 2: the EEG 2004 led to a total expansion in biogas production and an increase in average plant sizes. Under the EEG 2009 scenario, mainly small size plants with 150 kW$_{el}$ using 30% of manure as input are constructed. These plants are not only receiving higher basic FITs and an increased NaWaRo-bonus, but are able to claim an additional subsidy for using manure (see Table 1). The simulated outcome fits to the observed adjustments after the EEG 2009 as reported by the German Biomass research Centre (DBFZ 2011).

Figure 2: Share of plant sizes on total number of plants under the different scenarios



Simulation results show that under the EEG 2012 plants with a capacity of 500kW$_{el}$ and 2000kW$_{el}$ are the most profitable plant sizes (see Figure 2). 500kW$_{el}$ plants use 50% of the cost efficient input maize, and 10% of WPS grain, both falling in STC I substrate class. The remaining 40% from manure as a STC II feedstock receive higher tariffs per kWh$_{el}$. The simulated 2000kW$_{el}$ plants use 60% of maize, 30% of whole plant grain silage and 10% manure. Despite a share of only about 20% in plant numbers (see Figure 2), 2000kW$_{el}$ plants contribute to the total energy production with about 60% (see Figure 3). While electricity production under the EEG 2012 scenario is lower compared to the EEG 2009 scenario, total energy production (electricity plus heat) is larger due to strong incentives in the EEG 2012 to use heat (cp. section 2).

Figure 3: Electricity production under different scenario settings



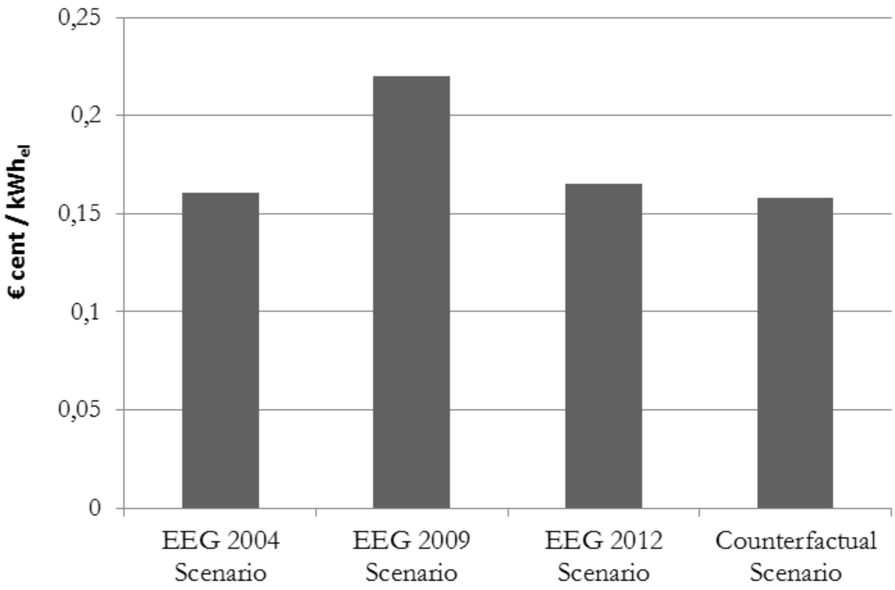
The same input shares are used in plants constructed under the counterfactual scenario, whereas the plant size differs: with feed-in tariffs which do not discriminate for plant size, large scale plants play out their economies of scale.

The per unit subsidies provided in the counterfactual scenario are chosen to result in an electricity production which is almost equal to the EEG 2012 scenario. Compared to the EEG 2009 scenario, total electricity production is about 3% lower under the EEG 2012 and the counterfactual scenario. In the following section we discuss whether that lower electricity production under the EEG 2012 stems from lower subsidies or a less efficient tariff system.

4.3 Subsidies under the three policy scenarios

Based on the total electricity produced, numbers of biogas plants by size and feed mix and resulting FITs paid in the three scenarios, average subsidies in €-cent per kWh$_{el}$ are calculated and illustrated in Figure 4. It shows that the per unit subsidies under the EEG 2009 scenario are higher than those paid under the EEG 2012 scenario, whereas, as to be expected, the counterfactual scenario is the most cost efficient one. These differences stem from variations in plant composition and reflect different energy efficiency levels and per unit cost. Specifically, the EEG 2009 favours small scale plant with a 35% efficiency and thus relatively high per unit cost, compared to the larger plants constructed under the EEG 2012 scenario which are more cost-efficient and show an average electric degree of efficiencies of BHPP of 37.5% in case of 500kW$_{el}$ plants and 41.7% in case of 2000kW$_{el}$ plants.

Figure 4: Average subsidies paid under the scenario settings



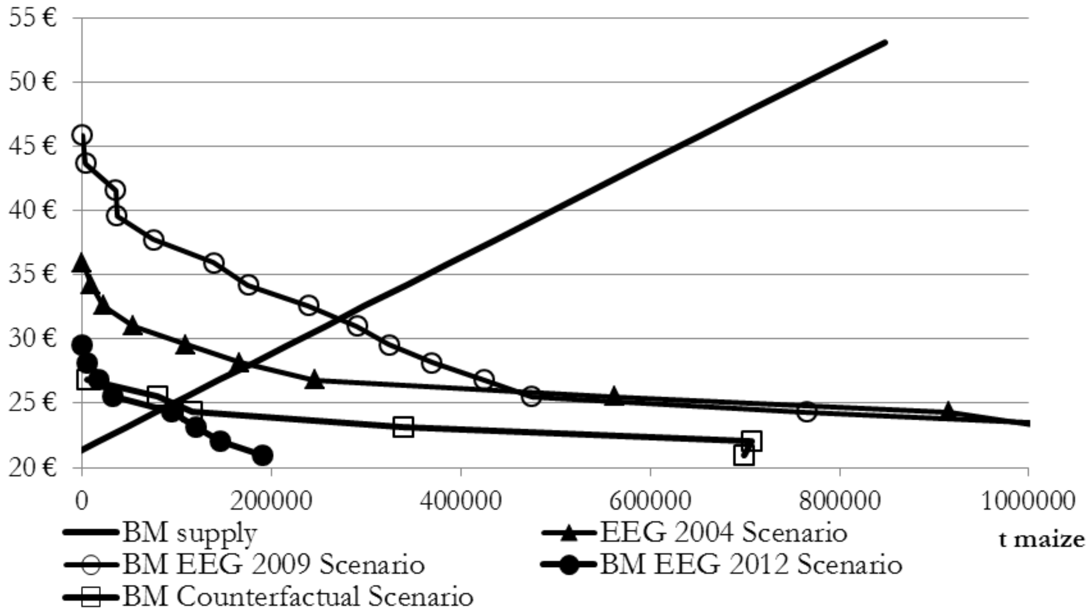
In the counterfactual scenario, special FITs supporting certain shares of inputs or technologies are removed, which results in cost-effective production structures and technologies. However, their economic advantage comes at the cost of a lower environmental performance linked to higher green maize feedstock shares. The impact on maize production is discussed in the following section.

4.4 Maize Markets and Resulting Maize Production

Maize production for each NUTS 3 region in Germany is determined by intersecting regional specific demand and supply functions (see section 3.4) which reflect characteristics such as land availability and distribution (see section 3.2). Demand curves additionally differ depending on FITs in the respective scenario setting. Figure 5 illustrates the maize market in Bergheim (BM) under the three scenarios discussed above, a region in western Germany which is characterised by high agricultural yields, a relatively low share of arable land on total land area, but a homogenous distribution of arable land. Accordingly, transport costs differ not much between locations inside the regions, so that the additional plants erected do not face serious cost increases from longer transport distance. Lower per unit transport costs allow biogas plants to produce at higher maize prices by shifting the demand function to the right. BM is located in the Cologne-Aachen Bay, a region with favourable soil and climate conditions for vegetable and grain production. Therefore, there is high competition between maize and other agricultural goods, which causes a relatively steep supply function generated by RAUMIS. Linking the supply function with demand functions under different scenarios, Figure 5 shows that the market clearing price for maize and thus the maize used for biogas production is highest under the EEG 2009, reflecting the high per unit subsidies in that scenario. Demand for maize is lower under the EEG 2012 scenario as well as under the counterfactual scenario compared to the EEG 2009. The counterfactual scenario uses a uniform FIT per unit electricity which is equal in sum to the FITs paid under the EEG 2009 divided by the electricity produced under the EEG 2009, so that the average costs to the electricity consumer are identical.

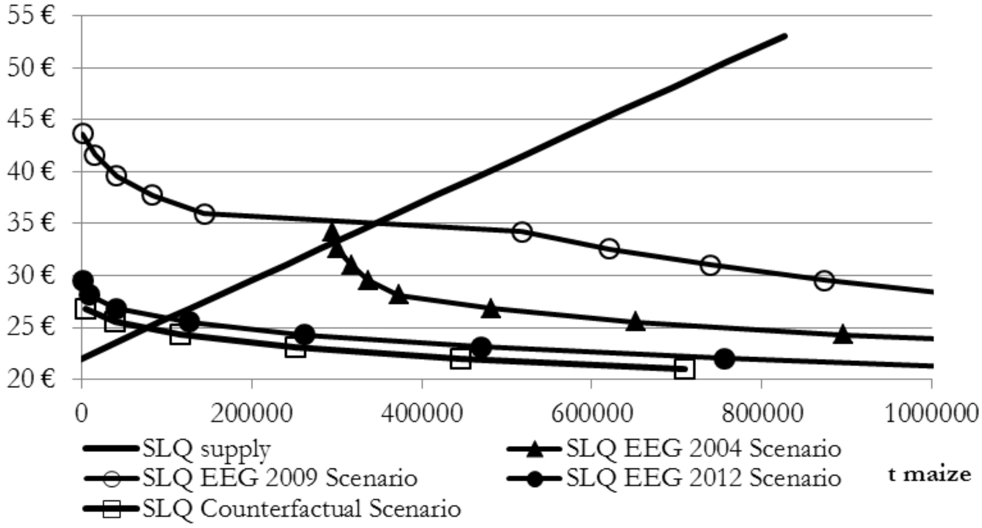
The average FTIs are set equal in both scenarios, but maize demand curves are different. The higher demand under the counterfactual scenario in the region is caused by relatively low transport costs which benefit large scale plants constructed in this scenario setting. At higher maize prices, large scale plants constructed under the counterfactual scenario are able to benefit from economies in production, since transport costs are low.

Figure 5: Maize market in Bergheim (BM)



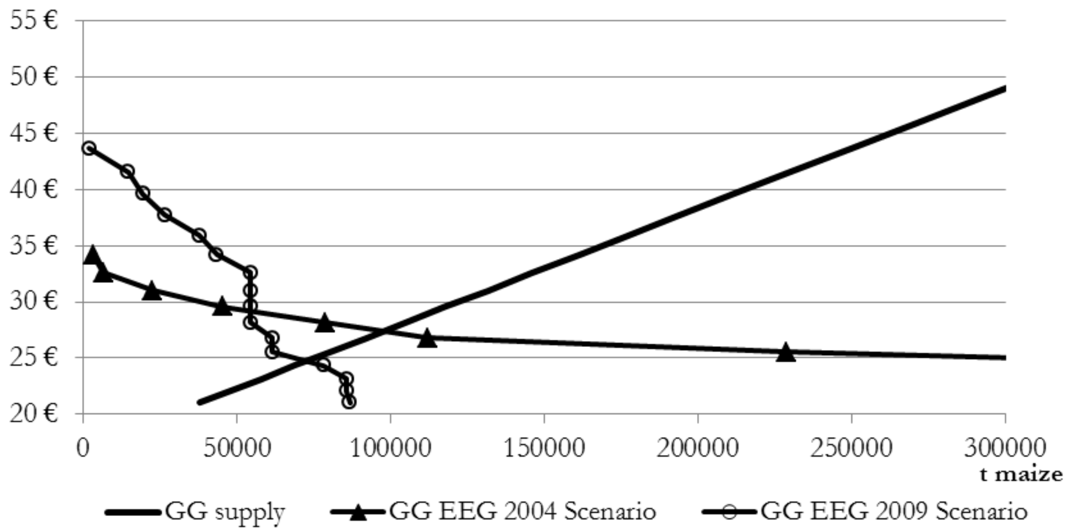
In Schleswig-Flensburg (SLQ) (see Figure 6), the market clearing maize price under the EEG 2009 scenario is about 4€/t higher than in BM region discussed above. The higher price stems from the fact that a higher availability of manure favours investments in small scale plants which receive the additional subsidy for a 30% manure share (“Güllebonus”). Demand curves under the EEG 2012 and the counterfactual scenario do not differ considerably while equilibrium price and quantity under the counterfactual scenario is lower compared to BM due to higher transport costs.

Figure 6: Maize market in Schleswig-Flensburg (SLQ)



A third example is provided in Figure 7 and aims to explain the impact of manure availability on maize production for biogas plants. Groß Gernau is a region with a low availability of manure, since it is dominated by cropping activities. Therefore, under the EEG 2009 scenario, maize production is lower compared to the EEG 2004 scenario, given that under the EEG 2009 scenario, plants using a high share of manure are most profitable.

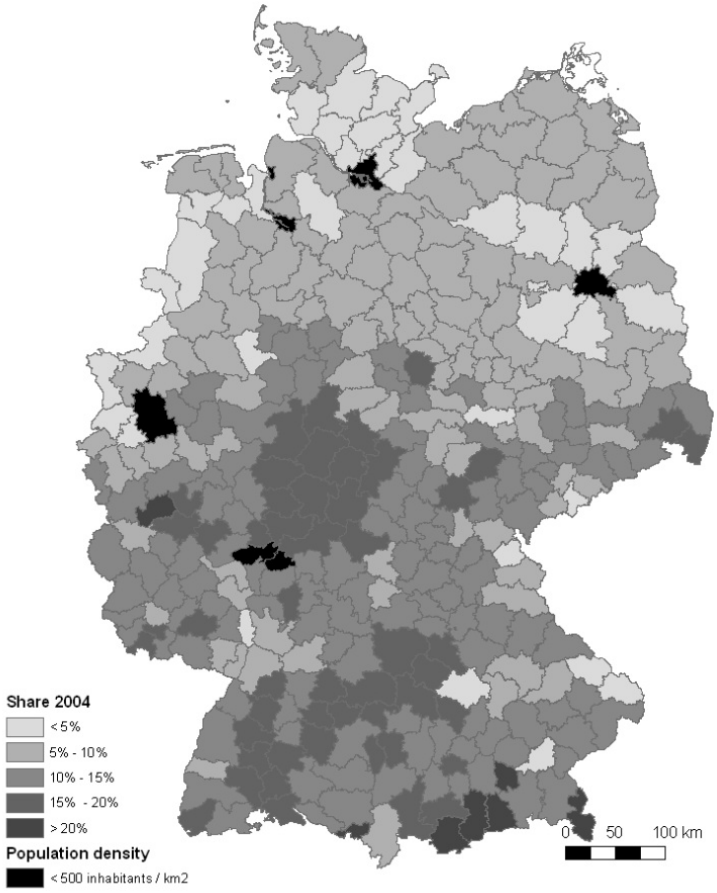
Figure 7: Maize market in Groß Gerau (GG)



4.5 Regional distribution of maize production under different scenario settings

NUTS 3 regions in Germany vary considerably in total size and share of arable land, making absolute comparison in hectares difficult. Therefore, the share of maize area on arable land is displayed. The simulated maize shares under the reference scenario are displayed in Figure 8.

Figure 8: Share of maize on arable land in Germany's NUTS 3 regions under the reference Scenario



Data: RAUMIS and ReSI-M simulation, population density BBR and SOFL (2005)

High maize shares are found in crop production areas such as Southern Lower Saxony to Saxony (central-eastern Germany), Soester Boerde and Cologne- Aachen Bay (western Germany), Kraichau (southwestern Germany), Mecklenburg- Vorpommern (northeastern Germany) and the centre of Bavaria (southern Germany). The total area for maize production amounts to approximately 1 mio ha in the reference scenario. The distribution shown does not fit perfectly with the distribution of biogas plants currently observed in Germany for manifold reasons.

Our results are conditioned on the parameterisation of both RAUMIS and ReSI-M and further assumptions such as input and output prices expected by the agents over the planning horizon. The latter can hardly be observed and are for sure uncertain. Additionally, the structure of the models does not account for further factors possibly impacting investment decisions into biogas plants such as risk behaviour, liquidity constraints, the influence of extension services, differences in granting building permits for biogas plants by local authorities and diversification of electricity producers towards renewable energies or. However, results should give a good indication for differences between scenarios in relative terms.

Total maize production is highest under the EEG 2009 scenario, leading to an average share of 17% of maize for biogas production on the arable land. The highest shares of maize on arable land occur in regions with high availability of manure (north-western Germany, see also Figure 6)). The specialisation in animal production lead to higher than average maize shares used as feed already in the absence of any biogas production. That high share is further increased by maize production for energy plants.

In some regions maize production is lower compared to the reference scenario. These are regions with a low availability of manure: the subsidy structure under the EEG 2009 renders new investment in biogas plants in these regions less attractive (compare Figure 7). The total area under maize cultivation simulated for 2020 is about 1.7 mio ha.

Comparing maize production under the EEG 2012 scenario to the reference scenario, the share of maize on arable land decreases from about 11% in the reference scenario to about 8% in the EEG 2012 scenario. High differences in maize production compared to the EEG 2009 scenario are found in the manure intensive regions where many small scale plants using some manure where simulated under the EEG 2009 scenario. Since the EEG 2012 pays feedstock subsidies only up to maize input share which is considerable lower than under the 30% manure plus maize mix favoured under EEG 2004, less maize is used (compare Figure 5 and 6). At the same time, almost the same amount of electricity is produced under the EEG 2012.

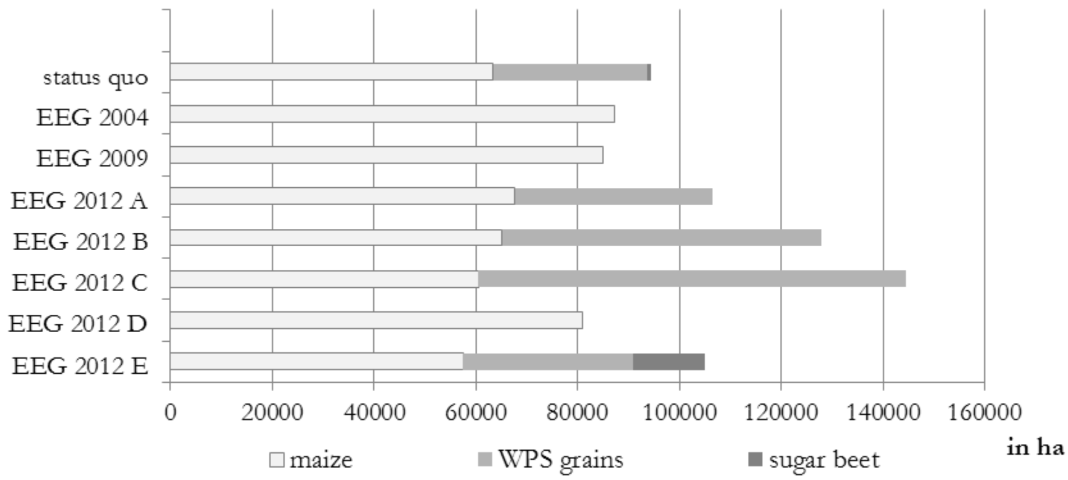
The counterfactual and the EEG 2012 scenario do not differ considerably regarding maize input. Note that the same amount of electricity is produced and in both scenarios the same feedstock mixes are offered to the plant investors. Under the counterfactual scenario 7% of arable and is cultivated with maize, compared to 8% under the EEG 2012 scenario. This slight difference is caused by a higher share of large scale plant under the counterfactual scenario: higher energy efficiencies of large scale plants such that for each produced energy unit, less land is needed.

4.6 Addressing total area used for maize production

In the previous sections, we focused on the land used for maize cultivation. Under the EEG 2012, silage maize is substituted by more environmentally friendly feedstocks such as manure and grains. On the other hand, due to the high energy content of maize per unit land, alternative feedstock mixes might cause a higher demand in total area needed for biogas production. Since ReSI-M does not include information on grain yields, in this section we take biogas production in Schleswig-Holstein as an example and base the calculations on information by the German Biomass Research Centre DBFZ (2011) the Ministry of Agriculture, the Environment and Rural Areas (MLRU 2011).

In order to feed the 380 existing biogas plants in Schleswig-Holstein with an average capacity of 400kW$_{el}$ (DBFZ, 2011 p. 39), the respective input demand by the different plant types is illustrated in Figure 9.

Figure 9: Calculated land requirements by different plant types in Schleswig-Holstein



Mass contents:
Typical EEG 2004: 90% maize, 10% manure; Typical EEG 2009: 70% maize, 30% manure, EEG 2012 A 40% manure(STC II)., 50% maize and 10% GPS grains (all STC I);
EEG 2012 B:20% manure(STC II)., 60% maize and 20% GPS grains (all STC I);
EEG EEG 2012 C:. 10% manure (STC II)., 60% maize and 30% GPS grains (all STC I); EEG 2012 D: 40% manure (STC II).and 60% maize (STC I);
EEG 2012 E: 20% manure (STC II),50% maize, 20% sugar beet , 10% GPS grains(STC I)
EEG 2012 F: 80% manure and 20% maize

Figure 8 points out that the higher the maize share the lower the total land area required. Reducing the maize share to 50% under the EEG 2012 A plant type, results in an increase in total land demand by 20%, under the EEG 2012 B plant type by about 34%. The figure also illustrates, that even plants using a high mass share of manure (80%) (see EEG 2012 F) still demand a considerable amount of land. Given the high energy content of maize, 20% mass content contribute about 61% of energy content. This is also shown by comparing EEG 2012

D and EEG 2009 plants: doubling the manure share from 20% to 40% reduces the maize input solely by about 5%.

5 Summary and conclusions

Based on simulations with economic models, we analyse in this article, effects of the recent amendment of the German Renewable Energy Source Act on biogas production from agricultural feedstocks, related land use changes and costs to electricity consumers. To assess different policy options, three scenarios are compared to a reference scenario: the version of the EEG 2009, the new EEG 2012 and in addition a counterfactual scenario with feed-in tariffs independent on biogas plant sizes and technologies.

The main results are summarised in Table 3.

Table 3: Summary of results

	EEG 2009 Scenario	EEG 2012 Scenario	Counterfacutal Scenario
Energy Production	175 mio GJ (157 GJ electricity)	226 mio GJ (152 GJ electricity)	221 mio GJ (154 GJ electricity)
Area for maize production	1.7 mio ha	0.8 mio ha	0.7 mio ha
Maize share on arable land	17%	8%	7%
Subsidies per kWh_{el}	0.219 € cent/kWh_{el}	0.165 € cent/kWh_{el}	0.158 € cent/kWh_{el}

The latest amendment (EEG 2012) leads to a higher total energy output (heat plus electricity) but lower electricity output compared to the EEG 2009 at lower subsidies per electricity unit by favouring more cost effective larger plants. Heat use increases in our simulation due to an obligation in the legislation to utilise heat in order to receive FITs. Less maize in the feed-mix carries the chance to reduce negative externalities linked to large-scale biogas production. The counterfactual scenarios where subsidies are no longer differentiated by plant size and feed mix has the expected effect of leading to an even more cost effective plant structure while at the same further reducing maize input by favouring energy efficient plants.

Regarding land used per unit of produced electricity, maize requires the smallest amount of land compared to the other crops used for biogas production; its land-efficiency is the highest. Taking the total land demand by all feedstocks into account, our results indicate that while the total maize production is reduced under the EEG 2012 scenario compared to the EEG 2004 and 2009, total land requirement for biogas production increases. The sole exception is a feed-mix where a very high share of manure is used (see EEG 2012 F), which is however hardly plausible given manure availability.

The results are conditioned on the structure and parameterisation of the economic simulation models used and further assumptions e.g. on the future development of prices for inputs and outputs which introduce some degree of uncertainty in the overall findings. However, the key uncertainties should affect the results under the different legislative proposals analysed in a similar manner, e.g. higher expected prices for agricultural feedstock should decrease investments in biogas plants independent from the specific subsidy structure. Nevertheless, as with any ex-ante analysis, results should be seen as indications, only.

Aiming to reduce competition for land under an increasing amount of biogas production, the EEG 2012 amendment is thus clearly a step in the right direction, but leaves room for further improvement. Incentives for using other waste materials, for example, would reduce the area needed for crop production. An increasing use of grass silage could provide an environmentally friendly alternative to maize, if transport costs (and emissions resulting from transport) can be kept at a low level. Furthermore, an increase in energy efficiency of plants results in lower input demand and also improves greenhouse gas emissions in the production chain.

References

Achilles, W. (2005): Faustzahlen für die Landwirtschaft. Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL), Darmstadt, 1095p.

BBR (Federal Office for Building and Regional Planning) and SOFL (Statistical offices of the Federation and the Länder), 2005. Bevölkerung, Stand 31.12. 2005.

BGBl (Bundesgesetzblatt) (1990): Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz, 07.12.1990, pp.2633-2634.

BGBl (Bundesgesetzblatt) (2000): Gesetz für den Vorrang Erneuerbarer Energien, Nb. 13, 31.03.2000, pp.305-309.

BGBl (Bundesgesetzblatt) Part 1 (2004): Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich, 21.7.2004, pp.1918-1930.

BGBl (Bundesgesetzblatt) Teil 1 (2008): Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften vom 25.10.2008, pp.2074-2100.

BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2007): Klimaagenda 2020: Klimapolitik der Bundesregierung nach den Beschlüssen des Europäischen Rates. Klimaschutz bedeutet Umbau der Industriegesellschaft. Bundesumweltminister Sigmar Gabriel, Regierungserklärung, 26.04.2007. Deutscher Bundestag, Berlin: BMU. Available online: http://www.bmu.de/reden/bundesumweltminister_sigmar_gabriel/doc/39239.php. (last online: 02.02.2010).

BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2010): Nationaler Biomasseaktionsplan für Deutschland – Beitrag der Biomasse für eine nachhaltige Energieversorgung, Berlin, 30pp.

BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2011): Erneuerbare Energien in Zahlen, Nationale und internationale Entwicklungen (in German), Berlin, 115p.

Cypris, C. 2000. Positive Mathematische Programmierung (PMP) im Agrarsektormodell RAUMIS. Schriftenreihe der Forschungsgesellschaft für Agrarpolitik und Agrarsoziologie e.V., H. 313.

DBFZ (German Biomass Research Centre (2011): Monitoring zur Wirkung des Erneuerbare-Energien-Gesetzt (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse.

Interim Report prepared for the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. March 2011, 123p.

Delzeit, R., Britz, W., Holm-Mueller K. (2012a): Modelling regional input markets with numerous processing plants: The case of maize for biogas production in Germany. In: Environmental Modelling & Software 32, pp.74-84.

Delzeit, R., Holm-Mueller K., Britz, W. (2012b): Ökonomische Bewertung des Erneuerbare Energien Gesetzes zur Förderung von Biogas (in German). In: Perspektiven der Wirtschaftspolitik 13(3), pp.251-265.

European Commission (2007): Renewable Energy Road Map Renewable energies in the 21st century: building a more sustainable future. KOM(2006) 848 final, Brussels, European Commission.

FNR (Forschungsanstalt Nachwachsende Rohstoffe) (2009): Daten und Fakten: Anbau nachwachsender Rohstoffe in Deutschland. Available online: http://www.nachwachsenderohstoffe.de/fileadmin/fnr/images/aktuelles/medien/RZ_Grafik_Anbau_09_rgb_300_ENG.jpg (last online: 30.11.2009).

FNR (Forschungsanstalt Nachwachsende Rohstoffe) (Eds.) (2010): Leitfaden Biogas. Von der Gewinnung zur Nutzung. ISBN 3-00-014333-5. Gülzow.

FNR (Forschungsanstalt Nachwachsende Rohstoffe) (Eds.) (2006): Handreichung, Biogasgewinnung und -nutzung, Gülzow. Available online: http://www.fnr-server.de/ftp/pdf/literatur/HR_Biogas.pdf (last online: 10.02.2010).

German Federal Carbinet (2002): Bericht über den Stand der Markteinführung und der Kostenentwicklung von Anlagen zur Erzeugung von Strom aus erneuerbaren Energien (Erfahrungsbericht zum EEG). Berlin, 28.06.2002. Available online: http://www.erneuerbare-energien.de/inhalt/2677/ (last online: 02.03.2010).

Gömann, H., Kreins, P., Münch, J., R. Delzeit, 2011. Auswirkungen der Novellierung des Erneuerbare-Energien-Gesetzes auf die Landwirtschaft in Deutschland (eng. Title: *„Impacts of the Renewable Energy Source Act's amendment on German agriculture")* . In: Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaus e.V., Bd. 46 "Möglichkeiten und Grenzen der wissenschaftlichen Politikanalyse".

Henrichsmeyer, W., Cypris, C., Löhe, W., Meudt, M., Sander, R., von Sothen, F., Isermeyer,F., Schefski, A., Schleef, K.-H., Neander, E., Fasterding, F., Helmcke, B., Neumann, M., Nieberg, H., Manegold, D., Meier, T., 1996. Entwicklung eines gesamtdeutschen Agrarsektormodells RAUMIS96. Endbericht zum

Kooperationsprojekt. Forschungsbericht für das BML (94 HS 021), vervielfältigtes Manuskript Bonn/Braunschweig.

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

Hofmann F., Plättner, A., Lulies, S., Scholwin, F. (2005): Evaluierung der Möglichkeiten zur Einspeisung von Biogas in das Erdgasnetz, Forschungsvorhaben im Auftrag der Fachagentur Nachwachsende Rohstoffe e.V. Leipzig: Institut für Energetik und Umwelt GmbH, 273p. Available online: http://publica.fraunhofer.de/dokumente/N-54119.html (last online: 30.11.2009).

Kellner, U. (2008): Wirtschaftlichkeit und Nährstoffmanagement der Gärrestausbringung von Biogasanlagen. Diploma thesis at University of Bonn, Institute for Food and Resource Economics.

Kooperationsprojekt. Forschungsbericht für das BML (94 HS 021), vervielfältigtes Manuskript Bonn/Braunschweig.

Kreins, P., Gömann, H., Herrmann, S., Kunkel, R., Wendland, F. 2007. Integrated agricultural and hydrological modeling within an intensive livestock region. Advances in the economics of environmental resources 7, pp. 113-142.

Leip A., Marchi, G., Koeble, R., Kempen, M., Britz, W., Li, C. (2008): Linking an economic model for European agriculture with a machanistic model to estimate nitrogen and carbon losses from arable soils in Europe. In: Biogeoscience 5, pp.73-94.

MLUR (Ministry of Agriculture, the Environment and Rural Areas) (2011): Landwirtschaft und Umwelt in Schleswig-Holstein. URL: http://www.schleswig-holstein.de/UmweltLandwirtschaft/DE/LandFischRaum/04_AgrarberichtStatistik/08_PflanzlicheErzeugnisse/ein_node.html.

Schulte Steinmann, M., Holm-Müller, K. (2010): Thuenen Rings of Biogas Production - the Effect of Differences in Transport Costs of Energy Crops in the Choice of Renewable Resources by Biogas Plants. In: German Journal of Agricultural Economics 59 (1), pp.1-12.

Scholwin, F., Thraen, D., Daniel, J., Weber, M., Weber, A., Fischer, E., Jahraus, B., Klinski, S., Vetter, A., Beck, J. (2007b): Monitoring zur Wirkung des novellierten Erneuerbare-Energien-Gesetzes (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse, Institut für Energetik und Umwelt. Final report on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 150p.

SRU (German Advisory Council on the Environment) (2007): Climate Change Mitigation by Biomass, Special Report, 122p. Available online: http://eeac.hscglab.nl/files/D-SRU_ClimateChangeBiomass_Jul07.pdf (last online 02.02.2010).

Toews, T., Kuhlmann, F. (2007): Transportkosten von Silomais: Bremsen die Transportkosten große Biogas-Anlagen aus?. In: Lohnunternehmen 9, pp.34-37.

Urban, W., Girod, K., Lohmann, H. (2008): Technologien und Kosten der Biogasaufbereitung und Einspeisung in das Erdgasnetz. Ergebnisse der Markterhebung 2007-2008. Fraunhofer UMSICHT, 124p.

[i] Simulations done for the NaRoLa Project and also used in Gömann et al. 2011; see Gömann et al. 2011 for more details on the implementation of green maize for biogas production in RAUMIS.