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by Ruth Delzeit and Wolfgang Britz

No. 1767 | April 2012

Web: www.ifw-kiel.de

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

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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 contributes to an expansion of biogas electricity generation compared to former versions, and thus to 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

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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. 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).

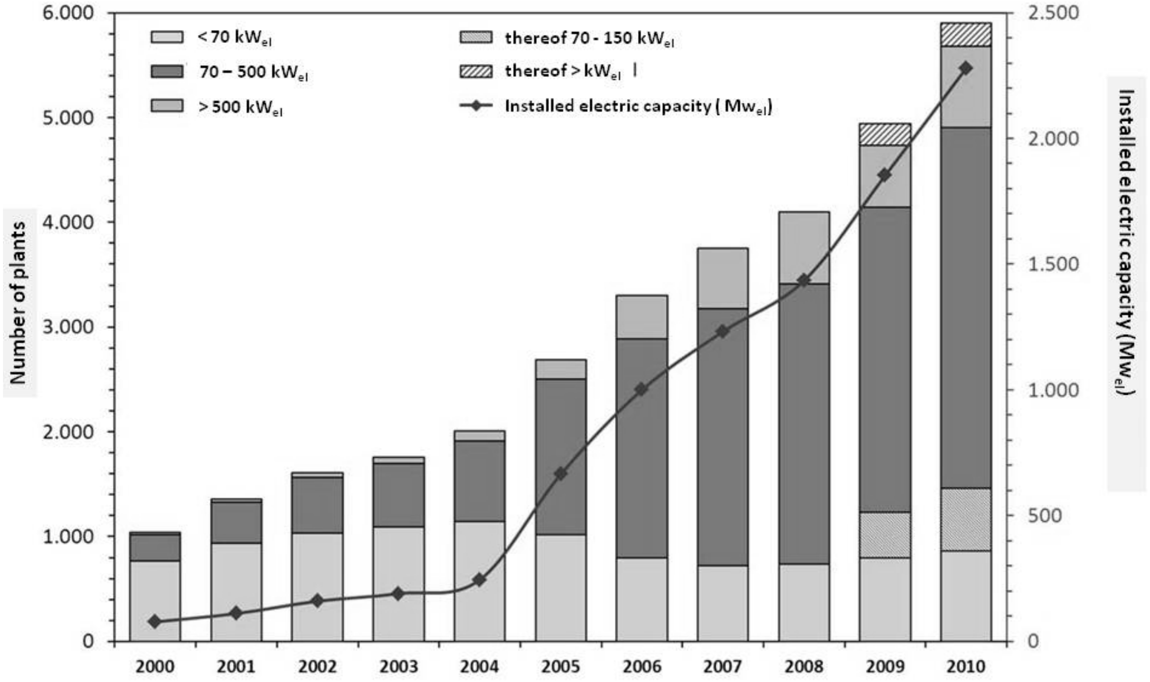
The objective of this paper is to analyse impacts on land use and biogas production as well as costs to electricity consumers in Germany caused by the reform of the EEG in 2011 (came into force January 2012) by comparing biogas production under three policy scenarios. The paper is structured as follows: 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 policy recommendations.

2 Biogas Production in Germany

The EEG was created in 1990 and revised in 2004, 2008 and 2011 (BGBL, 2004, 2008, 2011). Already the EEG 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 amended 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 food prices in 2007/2008 and therefore higher input costs, the EEG 2009 grants higher FITs with a focus on small scale plants. While for the use of Combined Heat and Power Generation (CHG) all plant sizes receive a higher bonus, the basic tariff 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

Increase of biogas production at unchanged technology is based on higher feedstock use. It is assumed that in 2009, 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 is very heterogeneous in Germany. Taking the most Northern German state Schleswig-Holstein as an example, in 2010, 176,756 ha were cultivated with green maize for biogas production (MLUR 2011) accounting for 26% of Schleswig-Holstein's arable land. In the states of Hessen or Saarland however, biogas production per arable land is very limited (DBFZ 2011, pp.39-40).

Land use changes as consequence of the EEG 2009 are also simulated in economic models by Gömann et al. (2010) 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 unexpected as the EEG 2009 introduced higher subsidies for manure use. Both 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) and the low energy content of manure overturn the positive feedstock mix effect.

A new amendment of the EEG will come 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 of the EEG 2012. "NaWaRos" are divided into two classes with one class (substance tariff class II) containing ecologically desirable substances (BGBl. 2011). Additionally, the use of maize and grains is limited to sum up to maximal 60% on the mass content.

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 used is based on so-called heat-electricity plants (BHPPs), where electricity is produced with the heat emitted from the engine used locally as a by-product. For the heat generated (thermal energy), suitable heat sinks (e.g. buildings that require heat) need to be found. Another option is to feed upgraded biogas into natural gas pipelines and transport it to locations with better opportunities to use heat. This increases the energy efficiency, but is only possible for large-scale biogas plants due to high processing 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 is described and 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 maize and manure feedstock inputs 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 across biogas plants, total feedstock at different prices for maize (21-53€/t) is determined for each NUTS 3 region, which by interpolation allows for regional maize demand curves to be 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*.

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

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).

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

3.1.2 Extending ReSI-M

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 ensilaged grass, sugar beet, and grains as possible inputs in different input shares and thus residue amounts. Note, that in opposite to silage 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 three different input mixes:

1) 80% manure and 20% maize
2) 50% maize, 10%grains, 20% sugar beet (all STC I) and 20% manure (STC II).
3) 50% maize, 10%grains, (all STC I); and 20% ensilaged grass plus 20% manure (STC II)

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 percent) (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 Data and Parameterisation

3.2.1 Production Costs and Revenues

Exogenous data to determine profits 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% 1000 kW_{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 large the 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). As data from the KTBL is categorised differently, only the sums are displayed (Achilles 2005, p. 942-944). Assumptions on energy efficiency and maximum operating hours are varied for a sensitivity analysis.

3.2.2 Feedstock Availability and Prices

The Regional Agro-environmental Information System RAUMIS (Henrichsmeyer et al. 1996, Gömann et al. 2007) 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 (α_t and β_t , see equations (4) and (5)) are extracted from Toews and Kuhlmann (2007), while Kellner (2008) provided these for manure.

Input prices biogas plants pay for ensilaged grass, sugar beet and 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.

3.2.3 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 those 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. 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).

3.3 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, but can significantly impact on demand for green 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%.

3.4 Simulating Market Clearing for Green Maize

In order to perform an impact analysis of biogas production on green maize cultivation, market clearing prices and quantities are derived by intersecting the regional demand functions from ReSI-M with supply functions for green maize derived from data provided by RAUMIS. Simulations using RAUMIS provided supply of green maize (net of regional feed use) for prices ranging from €20 to €53 per ton. Supply curves for green 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.

4 Results and Discussion

After introducing the applied scenarios, results on plant size are presented and validated with the observed trends in constructed biogas plants. Furthermore, the total electricity production from biogas plants under the scenarios is illustrated and the subsidies needed 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 with the resulting supply and demand functions of the target year 2020, while considering demand for feedstock of existing plants. The reference scenario is used to compare the EEG versions of 2008 and 2011 with each other.

2) In the scenario *“EEG 2009”* feed-in tariffs according to the EEG 2009 are adopted and the demand for feedstock of existing plants is considered. It includes simulated demand functions from ReSI-M as well as simulations of the supply functions by RAUMIS of the target year 2020.

3) To evaluate the EEG 2012 compared to its previous version, the “*EEG 2012”* contributes a scenario. FITs according to the EEG 2012 are presumed, and also feedstock demand by existing plants is taken into account.

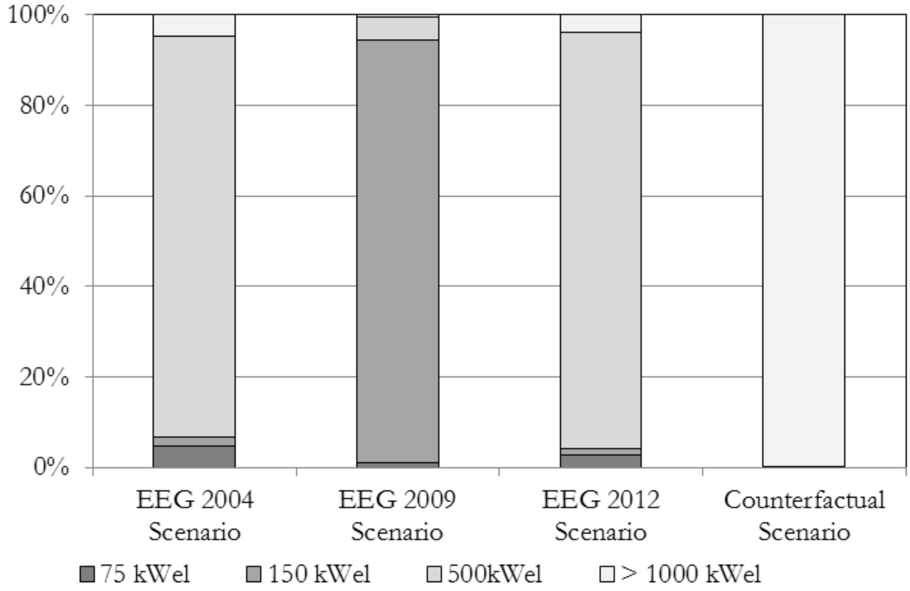
4) In a “*Counterfactual Scenario”*, all plant sizes receive the same output price per kWh_{el} and there are no extra subsidies for using specific inputs or particular techniques. A subsidy rate of 18.3 cent/kWh_{el} is chosen to result in approximately equal amounts of electricity produced compared to the scenario “EEG 2012” in order to make results comparable. In the counterfactual scenario there are no existing biogas plants – all plants are built from scratch. This scenario is chosen to compare the “reality” with a situation in which, theoretically, the resulting plant structure is a cost-minimal solution, due to a lack of influence over plant size and technology by policy intervention.

4.2 Profitable Plant Types and Electricity Production under the Scenarios

Figure 2 illustrates the plant structure under the different scenario settings. Plant sizes of 500kWel 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 feed-in tariffs and an increased NaWaRo-bonus, but are able to claim an additional subsidy for using manure (see Table 1), rendering them on most location the most profitable plant size. This fits well with observed data on trends in new plants 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$_{el}$ are the most profitable plant size (see Figure 2). These plants use 50% the cost efficient input maize, and 10% of grain. 40% are attributed to the STC II manure (20%) and ensilaged grass (20%), which receive higher tariffs per kWh$_{el}$ than STC I inputs such as maize and sugar beet.

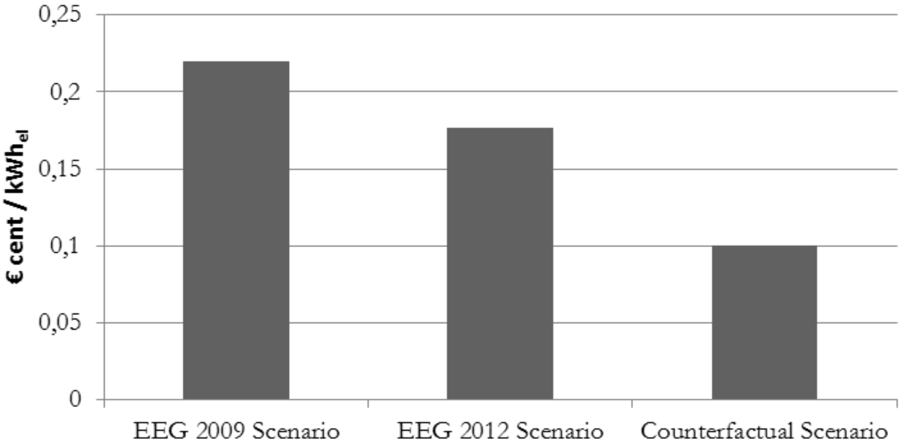
The same input shares are used in plants constructed under the counterfactual scenario, whereas the plant size differs: with feed-in tariffs which do not discriminate for plant size, large scale plants play out their economies of scale.

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 13% higher under the EEG 2012 and counterfactual scenario. In the following section we discuss whether that higher electricity production comes from higher subsidies or a more efficient tariff system.

4.3 Subsidies under the three policy scenarios

Based on the total energy 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 3. It shows that the per unit subsidies under the EEG 2009 scenario are higher than those paid under the EEG 2012 scenario, despite the lower energy input, 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 relatively high per unit cost, compared to larger the plants constructed under the EEG 2012 scenario which are more cost efficient and show an average efficiency of 37.5%.

Figure 3: Average subsidies played under the scenario settings

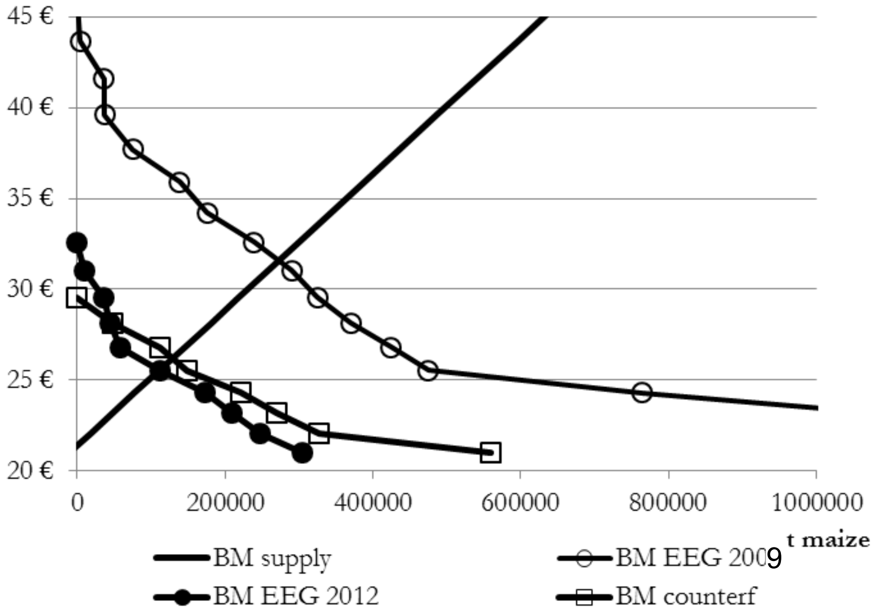


In the counterfactual scenario, special FITs supporting certain shares of inputs or technologies are removed, which results in cost-effective production structures and technologies. However, their economic advantage comes at the cost of a lower environmental performance linked to higher green maize feedstock shares (see Delzeit et al. 2012a). The impact on maize production is discussed in the following section.

4.4 Maize Markets and Resulting Maize Production

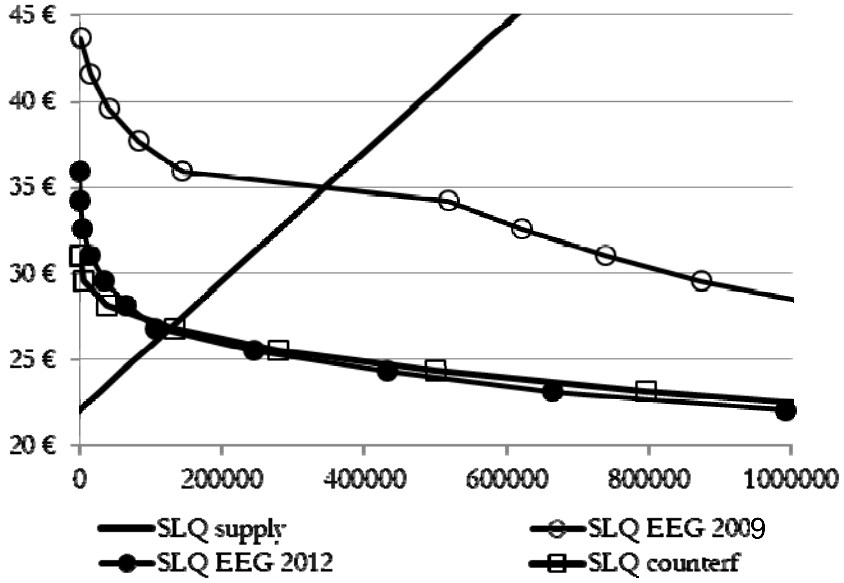
Maize production for each NUTS 3 region in Germany is determined by intersecting regional specific demand and supply functions (see section 3.4) which reflect characteristics such as land availability and distribution (see section 3.2). Demand curves additionally differ depending on feed-in tariffs in the respective scenario setting. Figure 4 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, 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 green 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 4 shows that the market clearing price for maize and thus the green 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 average feed-in tariffs are set equal in both scenarios, but maize demand curves are different. The higher demand under the counterfactual scenario is caused by low transport costs which have a major impact on large scale plants constructed in this scenario setting.

Figure 4: Maize market in Bergheim (BM)



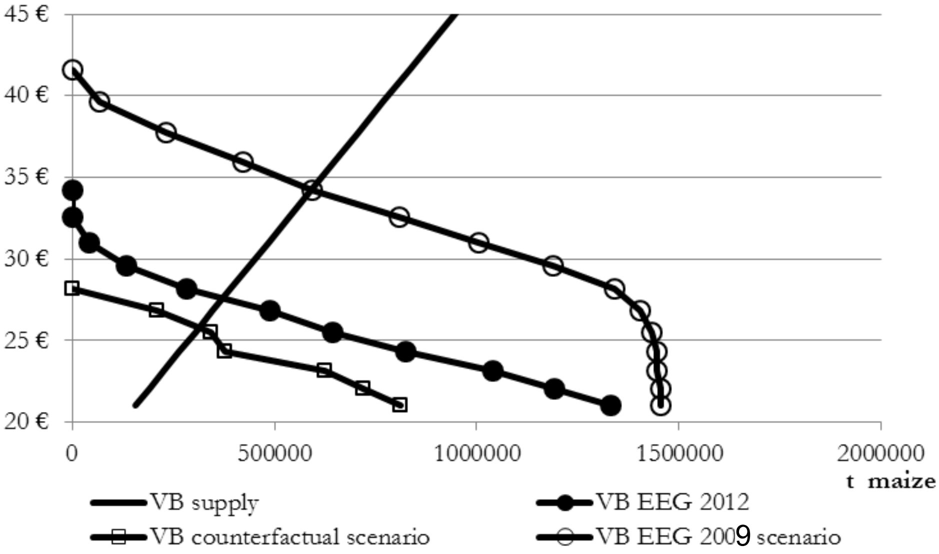
In Schleswig-Flensburg (SLQ), the market clearing maize price under the EEG 2009 scenario is about 4€/t higher than in BM region discussed above. The higher price stems from the fact that a higher availability of manure favours investments in small scale plants which receive the additional subsidy for 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 5: Maize market in Schleswig-Flensburg (SLQ)



A third example is provided in Figure 6. Vogelberg (VB) is a region with high transport costs. While maize prices under the EEG 2012 scenario are comparable to the equilibrium price under the EEG in BM, the equilibrium price under the counterfactual scenario is considerably lower due to low yields and availability of arable land in VB.

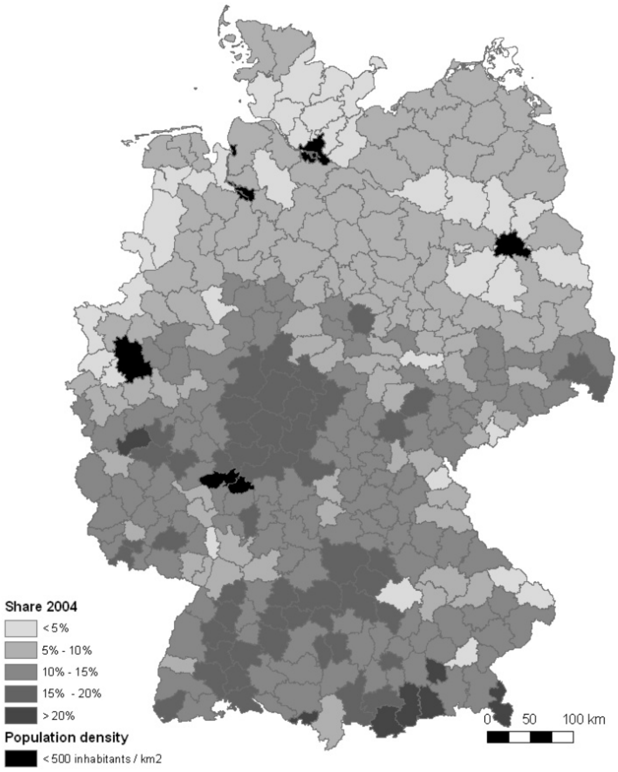
Figure 6: Maize market in Vogelberg (VB)



4.5 Regional distribution of maize production under different scenario settings

NUTS 3 regions in Germany vary considerably in size and arable land area, making comparison difficult. Therefore, the share of maize production on arable land is displayed. The simulated maize shares under the reference scenario are displayed in Figure 7.

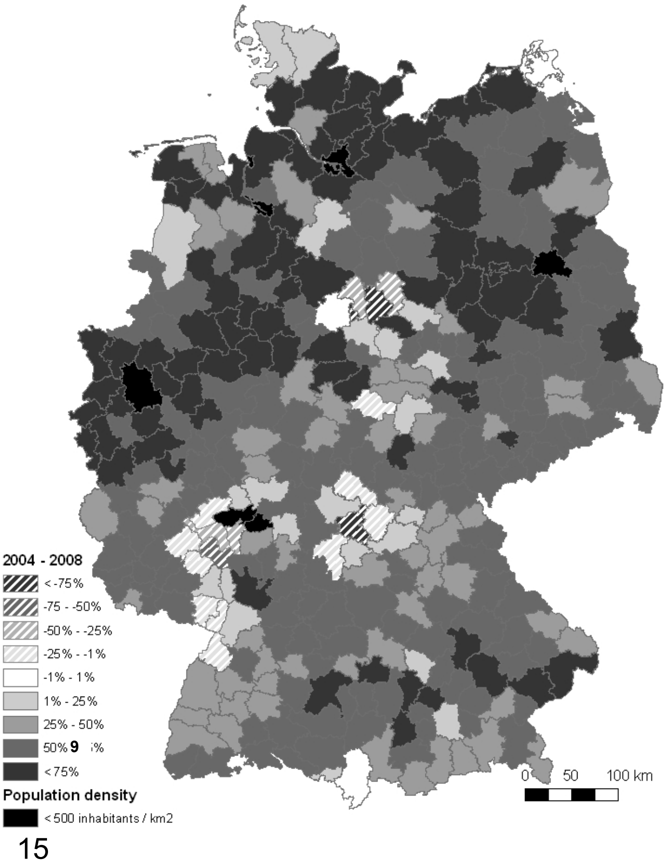
Figure 7: Share of maize on arable land in Germany's NUTS 3 regions under the reference Scenario



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.

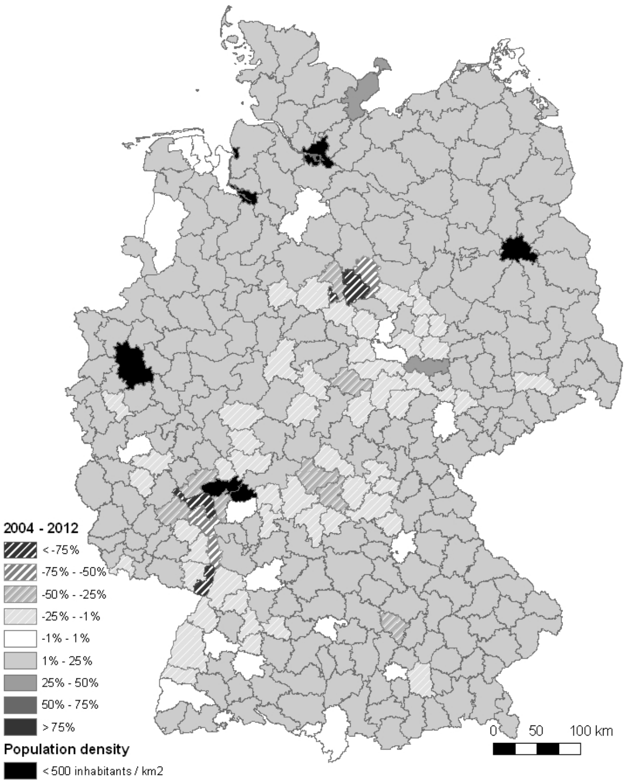
Total maize production is highest under the EEG 2009 scenario, leading to an average share of 17% on the arable land. The highest shares of maize on arable land occur in regions with high availability of manure (north-western Germany). The specialisation in animal production lead to higher than average green 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 (dark coloured regions in Figure 8).

Figure 8: Change in maize production under EEG 2009 compared to reference scenario



Dashed regions are those where 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. The total area under maize cultivation simulated for 2020 is about 1.7 mio ha.

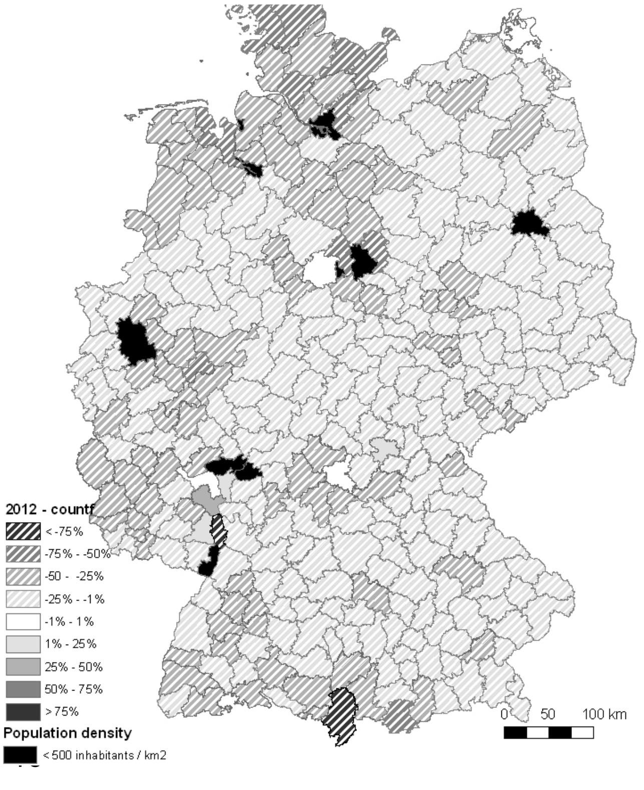
Figure 9: Change in maize production under EEG 2012 compared to reference scenario



Comparing maize production under the EEG 2012 scenario to the reference scenario Figure 9 shows are more moderate increase in maize production with a share of maize production on arable land at about 11%. 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 green maize mix favoured under EEG 2004, less maize is used. At the same time, more electricity is produced under the EEG 2012.

In the maize production under the EEG 2012 scenario and the cost efficient counterfactual scenario is compared. Note, that the same amount of electricity is produced and in both scenarios the same feedstock mixes are offered to plants. Under the counterfactual scenario only 9% of arable and is cultivated with maize, compared to 11% under the EEG 2012 scenario. This is caused by higher energy efficiencies of large scale plants such that for each produced energy unit, less land is needed.

Figure 10: Change in maize production under EEG 2012 compared to counterfactual scenario

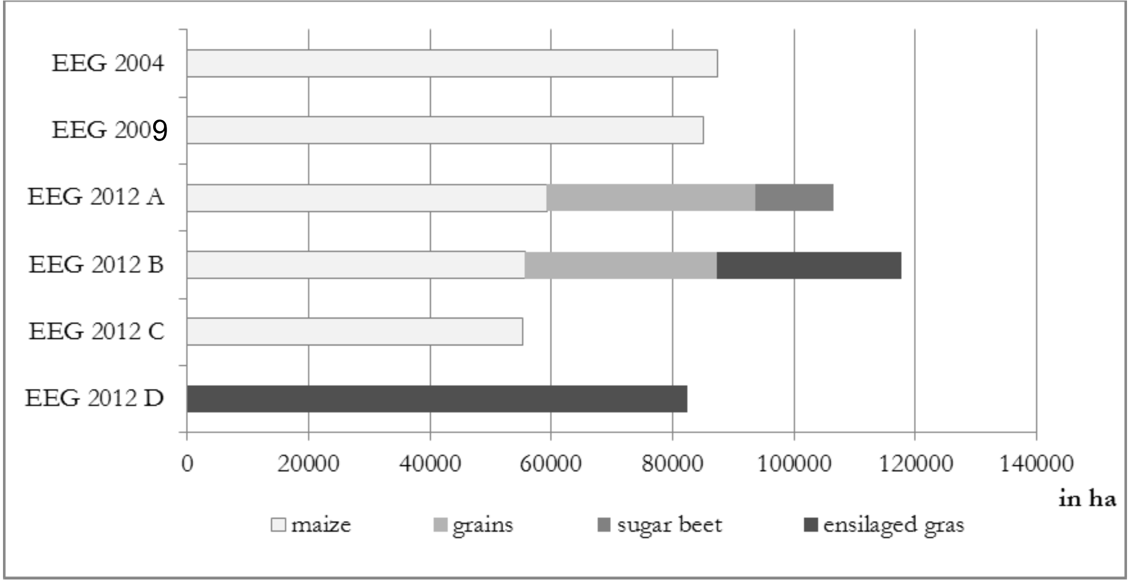


4.6 Addressing total area used for maize production

In the previous sections, we focused on the land used for maize cultivation. Under the EEG 2012, maize is substituted by more environmentally friendly crops such as grass, and grains. On the other hand, due to the high energy content of maize per unit land, these alternative crops might cause a higher demand in total area needed for biogas production. Since ReSI-M does not include information on yields from the extended crops, in this section 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 biogas plants with an average capacity of 400kW$_{el}$ (DBFZ, 2011 p. 39), the respective input demand by the different plant types is illustrated in Figure 11.

Figure 11: 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,*
Possible EEG 2012 A: 50% maize, 10%grains, 20% sugar beet, 20% manure
Possible EEG 2012 B: 50% maize, 10%grains, 20% ensilaged grass, 20% manure
Possible EEG 2012 C: 20% maize, 80% manure *Possible EEG 2012 D: 20% ensilaged grass*

Figure 11 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 plants using a high share of manure (80%) (see EEG 2012 C and D) still demand a considerable amount of land. Given the high energy content of maize, 20% mass content contribute about 61% of energy content. Due to the comparably low energy content of ensilaged grass, the area required for EEG 2012 D plants is 3% lower than plants that evolve under the EEG 2009.

5 Summary and conclusions

In this article we analyse, based on simulations with economic models, 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 latest amendment (EEG 2012) leads to a higher electricity output compared to the EEG 2009 at lower subsidies per electricity unit by favouring more cost effective larger plants. 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 reducing maize input further.

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 compared 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. Exception is a feed-mix where a very high share of manure is used (see EEG 2012 C).

Aiming to reduce competition for land under an increasing amount of biogas production, the 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 ensilaged grass 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.

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