MODELLING REGIONAL MAIZE MARKET AND TRANSPORT DISTANCES FOR BIOGAS PRODUCTION IN GERMANY

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Abstract

Our location model aims to simulate location decisions for biogas plants based on profit maximisation to generate regional demand functions for maize and corresponding plant size structure and transport distances. By linking it with an agricultural sector model we derived regional maize markets. Comparing results for the REA with a scenario applying uniform per unit subsidy and producing the same energy, we see higher subsidy costs with the REA but lower transportation distances.

Keywords

Biogas, environmental effects, transport costs, choice of location.

1 Introduction

Biogas is one promising candidate in a sustainable energy-mix. The so-called Renewable Energy Act (REA) subsidizes production of biogas in Germany and was reformed in 2004 and 2008 (BGBL. 2004 & 2008). As a consequence, many new biogas plants were built, most of them based on maize. However, the use of biomass for energy production in general is accused to have caused rising food prices in 2007, and concerns about negative environmental effects e.g. increasing transport volumes came up. Thus, different types of agricultural models are applied to capture effects on competition for primary factors, analyse welfare impacts and assess environmental externalities arising from bioenergy policies. Generally though, these models do not capture the demand side for crops with high transportation costs such as maize.

Our location model ReSi-M (Regionalisiertes Standortinformationssystem – Mais) aims to estimate maize demand at different price levels by identifying optimal locations that maximise the profit per unit investment costs for four sizes of biogas plants. In order to calculate market clearance ReSi-M needs information about the price-quantity relation of the input supply. This information can be gained from any agricultural supply-side model. Here, we use data from the Regional Agricultural Environmental Information System (RAUMIS). ReSi-M simulates regional maize prices and quantities traded, as well as the structure of biogas plants. These results are then used to calculate transport distances per kWh_{el} (kilowatt hour electric) in order to be able to estimate environmental effects of transport, which can then be added to the assessment of environmental effects stemming from the agricultural model. As subsidies have an important impact on location decisions and are incorporated into our model, the model can be used to evaluate different policy options. In this paper we compare the REA, where producers of biogas receive a staggered feed-in-tariff for the produced electricity depending on the plant size, with a uniform subsidy per produced kWh_{el} leading to the cost-minimal provision of a given amount of biogas.

Exemplifying our approach, calculations have been carried out for the NUTS 2 region Arnsberg in Germany, consisting of six NUTS 3 regions (counties). Arnsberg represents a region dominated by small farm structures and a high variance of agricultural yields and share of agricultural lands among the counties.

The paper is structured as follows: In section 2 we will first describe the theoretical approach and the method for solving the location problem and for deriving regional maize demand and transport distances. The data sources used and data preparation are specified in chapter 3. The fourth part discusses model results and applies the model to policy analysis.

2 Theory and method

To develop a location model for the problem at hand, a suitable model is derived from theory. The necessary parameters to fill the model are identified and the model is then applied to locate biogas plants.

2.1 Choice of a location model

A literature review on different facility location models (e.g. DREZNER & HAMACHER 2004, KLOSE & DREXL 2005) concluded that a Capacitated Facility Location Problem (CFLP) is the best model to solve the location problem at hand. The objective of a CFLP is to minimize costs considering the trade-off between fixed operating and variable delivery cost. Assuming a single-stage model (=simple plant location problem) it has to be decided, whether to establish facilities (binary variable y_i) and which quantities x_{ij} to supply from facility *i* to customer *j* such that the total cost (including fixed and variable costs) is minimized.

$$\min\left(\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} + \sum_{i=1}^{m} f_i y_i\right) \qquad \text{s.t.} \qquad \sum_{j\in j} d_j x_{ij} \leq s_i y_i$$

It is assumed that the plant operates on one stage, produces one product, a set of candidate sites for facility location and a set of customers are considered. Each facility $i \in I$ has fixed cost *fi*. Every customer $j \in J$ has a demand d_j, and c_{ij} is the unit transportation costs from *i* to j. Due to scarce capacities s_i shipments are limited (cp. KLOSE & DREXL 2005).

Objectives of location problems are discussed in [[=345 - Eiselt 1995 Objective in Locatio...=]]. As in the CFLP, the objective of most location models is to minimize costs (in the case of given fixed demands which have to be met) or to maximize the profit. A better decision criterion in business decision-making environments might be the return-on-investment (ROI), as most financial decisions are not based on the absolute value of the profit but rather on the efficiency of investments. Reviewing plant location problems, [[=333 - Revelle 1996 The Plant Location P...=]] formulate a location problem statement under the ROI objective, where ROI is the annual return divided by the initial investment. The annual return is the revenue minus costs of manufacturing distribution ([[=333 - Revelle 1996 The Plant Location P...=]], p. 866).

However, solving the model formulated as a CFLP was not possible due to the high number of variables and binarity (see DELZEIT 2008). Therefore, the model and solving approach had to be revised. The model is now formulated to sequentially solve simple transport costs problems for a given location, plant sizes and regional maize availability and prices. The model and solving process are described in detail in section 2.3.2 and 2.3.3.

2.1 Application to location choice of biogas plant

Location and sizes of bioenergy plants depend on a variety of regional factors which show interferences: output prices according to current legislation, input factor availability and resulting transportation costs, processing costs, and utilization possibilities for crude biogas and heat.

In the following section the system of biogas production and resulting assumptions for the location problem are described and a location model is derived.

2.2.1 Behavioural assumptions

We assume that the decision of building a biogas plant is made by a profit maximising investor.[1] We calculate the profit per invested Euro. A constructed biogas plant demands a

[1] This accounts for plants to be built. Existing biogas plants are considered in the model by respecting their demand for resources.

certain amount of inputs, which is supplied from surrounding fields. Biogas plants have to cover emerging transportation costs. The current legislation grants biogas plants pay-offs for produced electricity depending on their size. According to these size classes, we assume that the investor can decide between four sizes of biogas plants: 150, 500, 1000, and 2000 kWh_{el}, which have a predefined demand for input factors. Additionally, plants with different shares of input factors are defined leading to different subsidies in the case of the REA (2008).

2.2.2 Revenues

The most important legislation determining revenues from biogas plants in Germany is the Renewable Energy Source Act (REA 2008). It guarantees a feed-in tariff differentiated for different sizes of plants, the used technology and input materials. Additionally, surcharges are granted for the exclusive use of renewable primary products (RPP), the use of combined heat and power generation, the use of manure, and the use of new technologies. In addition to bonuses from the EEG, biogas plants can sell the by-product heat. Here a price of 3 cent/kWh_{el} is assumed.

2.2.3 Production costs for (crude) biogas

Production costs of biogas are divided into variable costs, which consist of costs for raw material, costs for maintenance and repair, labour, insurance, operating staff, and parasitic energy, and fixed costs (fixed capital). Fixed costs are derived from total investment costs with an imputed interest rate of 6%, and a useful live expectancy of 15 years (further assumptions see chapter 3). In the model, these costs are summed to annual costs. They depend on the plant size.

The produced crude biogas can be used in different ways. The current legislation favours two pathways of usage for the produced crude biogas:

2.2.4 Direct production of electricity in block heat power plants

In Germany, the major technology to use the produced crude biogas is block heat power plants (BHPP) with combustion engines, combined with a generator. Currently, the produced biogas is almost entirely used for a direct production of electricity in motor-BHPP (INSTITUT FÜR ENERGETIK UND UMWELT 2005, p. 75). Additionally, the BHPP modules contain a heat exchanging device, for recovering heat from exhaust gas, cooling water and lubricating oil cycle, hydraulic advices for heat-distribution and electrical switchgear and controlling units for electricity distribution and regulation of the BHPP (FACHAGENTUR NACHWACHSENDE ROHSTOFFE 2006, p. 101). A 500 kWh_{el} biogas plant produces 3.484.732 kWh of electricity and 2.647.861 kWh/a heat at 8000 operating hours (FACHAGENTUR NACHWACHSENDE ROHSTOFFE 2005). Electric efficiency is the sum of thermal and electrical energy, and usually is 80-90% (FACHAGENTUR NACHWACHSENDE ROHSTOFFE 2006, p. 104).

Combined Heat Generation (CHG) is the simultaneous production of power (e.g. electricity) and heat (FACHAGENTUR NACHWACHSENDE ROHSTOFFE 2006, p.19). It is assumed that with rising prices for raw materials only those biogas plants persist, which use combined heat power generation, as additional revenue from heat sales and subsidies can be acquired. For the produced heat, suitable heat sinks (demand for heat) need to be developed.

In the model, this pathway embraces the production costs for crude biogas, costs for the BHPP and costs for a heat net for the decentred use of the produced heat. Due to the de-central production of heat, utilization degrees of 0% for capacities of 100kWh_{el}, and 50% for 500 kWh_{el} are presumed.

2.2.5 Gas induction and production of electricity in BHPP

Biogas can be inducted into the gas grid, using qualitatively high processed biogas. This method is applied in pilot projects already. It is assumed that it becomes technically mature in the next years and is therefore included in the location module. The possibility of induction depends on several standards and legislation, as well as on the technical and economic side on the gas net at hand with different gas qualities and gas pressures. This pathway of usage is only cost-effective for plant sizes of 1000 and 2000 kWh_{el}, whose utilisation degree of heat is assumed to be 90% (cp. URBAN et al. 2008).

The cost effective pathway for each plant size can be calculated by summing up the respective costs. This sum for each plant size enters the model in order to simplify and speed-up the solving process. The same pertains to different revenues from heat sale and electricity induction which depend on the pathway of usage.

2.2.6 Raw materials as factor input

Biogas can be produced from a wide variety of input factors. Due to its costs efficiency the dominating factor is maize, which is often combined with manure and grain. Biogas plants with capacities of 150kWh_{el} additionally can claim 4 cent/kWh_{el} and plants with 500kWh_{el} can receive 1 cent/kWh_{el} for using at least 30% of manure as input factor. Hence, we assume plants with 150 and 500 kWh_{el} can use a relation between maize and manure of 70:30 or 10:90. According to the study of URBAN et al. 2008 we assume a share of 90:10 for the remaining two size classes. In addition, the all plants can alternatively use 99% of maize and 1% of manure.

Input prices for maize are varied from 20 to 40€/t and for manure, being a by-product of animal farming, no input costs are presumed.

Existing plants have a certain demand for maize and manure. The demand for maize and manure are subtracted from the regionally available amount of maize and manure.

2.2.7 Transportation distances and costs

Maize needs to be cut on the field and be transported to the biogas plant. Manure has either to be transported from an animal stable, which might be close by the biogas plant depending on the stock density of the county. After the fermentation process of the biogas production residues (digestates) have to be transported back to the field. Transportation costs per km are multiplied by a driving distance in km, which depends on the regional structure of land-use, yields in the case of maize and animal stock density for manure and residues.

Regarding the input factor maize, TOEWS & KUHLMANN (2007) analyse three transportation techniques regarding costs and transportation distances. For the location model it is assumed that plant sizes of 150 kWh_{el} use a technique where maize is chaffed on the field and carried by transportation units. Larger plants with 500, 1000 and 2000 kWh_{el} are assumed to use a different technique by overloading the chaffed maize on lorries. We assume rising transport costs depending on the distribution of maize, if the availability of maize decreases (see section 3).

In regions with a high animal stock density, the availability of manure is higher than in regions which are dominated by crop production. Therefore, we assume differences regarding the payment of transports. In regions with high stock densities, usually farmers pay biogas plants for using manure, whereas in regions dominated by crop production it is the other way around. As in the case of maize, we presume that transportation costs for manure increase with rising about of used manure in a region.

Payment of transport costs of residues disposal also depend on the stock density of the region, and additionally, in regions with a high animal stock density, surpluses in nutrient can limit the re-distribution of residues. In the current version of the model, there are no restrictions for disposal of residues[2], and therefore the disposal area is assumed to be equal to the cropping area.

[2] An improved version of the model will also include restrictions on the disposal of residues.

2.3 Method

The methodology consists of two interlinked methods: an analysis using a Geographical Information System (GIS) to gain data input and the location model ReSi-M.

2.3.1 GIS-Analysis

A GIS-analysis delivers data on regional characteristics on NUTS3 level. First, counties with more than 500/km^2 habitants are excluded as no biogas production is possible in urbanized areas due to availability of raw material and restrictions in building laws. Then, the GIS-tool “intersection” delivers data on selling opportunities regarding using the by-product "heat" and to induct gas into a natural gas pipeline.

In a third part, variances and mean shares of agricultural land are calculated for each county and weighted with the area of the respective attribute. We use the resulting means and variances from the GIS-analysis to generate the slope a Continuous Uniform Distribution function. The resulting values are multiplied with “initial” transportation distances.

2.3.2 The location model ReSi-M

To determine the optimal number and size of biogas plants, the objective function maximises profits per investment costs of biogas plants in each county. Revenues depending on plant sizes are subtracted by variable and fixed costs for biogas production, whereas prices for maize input are varied. Additionally, transport costs for maize and residues in different counties for price levels and plant sizes are subducted.

$$\max \pi = \sum_{l \in L} \sum_{p \in P} \frac{r_l - v_l - \eta_{lp} - f_l}{q_l} - \sum_{l \in L} \sum_{c \in C} \sum_{k \in K} \sum_{f \in F} \left(\frac{tm_{lck} * z_{lc}}{q_l} + \frac{tr_{lckf} * x_{lc}}{q_l} + \frac{tn_{lkf}\, y_{lc}}{q_l} \right)$$

Indices / Sets:

l…L: current plant size

p…P: current prices for maize

c…C : current county

k…K: counties

Decision variables:

z_{lc}: transported amount of maize (in tons)

y_{lc}: transported amount of manures (in m^3)

x_{lc}: transported amount of residues (in m^3)

π: profit

Parameters:

r_l sum of revenues (in € per year)

v_l: sum of variable costs (€ per year)

η_{lp}: input costs per year (maize price times maize demand at l)

f_l: summed fixed costs (in € per year)

$q_{l:}$ investment costs (in €)

tm_{lck}: transport costs for maize (in € per t)

tr_{lck}: transport costs for residues (in € per t)

tn_{lck}: transport costs for manure (in € per t)

α_l: costs for the first km of maize including up and unloading (in € per t)

β_l: transportation costs for each additional km of maize (in €/t per km)

δ_l transportation costs for the first km of manure and residues (in € per m^3)

λ_l transportation costs for each additional km of manure and residues (in € per m^3)

km_{lck}: driving distance (in km)

b_{cp}: amount of maize produced in county at price (in tons)

d_l: demand for maize per capacity (in tons)

dm_l demand for mature per capacity (in tons)

dr_l residues per capacity (in tons)

s_l share of input factor

fz conversion factor for residues output from maize input

fm conversion factor for residues output from manure input

$tcout_{ck}$ distance between c and k (km)

$tcin_{lc}$ driving distance within c (km)

$tc0_{lc}$ initial transport costs in current region

$tc1_{lc}$ additional transport costs with rising amount of used maize

e_c yields in tons per hectare

$share_c$ factor derived from share on crop land on total land

$dens_c$ density factor

<u>Side conditions</u>

(1) $\sum_{l \in L} z_{lc} \le b_{cp}$ for all $p \in$ P, $c \in$ C

(2) $\sum_{c \in C} z_{lc} = \sum_{l \in L} d_l * s_l * 1.08$ for all $l \in$ L

(3) $\sum_{c \in C} y_{lc} = \sum_{l \in L} dm_l * s_l$ for all $l \in$ L

(4) $\sum_{c \in C} x_{lc} = \sum_{l \in L} (z_{lc} * fz + y_{lc} * fm)$

(5) $z_{lc} \ge 0$ $c \in$ C, and $l \in$ L

(6) $x_{lc} \ge 0$ $c \in$ C, and $l \in$ L

(7) $y_{lc} \ge 0$ $c \in$ C, and $l \in$ L

(8) $\pi > 0$

<u>where</u>

(9) $$tc0_{lck} = \alpha_l + \left(\sqrt{\frac{d_l}{e_c * \Pi * share_c}} + tcout_{ck} - 1 \right) * \beta_l$$

(10) $$tr_{lck} = \delta_l + \left(\sqrt{\frac{d_l}{e_c * share_c * \pi}} + tcout_{ck} - 1 \right) * \lambda_l$$

(11) $$tc1_{lc} = \sqrt{\frac{\sum_{l \in L} d_l}{e_c * \Pi * dens_c}} * \beta_l$$

(12) $$tm_{lck} = (tco_{lck} + tc1_{lc}) * 1.33$$

Condition 1 ensures that not more maize is transported from counties to plants than is produced in a county. Input of maize for a plant at a certain capacity is related with the transports in condition 2. Additionally, a silage loss of 8% is considered. The same relation is defined in constraint 3 for the input of manure. Constraint 4 relates the transported inputs to the amount of residues for the plant sizes. Constraints 5 to 8 determine the range of value for variables.

Transportation costs for maize (9) and residues (10) consist of a cost term for the first km, as well as up and unloading a transportation unit (α_l for maize and δ_l for residues) and a cost term which is multiplied with the initial driving distance (β_l for maize and λ_l for residues). From the transport costs for additional kilometer, the first km is subtracted, as it is already included in α_l and δ_l. A transportation matrix which contains the mean distances between counties is represented by $tkout_{lk}$. The factor 1.33 respects that streets do not occur in straight bee-line distances. The resulting costs are multiplied with the amount of maize or residues needed at the predefined plant sizes.

In the case of maize, additional transport costs arise the more maize is used and also depend on the distribution of land in the respective county (11). (9) and (11) are summed up to the total transport costs (12).

2.3.3 The solving process

Calculations are executed for NUTS 2 regions in Germany allocating biogas plants of different sizes to its respective counties (NUTS 3). German counties have an average size of ~900 km². Consequently, in the model maize can be transported between different NUTS 3 regions within a NUTS 2 region, but no transport is possible between counties of different NUTS 2 regions. This is a modelling error that cannot be helped at reasonable calculation time. We assess this error to be negligible on average, though it might be important for certain NUTS 3 regions.

To avoid a large-size mixed-integer model working simultaneously for different plant size classes, prices and different locations, ReSi-M solves the plant location problem sequentially. The core of the problem consist of a simple transport costs minimization model, which determines the cost minimal transport flows for a given location and biogas plant size and given regional maize availability. Assuming an energy maize price at field level, the transport costs along with given other data allow us to define the profit for each combination of county and size class. Thus, in each sequence, the most profitable location and plant size according to the percentage net returns to capital in any county is chosen assuming that investors will first realize those projects with the highest internal returns. After each iteration, the available maize and manure quantity for each county is redefined based on the demand of the already located plants.

Based on the simulations at different prices, for each county a demand function as well as information on plant sizes and average transportation distances is generated.

The iteration process continues as long as a project has positive profits and there are sufficient inputs. Profits cannot increase over iterations as maize availability decreases and consequently per unit transport costs increase. Accordingly, any county - size class combination with negative profits in a given iteration will never be realized in any follow up iteration. That allows reducing rapidly many combinations of location and size class during iteration and speeds up the process.

Using this model formulation, no optimal solution can be determined by the model, but a solution, which is close to an optimum.

2.3.4 Scenarios

We have introduced two scenarios to analyse effects of the current legislation in Germany: a baseline scenario where biogas plants receive feed-in tariffs according to the REA (2009) and where the demand for maize of existing plants is respected. In a counterfactual scenario, biogas plants also are paid for inducting produced power in the electricity grid, but in this scenario all plant sizes get the same prices per kWhel and there are no extra subsidies for using specific inputs or using a particular technique. The subsidy of 16.5 cent/kWhel was chosen to result in equal amounts of produced energy in both scenarios in order to make results comparable. In the counterfactual scenario there are no existing biogas plants – all plants are built from scratch.

2.4 Calculation of CO_2 emissions from transport

The model results display transport radii for the plants which are build under the applied scenario. These transport radii are different depending on the plant size, yields and distribution of land.

Emissions are caused by diesel consumption of the chaffing machine and by transport units which transport the chaffed maize to the plant. As for transport costs for maize used in the model, TOEWS AND KUHLMANN (2007) have calculated the fuel consumption per ha for defined driving distances. We use our regional differing transport radii and the harvesting areas to calculate CO_2 emissions from those transports. Furthermore, we add emissions from the chaffing machine, adapting assumptions from TOEWS AND KUHLMANN (2007): 0.4 hour / ha for chaffing and diesel use of 32.6 litres / hour. To calculate fuel consumption, we multiply the harvesting area (ha) from the model results with the chaffing speed (h/ha) and the diesel consumption (litres / hour). The resulting diesel consumption of chaffing machine and transport units (in litres) is then multiplied with CO_2 emissions caused by each litre (2.65 kg/litre) (BMU 2008).

3 Data and data preparation

Land-use data for the GIS-analysis stem from the European CORINE land cover (CLC) database, which was calibrated by CAPRI (Common Agricultural Policy Regional Impact) to agricultural statistics (LEIP et al. 2008). LEIP et al. (2008, p. 75ff) created “Homogenous Spatial Mapping Units” (HSMU) with a resolution of 1x1 square kilometres (km^2) respecting soil, slope, land cover and administrative boundaries. In Germany, there are 17441 HSMUS with a mean size of 20.4 km^2, embracing an area of 3.562.000 km^2 (ebid. p. 80). As HSMUs cover a wide range of sizes and often contain multiple features, they are split in order to increase the comparability of analysis results between NUTS 3 regions.

As mentioned before, transportation costs for maize are extracted from TOEWS & KUHLMANN (2007), those for manure and residues from KELLNER (2008).

The currently available amount of energy-maize and yields at county level are gained from the model RAUMIS. A model run, simulation changes of agricultural and energy policies, was used to simulate maize production for four price levels of maize (GÖMANN et al. 2007). As data on maize supply shows a linear behaviour, a supply function is derived using a simple regression and included into the location model. To start the search for optimal locations and plant size, the maize supply by RAUMIS is corrected by the demand from existing plants.

We have calculated the available manure for biogas production from data on animal stocks from the Regional Statistics of Germany “Regionaldatenbank Deutschland” (Statistische Ämter des Bundes und der Länder 2009), and converted animal stocks into manure production based on factors taken from Statistisches Bundesamt (1991) and Niedersächsisches Ministerium für den ländlichen Raum, Ernährung, Landwirtschaft und Verbraucherschutz (2006). This calculation resulted in the total available manure per county and is adjusted by respecting the shares of solid and fluid manure on total manure quantities. The latter shares are taken from RAUMIS.

Existing maize demand from biogas plants was provided by the federal ministries (or institutions in charge) and subtracted from the available maize supply from RAUMIS.

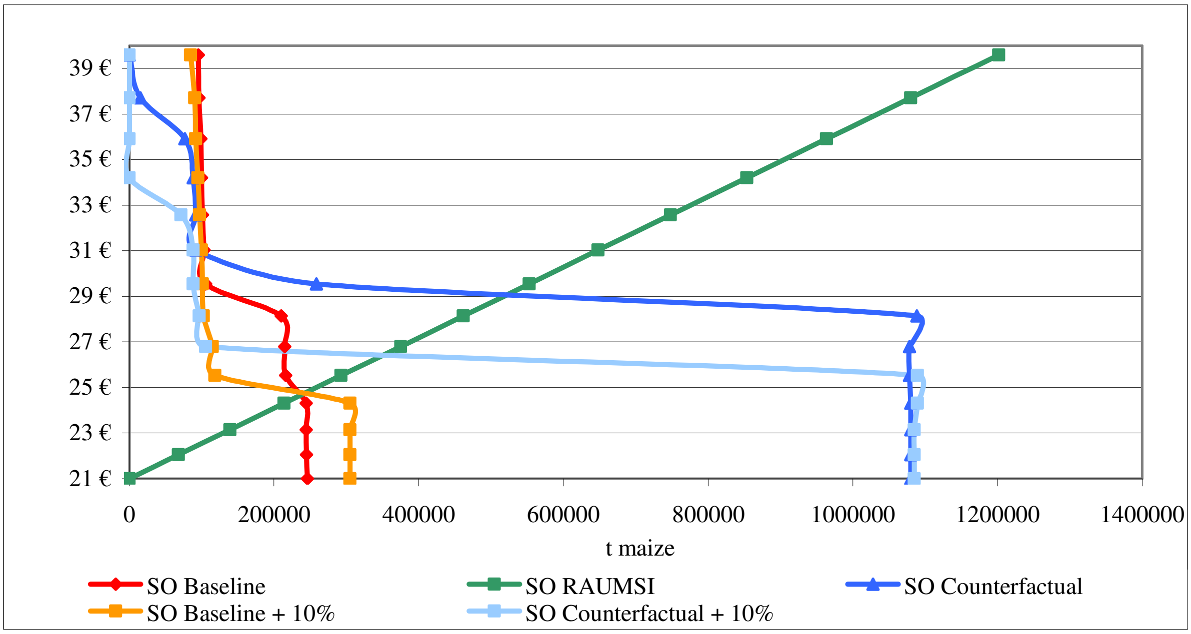
URBAN et al. (2008) have contributed production and processing costs for three sizes classes, whereas for the size class 150 kWh_{el} we have used data from the Association for Technology and Structures in Agriculture (KTBL, 2005).

4 Results and Discussion

First results show that under current legislation (baseline) plants of 150 kWh_{el} using 30% of manure are built. Additionally, plants with 500 kWh_{el} are constructed. Thus, in the baseline scenario economies of scale are not able to offset the combined effects of decreasing per unit subsidies and higher per kWh_{el} transportation costs when transport distances increase. In the counterfactual scenario, where we assume unified input-tariffs per kWh_{el}, plants with 500 kWh_{el} using 10% of manure and large scale plants (2000 kWh_{el}) are most cost efficient.

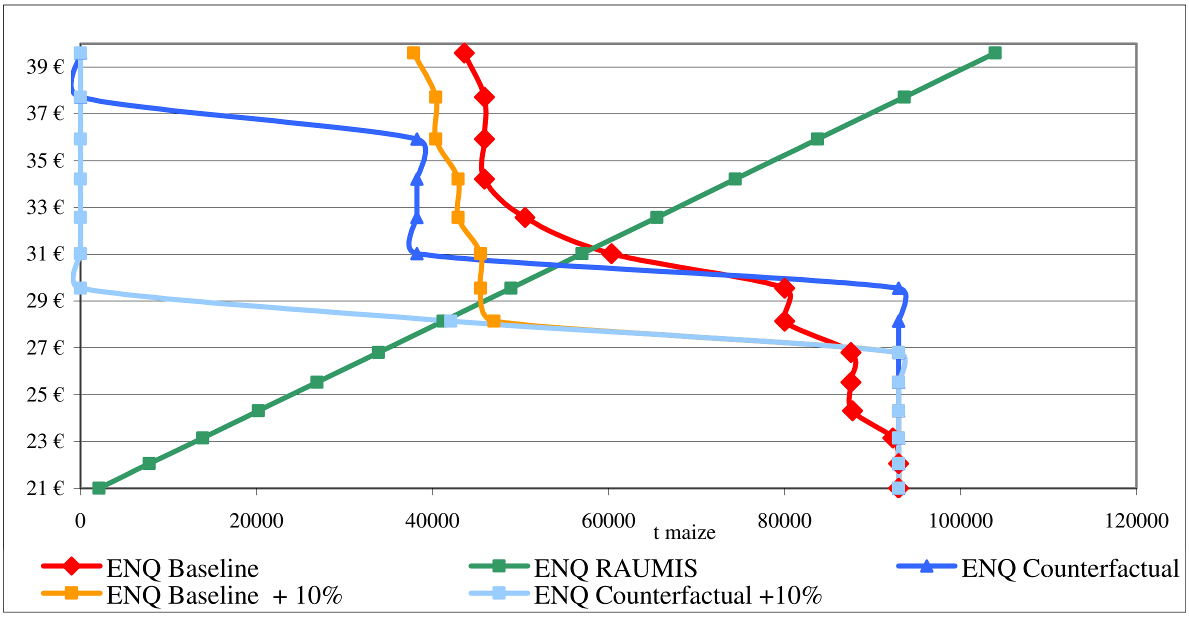
We compared this demand of maize with the supply derived from the RAUMIS model. Thereby, we determine regional equilibrium maize prices and quantities. At maize prices between 20 and 23€/t there is no sufficient supply of maize in both scenarios. With small scale plants built under the baseline scenario, regional market equilibrium prices between 24-40€/t are simulated, which depends on transportation costs and availability of manure in the respective county. Examples are the counties Soest (SO) and Ennepe-Ruhr-Kreis (ENQ), which are illustrated in Figure 1 and Figure 2. For SO we simulated an equilibrium prices of 24€, and in ENQ this prices is about 30€. Given, that in SO transportation costs are lower these results seem counterintuitive, but can be explained with the relative amount of available manure which is used for the small scale plants. In the counterfactual scenario, the market equilibrium prices range between 30 and 37€/t. Soest is the only county where plants with 500 kWh_{el} and also large scale plants are constructed. The advantage of high manure availability cannot be used by small scale plants, and thus compared to the baseline the equilibrium price decreases in counties with high transportation costs. In Soest, more maize is demanded by plants at higher prices, and the equilibrium price increases to about 29€/t.

Figure 1: Demand and supply functions Soest



Source: own calculations

Figure 2: Demand and supply function Ennepe-Ruhr-Kreis (ENQ)



Source: own calculations

A sensitivity analysis of energy efficiency (input need +10%) shows that a lower energy efficiency has a greater effect in ENQ than in SO (see light blue and orange in Figure 1 and Figure 2), which is caused by the higher transport costs in ENQ. The modelling of small scale plants is consistent with reality in that we find some dominance of small plants today and in planning. However, also some larger plants were recently built and are planned. They mostly stem from energy companies who use biogas inducting plants to save costs in the emissions trading scheme. If we include transaction costs in the reasoning, it may well be more cost-efficient for larger companies to open one larger plant than to handle spatially dispersed small scale plants. Nevertheless, the bulk of plant opening decision is captured correctly with our model.

In the counterfactual scenario, the effect of a lower energy efficiency is higher than in the baseline scenario, which can be explained by the relatively higher share of transport costs for the larger plants, realized in the counterfactual scenario. Thus, a higher energy efficiency ratio shifts the break even point towards higher per unit transport costs that will still entail sufficient profitability for biogas plants. With higher revenues longer distances can be driven to harvest maize and potential gains of the CO_2 balance in processing will at least partly be offset by rising emissions from transport.

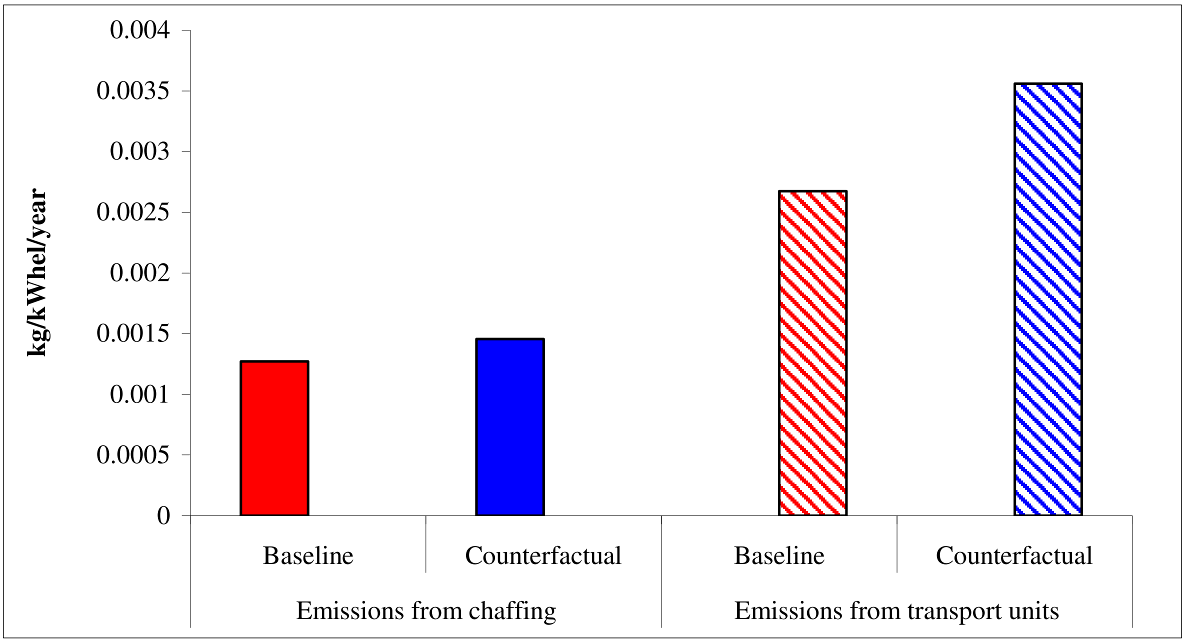
Given these different plant sizes, if we sum up the energy production of the biogas plants, we see that energy production is almost equal. This was intentionally done in the model design in order to compare transport distances per produced energy and to compare different costs for subsidies. These results are discussed in the following sections.

We calculated emissions from maize transports resulting from the two scenarios, as they are important to assess overall environmental effects of biogas production, which will be done in further research. To make transport distances of different plant sizes comparable, we divided the transportation distances by the total summed produced energy (kWh_{el}/a).

If we sum up transports of all constructed plants from our two scenarios we see that transport distances are higher in the counterfactual scenario than in the baseline scenario where plants of 150 and 500 kWh_{el} are built (see Figure 3). Note, that transports of residues from large scale plants can be reduced substantially by implementing a processing of residues (reduction of water content) before transporting it back to the field. This effect will be included in an improved version of the model. Also note, that in the counterfactual large scale plants, which use less manure are built.

Looking at CO_2 emissions from transport per produced annual energy caused by different plant sizes and types, our results show higher emissions in the counterfactual scenario. This is especially the case for emissions from transports between field and plant. Emissions from disposing residues back to the fields are neglected in this first assessment, as at least in the case of small scale plants those emissions would have be caused by the disposal of manure, too. However, an analysis of these effects is intended in further research.

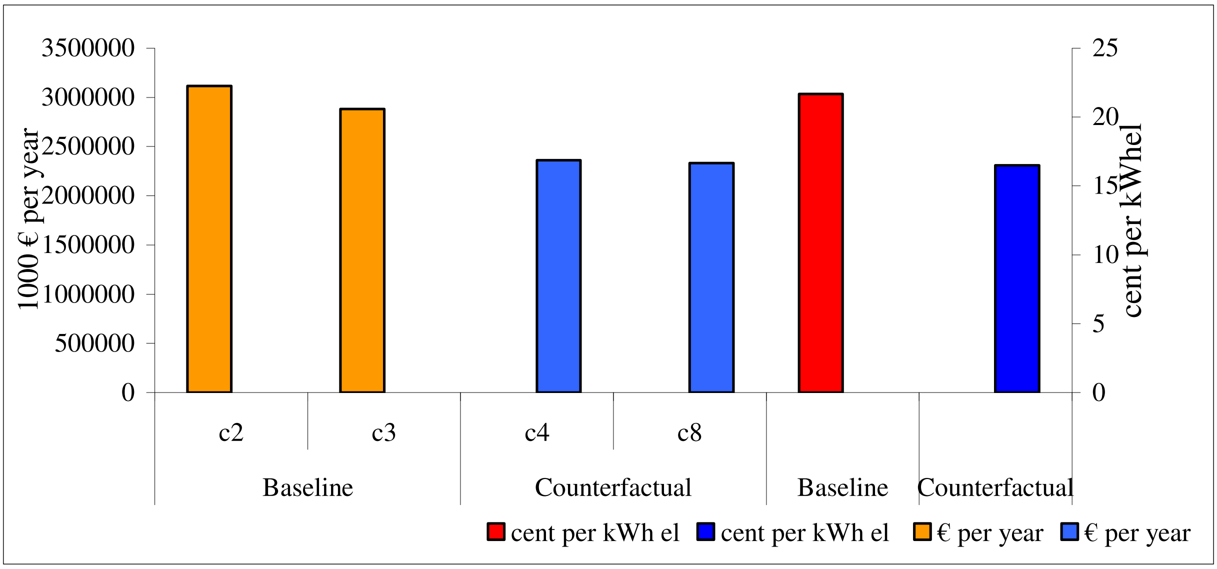
Figure 3: CO2 emissions from transport per annual production of kWh_{el}



Source: Own calculations

In order to compare our results regarding costs for promoting the production of bioenergy, we summed up the feed-in tariffs paid for the respective size structure and number of plants in the two scenarios. To analyse the policy with respect to welfare impacts of bioenergy production, distributional effects and production costs etc. would need to be included. Nevertheless, looking at costs for subsidies, our results show that in the baseline scenario more subsidies need to be paid than in the counterfactual scenario to produce the same amount of energy (see Figure 4). We give some concluding remarks on the results in the next chapter.

Figure 4: Costs for subsidies



Source: Own calculations; c2=150 kWh_{el} (30%Manure), c3 = 500 kWh_{el} (1%Manure), c4= 500 kWh_{el} 1 (10%Manure), c8 = 2000 kWh_{el} (1%Manure)

5 Conclusions

In summary, our model ReSi-M proves to be an interesting tool to analyse environmental policy options as it enables us to assess and analyse the regional dispersion of biogas plants, dominant plant sizes and relating transport distances stemming from different policy designs. Additionally it allows us to calculate regional market equilibrium prices for maize, which is not possible with agricultural models, which neglect high transportation costs.

A first glance at the German biogas policy our results show that the subsidies, paid in terms of the feed-in tariff to reach the same amount of renewable energy, are higher in the baseline scenario than in the counterfactual scenario. These costs to the consumer do not respect differences in production costs of the biogas plant. Furthermore, distributional effects are neglected: small scale plants are run by farmers, whereas they only supply raw material to large scale plants, which are not operated by farmers. Thus, under our model assumptions, there is scope for some reduction in feed-in tariffs in the current regulation, even if maize prices are going to rise again.

Looking at the transportation distances, they are lower in the baseline than in the counterfactual scenario, showing some positive effects of the current legislation. On the other hand the current legislation does not favour plant sizes with lowest transportation costs as it promotes the use of manure. From an environmental point we here face a trade-off between saving of fossil fuel by minimising transport and reducing the use of valuable resources in the production process. In a further paper we plan to compute maize used into indirect energy use and will then been able to compare both scenarios from a greenhouse gas perspective. Additionally, deeper analysis of the environmental effects of different scenarios will be possible, once we use environmental indicators from the RAUMIS model and combine them with our results. It will then also be possible to look deeper into comparisons of welfare and distributional effects.

Additionally, we will improve the calculation of transports of residues. Currently, there is no restriction for the disposal of residues per hectare. Additionally, large scale plants could use their economies of scale to process residues and thereby lower transport costs and distances. By classifying counties in counties dominated by cropping or by animal production differences in the payment of manure and residues transport can be elaborated, which might lead to different plant structures and different equilibrium prices for maize.

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