Flexible Load of Existing Biogas Plants: A Viable Option to Reduce Environmental Externalities and to Provide Demand-driven Electricity?

David Schäfer, Wolfgang Britz and Till Kuhn
University of Bonn

Abstract

The expansion of fluctuating renewable energies such as wind and solar increases the need for electricity produced on demand to stabilize the grid. Electricity from existing biogas plants in Germany allows flexible energy output and is increasingly marketed on demand requiring technical modifications such as increased gas storage and engine capacity. In this study we investigate an alternative approach in which a reduced fermenter load provides additional gas storage and engine capacity with no additional investment. This reduces input use and digestate production, thereby decreasing environmental externalities in regions with high biogas and animal densities.

We quantify the required increase in subsidies for two dairy farms in Germany to switch from guaranteed subsidies for continuous electricity production to different levels of flexible load. The farms are assumed to have invested in a biogas plant under the Renewable Energy Sources Act of 2009 and 2012. We simulate the reduced biomass demand and its implications on farm management with a focus on fermenter input composition. Thereto, we develop a bio-economic model of a biogas plant and integrate it in the dynamic single-farm model FarmDyn. We find that provision of electricity on demand reduces especially the demand for maize silage, a feedstock with high negative environmental externalities. Even a moderate input reduction of 30% requires a subsidy increase of 1.8 to 3.2 cents/kWh contingent on the initial RES. We conclude that despite the approach being able to provide electricity on demand and to reduce negative environmental impacts, a widespread application seems unrealistic due to high additional subsidies.

Key Words

biogas; policy; flexible electricity production; biogas plant feedstock; environmental impacts

1 Introduction

As a continuation of efforts towards a low carbon economy in the European Union, the European Council agreed upon the "2030 framework for climate and energy policies" (EUROPEAN COMMISSION, 2015). It sets targets for reducing greenhouse gas (GHG) emissions by 40% and increasing the share of renewable energies and energy efficiency by 27% by 2030, respectively. Germany fosters the expansion of renewable energies since 2000, especially in the electricity sector, by the so-called Renewable Energy Sources Act (RES). It aims to mitigate GHG emissions and further negative external effects attributed to the use of non-renewables while at the same time protecting the environment (BGBL., 2008; BGBL., 2012b). The RES promotes both intermittent and continuously producing renewable energies through fixed feed-in tariffs (FITs), guaranteed over two decades, and market premiums for participants in a direct marketing scheme. These subsidies rendered investments in renewable energies profitable while largely reducing market risks, resulting in a share of 25.8% of renewable energies on the gross electricity consumption in 2014 (BMWI, 2015).

While the biggest share is derived from wind energy, bio-energy contributed about 6.9% to the gross electricity production in 2014. Bio-energy use promoted by the RES focuses on electricity – the bio-fuel sector is not part of the act – which comes primarily from decentralized biogas plants. Whereas in 2004 biogas plants produced less than 500 Megawatt (MW) electricity, the amount increased sevenfold to over 3,900 MW per year in 2014 (FACHVERBAND BIOGAS E.V., 2015). This increase was triggered by the first RES amendment in 2004 which promoted the use of energy crops by changes in the FITs for biogas production; this subsidization continued until the RES 2012. However, that massive expansion of biogas production was only feasible with a substantial increase in biomass use of energy crops: in 2014, 7% of the agriculturally used area in Germany was devoted to feedstock production for biogas, of which 63% was energy maize (DESTATIS, 2015).

1.1 Environmental and Economic Implications of Extended Biomass Demand

It is increasingly acknowledged that the high demand for energy maize contradicts the environmental protection objective of the RES. Loss of biodiversity, increased soil erosion and ploughing up of permanent grassland are attributed to expanded energy maize cultivation which is often cropped as a monoculture (EUROPEAN ENVIRONMENT AGENCY, 2007: 54; OSTERBURG and RÖDER, 2012). Integrating biogas production in existing farming systems under the subsidies of the RES – at least until 2012 – drove up the overall biomass demand, as the low energy concentration of substrates such as animal excrements or plant based by-products does not suffice for a production of relevant amounts of bioenergy and renders the process quite expensive. Even with considerably increased shares of crops such as maize, which produce more biomass per hectare relative to other crops, the additional biomass demand of a biogas plant requires additional imports of either compound feed or fodder into the farm, the latter either used for animals or biogas production (BRITZ and DELZEIT, 2012).

The RES rendered investments into biogas plants especially lucrative for farms (or group of farms) with high animal densities. That was due to high FITs for the use of moderate mass shares of manure in the RES 2009 – which contributed little to overall energy output due to their low energy concentration – and favorable accounting rules for nutrients from biogas plants in environmental law. Consequently, after investing into biogas plants, farms typically disposed higher organic nutrient loads on their own or neighboring plots. Already often high nutrient surpluses were driven further up and enforced threats to ground and surface water (HEIDECKE et al., 2012: 34; GUENTHER-LÜBBERS et al., 2014).

Besides environmental issues, the additional biomass demand for biogas production impacts land lease and fodder prices, potentially crowding-out other types of agricultural production and their respective value chains (RAUH, 2010; EMMANN et al., 2012; EMMANN et al., 2014). The German government reacted to these negative effects in a RES amendment in 2012 by decreasing incentives for the use of energy maize. As electricity production from biogas, compared to other renewable energies, is rather expensive, the subsequent RES amendment in 2014 lowered the FITs for newly erected biogas plants to a level where new investment into biogas plants and thus a further expansion of the sector seems unlikely (SCHEFTELOWITZ et al., 2014). In addition, this latest amendment prescribes a maximal expansion of installed electric capacity of 100 MW from biogas per year (BGBL., 2014a). However, the reader should keep in mind that all existing plants benefit from the FITs guaranteed in the legislation when they were built, if the operator did not opt to switch to a newer legislation. Due to sunk costs and guaranteed output prices, these existing plants will operate typically from the year of installation onwards for the full period of guaranteed FITs, i.e. for 20 years. With the sharp increase in new constructions especially in the years 2004 to 2010, the consequences attributed to the biogas sector will hence be felt until 2030.

1.2 The Role of Flexible Electricity Production of Biogas in the Energy Transition

The German government fosters the replacement of nuclear and fossil fuels with renewable energies within the electricity sector in the so-called energy transition (STRUNZ, 2014). Consequently, reducing the costs of electricity produced from renewables by limiting further increases in the expensive biogas sector in favor of cheaper renewables such as wind and solar, corresponds to the renewable expansion goals of the energy transition. However, most alternatives to biogas, such as wind and solar, lead to volatile electricity output and thus require balancing energy sources, as technologies to store electric energy at industry scale have not yet reached market maturity. Here, despite higher costs, electricity from biogas production could play a role as biogas could be stored and electricity produced on demand at times when output from other renewable sources is low (AUBURGER and BAHRS, 2013). Accordingly, the recent amendments of the RES in 2012 and 2014 introduced incentives for flexible electricity production from biogas to promote market integration and demand-driven electricity production. As a further expansion of the biogas sector at the low FITs for new investments is unlikely, this flexibilization approach mainly targets the current biogas inventory. Based on a survey, SCHEFTELOWITZ et al. (2014a) estimated that 8% of the existing plants already produce electricity flexibly based on direct marketing.

The most commonly used biogas plant setup for flexible electricity production is based on continuous biogas output, buffered by extra gas storage and engine capacity (HAHN et al., 2014). In case of higher demand, power engine output is increased by adding biogas from storage to the continuous output from the fermenter. Accordingly, a larger combined heat and power engine capacity relative to the size of the biogas fermenter plus storage capacity is necessary. That storage capacity and the potential of the engine to convert biogas beyond the continuous output from the fermenter define jointly the maximum flexible load and drive up investment costs. Several studies investigated the economic viability of this biogas set-up and found that flexibly produced electricity could be provided without additional subsidies (HOCHLOFF and BRAUN, 2014; BARCHMANN and LAUER, 2014). While these studies focus only on the economic viability of flexible electricity production, to the knowledge of the authors no study exists, which examines a biogas plant setup taking the aforementioned environmental and agricultural sector concerns into consideration.

1.3 Investigating the Influence of Reduced Biomass Demand

Based on this background, we aim to fill the gap in literature by taking agricultural economic and environmental impacts of existing biogas plants into account and propose a biogas setup for flexible electricity production with reduced biomass input. In contrast to the aforementioned studies, the larger combined heat and power engine capacity relative to the size of biogas plant is not achieved by increasing power engine and gas storage, but by reducing the continuous biogas production through decreased biomass input. This study has thus two main objectives: first, to investigate the economic viability of such a biogas setup by quantifying the required increase of subsidies for different levels of desired flexibility. Second, to examine related changes in farm management, in particular biomass demand differentiated between source and crop. In order to achieve the objectives, we develop an economic supply-side biogas model based on a fully dynamic mixed integer linear programming (MILP) approach which simulates simultaneously the economic and technical aspects of a biogas plant. As most biogas plants in Germany are linked to an existing farm, the biogas model is integrated as a module into the existing bio-economic FarmDyn model (BRITZ et al., 2016).

The remainder of the paper is structured as follows. Section 2 presents the modeling framework for the biogas plant. Further, it introduces the economic and technical aspects of the biogas model as well as the data basis. In addition the farms and amendments which will be investigated are presented. Section 3 examines the results and discusses their implication with respect to potential environmental and economic benefits as well as discussing the role of biogas in the electricity sector. Finally, Section 4 summarizes and concludes the findings of this study.

2 Methodology

2.1 Modeling Framework

The biogas plant is integrated in the highly detailed bio-economic single farm-level model FarmDyn[1] realized with the General Algebraic Modelling Language (GAMS). FarmDyn is an economic supply-side model building on fully dynamic mixed integer linear programming (MILP). The linear programming approach facilitates the depiction of technological and economic activities as linear combinations (TEN BERGE et al., 2000). These activities are defined by input-output coefficients (HAZEL and NORTON, 1986) to return e.g. the generation of electricity or the production of substrates for the biogas plant. The high detail of FarmDyn is advantageous as the additional incentives necessary for flexible electricity output are contingent on technological aspects such as the input mix used in the fermenter while reduced biogas demand impacts farm management.

Extending linear programming with a mixed integer approach serves two purposes. On the one hand, the MILP approach depicts correctly non-divisibility of investment decisions (CIAIAN et al., 2013: 18f.) such as reinvestments of existing biogas plant parts which differ in physical lifetime. In our setup, also part of off farm work is captured by integer variables. Furthermore, it allows for strategic decision options (JANSSEN and VAN ITTERSUM, 2007), as for example in our application a switch between different amendments of the RES. In addition, the fully dynamic approach simultaneously depicts the full planning horizon (GALLERANI et al., 2013: 42f.), allowing a detailed assessment of future returns to alternative investment decisions. As discussed in the result section, this encompasses re-investments in dairy stables and equipment.

We assume a rational and fully informed decision maker maximizing the net present value (NPV) over a predefined planning horizon; in our application cover-

[1] For further information on FarmDyn please consult the technical documentation BRITZ et al. (2016).

ing the two decades for which FITs are guaranteed. Even though several authors propose a risk-averse decision maker (PANNELL et al., 2000; JANSSEN and VAN ITTERSUM, 2007) maximizing over multiple objectives (TEN BERGE et al. 2000) in a farm-household context, risk neutrality is chosen in here for several reasons. It renders result analysis straightforward as the derived increases in subsidies relate to costs only and do not comprise risk premiums. The latter would reflect our assumptions on risk behavior for the hypothetical case study farms, with little empirical content. And finally, the combination of a fully dynamic optimization and the MILP approach within FarmDyn render the model already quite large and limit further extensions due to computational restrictions.[2]

The optimization problem is constrained by possible production patterns, willingness of the family to work on farm, liquidity constraints as well as policy and environmental restrictions.

The biogas module is integrated as a farm branch module which is consistently interlinked with mass flows and the economic optimization section of FarmDyn. It covers the cash flows, accommodations of loans, variable and investment costs, distribution of work and the calculation of the net present value of cash balance. In addition, the required biomass for the biogas production process can be either delivered from own production depicted by the manure and cropping modules or can be purchased.

The biogas module covers the technological and economic aspects of a biogas plant including the RES amendment specific restrictions and payment structures. In addition, the investment part of the biogas module covers the necessary reinvestments to keep the existing plant operational. These three essential aspects – investments, biogas and electricity production and related revenues and costs – are discussed in the following.

2.1.1 Investment Part

The maximal number of biogas plants per farm is set to one in the model. Besides the initial investment, continued use of a biogas plant requires reinvestments in intensively used machinery parts shown in Equation (1). The model differentiates machinery parts by investment horizon, i.e. the combined heat and power engine has to be replaced every 7 years, whereas the existing mixer in the fermenter as well as the mixer in the storage for digestates has to be replaced every 10 years. Constructions such as the fermenter or the substrate storage have to be replaced every 20 years. The corresponding costs for different biogas plant sizes, investment horizons and credit rates are shown in Appendix A. The overall investment costs for a biogas plant in each year are calculated in (2) and are integrated in the overall yearly investment costs of the farm in FarmDyn.

$$I_{ih,b} \leq \lambda_{ih,b} + B_{ih,b} \quad (1)$$

$$\Gamma_b = \sum_{ih} B_{ih,b} * \pi_{ih} \quad (2)$$

where $I_{ih,b}$ is the biogas parts inventory for each biogas plant part ih and biogas plant size b, $\lambda_{ih,b}$ is the biogas inventory prior to the simulation, $B_{ih,b}$ is the bought inventory during simulation, Γ_b are the biogas plant parts investment cost and π_{ih} is the price of each biogas plant part.

2.1.2 Technological Part

The biogas and electricity production process for each month is described as a Leontief production function constrained by technological and biological process restrictions shown in Equation (3) to (8). Electricity output depends on input quantities, the methane content of inputs, energy content of methane and the electric conversion efficiency of the engine (3). The production process of heat differs from the electricity production process only in the conversion efficiency and is not shown here in addition. The electricity production is constrained by the maximal capacity of the engine in kW to convert electricity (4).

$$Y_b = \sum_i (X_i * \varepsilon_i) * \omega * \eta_b \quad (3)$$

$$Y_b \leq I_b * \alpha_b \quad (4)$$

where Y_b is the electricity output for each biogas plant size b, X_i is the biomass input for each input i, ε_i is the methane content per ton fresh matter, ω is the energy content in kWh per m^3 methane, η_b is the conversion efficiency for electricity for each biogas plant size and α_b is the maximum capacity of the combined heat and power engine.

Equations (5) and (6) describe the technological constraint that the input amount cannot exceed the

[2] A stochastic programming extension based on stochastic trees for FarmDyn where all variables are stage contingent has been recently developed, but the complexity of the model severely restricts the size of the decision tree. Applications are still experimental and deemed not appropriate for the current study.

net-volume of the fermenter[3]. Further, Equation (6) includes a parameter to restrict the fermenter load to a certain maximum level. This parameter ϕ is used to quantify the FIT levels for different input amounts. In addition, the production process in the module is constrained by restrictions prescribed by legislation to receive additionally bonus payments or payments at all. The model includes the bonus payments for manure use in the RES 2009, where 30% of the input volume has to be manure sourced to receive the bonus. Further, it accounts for the fact that payments in the RES 2012 are contingent on the fulfillment of a 60% input volume limit for maize sourced inputs and a minimum of 35% external utilization of heat. Bonus payments for the RES 2012 differentiate between two input classes (BGBL., 2012a).

$$V_b \geq \sum_i X_i \tag{5}$$

$$V_b \leq I_b * \beta_b * \phi \tag{6}$$

where V_b is the net-volume of the fermenter, X_i is the biomass input, I_b is the biogas inventory, β_b is the maximal net-volume and ϕ is the defined input reduction level.

The continuous biogas production is contingent on favorable biological and chemical conditions for the bacteria culture in the fermenter (MULAT et al., 2015). A measure to maintain such conditions for the bacteria is the digestion load. The digestion load is determined by the organic dry matter content in the fermenter per day relative to the volume of the fermenter expressed in Equation (7). Recommended levels for the digestion load are given by literature and added as a restriction in Equation (8) (KTBL, 2013: 78; FACHAGENTUR FÜR NACHWACHSENDE ROHSTOFFE E.V., 2013: 154). Parameters applied in the production process can be seen in Appendix B.1, B.2 and B.3.

$$\Delta_b = \frac{\sum_i (X_i * p_i)}{\beta_b} \tag{7}$$

$$\Delta_b \leq I_b * \gamma_b \tag{8}$$

where Δ_b is the digestion load, X_i is the biomass input, p_i is the dry matter content of each input, β_b is the maximal net-volume, I_b is the biogas parts inventory and γ_b is the maximal digestion load.

2.1.3 Economic Part

The subsidies received for electricity from a biogas plant depend on the RES. The RES amendments differ with regard to requirements for total or partial bonus payments. Further, the payments can be subdivided into FITs and direct marketing premiums, the latter granted if electricity is sold on the spot market. The payments for FITs in the model reflect sliding scale prices as defined in the legislation (BGBL., 2008), i.e. for the first 150 kW of electricity produced, the operator receives the payment for a 150 kW biogas plant and for the electricity produced between 150 kW and 500 kW the lower payment for a 500 kW plant. Furthermore, payments depend on the composition of the agricultural biomass used. Non-agricultural sources, which play a minor role overall, are not considered. For the RES 2009, it is assumed that 35% of the heat is utilized and all inputs are biomass based. Thus, the payments include a base rate, the Combined-Heat-Power-bonus (CHP-bonus), the NawaRo-bonus[4] and additionally the manure bonus if the manure input restriction described in the technological part is met. The RES 2012 payment structure includes the base rate and additional bonus payments based on the input specific electricity outputs. The payment structure of the FITs is shown in Equation (9) and shows exemplary the payment structure of the RES 2012 with differentiated input classes.

$$\begin{aligned} R_{fit} = & \sum_b \sum_e \sum_{ic} Y_{ic,b} * \rho_{b,e} \\ & + \sum_b \sum_{ic} (Y_{ic_1,b} * \sigma_{ic_1,b} + Y_{ic_2,b} * \sigma_{ic_2,b}) \end{aligned} \tag{9}$$

where R_{fit} is the revenue of FIT payment system, $Y_{ic,b}$ is the electricity output, $\rho_{b,e}$ are the FITs for electricity, $\sigma_{ic,b}$ is the bonus payments for both input classes.

The direct marketing payment structure is shown in (10). The revenue from direct marketing is based on the assumption that the electricity is sold during two differing price level periods each day. The high price levels are the monthly arithmetic average prices of the

[3] The model assumes that the density of manure and all silage inputs is equal to 1 t/m³ in the fermenter. (KTBL, 2013: 252).

[4] The NawaRo-Bonus is added to the payment if all input are derived from renewable resources or manure (BGBl, 2008: §27(4) – Anlage 2).

12 hours with the highest prices and the low price levels are the monthly arithmetic average prices of the 12 hours with the lowest price levels based on the year 2012 at the EPEX Sport market (EPEX SPOT, 2015). The share determining the amount of sold electricity during high or low price levels is contingent on the degree of flexibilization and thus on the input reduction level. The market premium for flexibly produced electricity is calculated based on the applicable FIT for the biogas plant and depends on plant size, input mix and the initial RES as well as the market value, which is the monthly average electricity spot price of hourly contracts. Consequently, the revenue of direct marketing is determined by the amount of electricity sold during high price levels or low price with the respective spot price and the market premium as a subsidy. Further, the necessary FIT increase to achieve a certain given input reduction level is included in the payment structure.

$$R_{dm} = \sum_b \sum_e \left[(\sum_{ic} Y_{ic,b} * \delta) * (\upsilon_{b,e} + \theta_h + \chi_e) \right] + \sum_b \sum_e \left[(\sum_{ic} Y_{ic,b} * (1-\delta)) * (\upsilon_{b,e} + \theta_l + \chi_e) \right] \quad (10)$$

where R_{dm} is the revenue of the direct marketing system, $Y_{ic,b}$ is the electricity output, δ is the share sold during high price levels at the electricity spot market, $\upsilon_{b,e}$ are the market premium levels based on the applied FIT, θ_h and θ_l are the average high h and low l EPEX Spot price levels, χ_e are compensatory FIT increases to achieve the desired input reduction.

The biogas module distinguishes between variable costs depending on production level and biogas plant size. The electricity production level determines the electricity consumption of the biogas plant itself, which is assumed to be externally purchased. Further, costs for purchasing substrate from external sources are accounted for. Variable costs for on farm produced inputs are determined by the cropping module and the economic section of FarmDyn and thus comprise opportunity costs of land, labor and the machinery park. Last, variable costs also include yearly costs for maintenance and repairs, insurance and laboratory tests, depending on biogas plant size.

$$C_b = Y_b * \iota * \tau + \sum_i (X_i * p_i) + m_b \quad (11)$$

where C_b are yearly variable costs for the biogas plant, Y_b is the electricity output, ι is the price for electricity, τ is the consumed electricity as share of produced electricity, X_i is the biomass input, p_i is the price for each biomass input, m_b are the costs for maintenance and repairs, insurance and laboratory analysis.

2.2 Model Application and Scenario Design

We quantify the necessary increase in FITs for two German regions with high livestock and high biogas plant densities and related negative externalities. Each region is represented by a dairy farm operating a biogas plant as a farm branch (cf. Table 1) (THÜNEN-ATLAS, 2014; FACHAGENTUR FÜR NACHWACHSENDE ROHSTOFFE E.V., 2009). Farm I with a 500 kW biogas plant represents a typical dairy farm producing biogas in North-West Germany. It has 80 hectares arable and 60 hectares permanent grass land, respectively, and maintains a 105 cow herd. Farm II, situated in Lower Franconia, is a smaller dairy farm with 60 cows and a biogas plant with a nominal power of 250 kW. It has 20 hectares arable and 60 hectares permanent grass land available.

The nominal power of the biogas plants is chosen to come close to regional averages (SCHEFTELOWITZ et al., 2014a). Both farms use 35% of engine heat, corresponding to the required minimal heat utilization of the RES 2012 amendment.

Table 1. Case study farms

	Unit	Farm I		Farm II	
Initial amendment		**RES 2009**	**RES 2012**	**RES 2009**	**RES 2012**
Construction year	*[year]*	2009	2012	2009	2012
Application Year	*[year]*	2015		2015	
Nominal power	*[kW]*	500		250	
Arable land	*[ha]*	80		20	
Grass land	*[ha]*	60		60	
Cows	*[count]*	105		60	
Average working unit	*[count]*	4.5		3.5	

Source: farms constructed based on data from THÜNEN-ATLAS (2014), FACHAGENTUR FÜR NACHWACHSENDE ROHSTOFFE E.V. (2009)

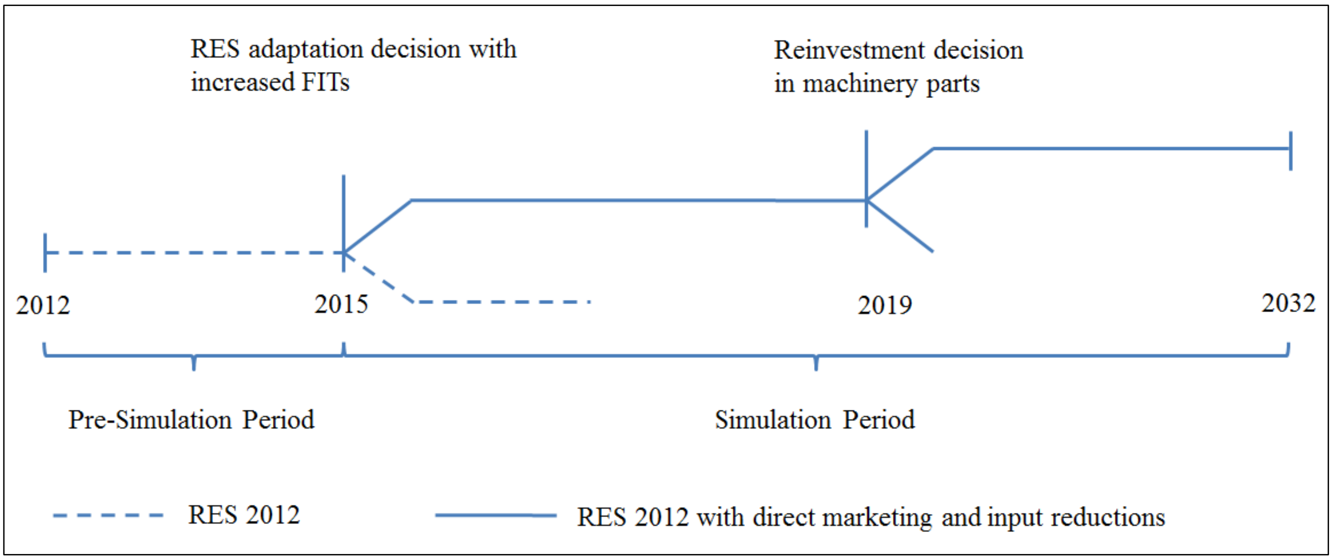
As the model does not yet entail the possibility to hire additional workers, farm family work units are set to a realistic but non-binding level. We assumed that unused labor can work off farm on an hourly basis for a wage of six Euros per hour. This assumption is based on a sensitivity analysis in which we found that already slight increases in hourly wages to eight Euros per hour and the assumed milk price of 32 cents per kg, the dairy branch of the farm was discontinued. KTBL (2014: 587f.) calculates for example farms with 64 and 120 dairy cows at a milk price of 36 cents per kg considerable losses when full costs are considered and labor is remunerated at 17.50 €/hour. Calculating the remuneration residually assuming full cost coverage yields implicit returns of around 3.60 €/hour (60 cows) and 9.75 €/hour (120 cows). Considering that our assumed milk price is with 32 cents per kg is somewhat lower while full investment costs are not considered over the two decades, the price of 6 €/hour found in the sensitivity analysis seem to fit to the KTBL data set, which is the main data source of the FarmDyn model.

The farmers' investment in biogas plants is made prior to the simulation as shown exemplary for the RES 2012 in Figure 1. At the start of the simulation the farm has the option to either remain in the initial RES, contingent on the construction year, or to switch to a new RES with direct marketing and reduced input. We determine the required FIT for a certain input reduction level by increasing the subsidy at the beginning of the simulation in 2015 until the farmer opts for the path with the new RES. After opting for the new RES, the farmer will continue to produce electricity until the end of the guaranteed subsidies in 2032, unless he decides not to reinvest in machinery parts with a lifespan smaller than 20 years.

We consider two alternative construction time points for the biogas plants of each farm which determines the applied initial RES: the RES 2009 for the construction year 2009 and the RES 2012 for the construction year 2012. The two different payment schemes and their compositions are shown as examples for the RES 2009 amendment for Farm I in Figure 2.

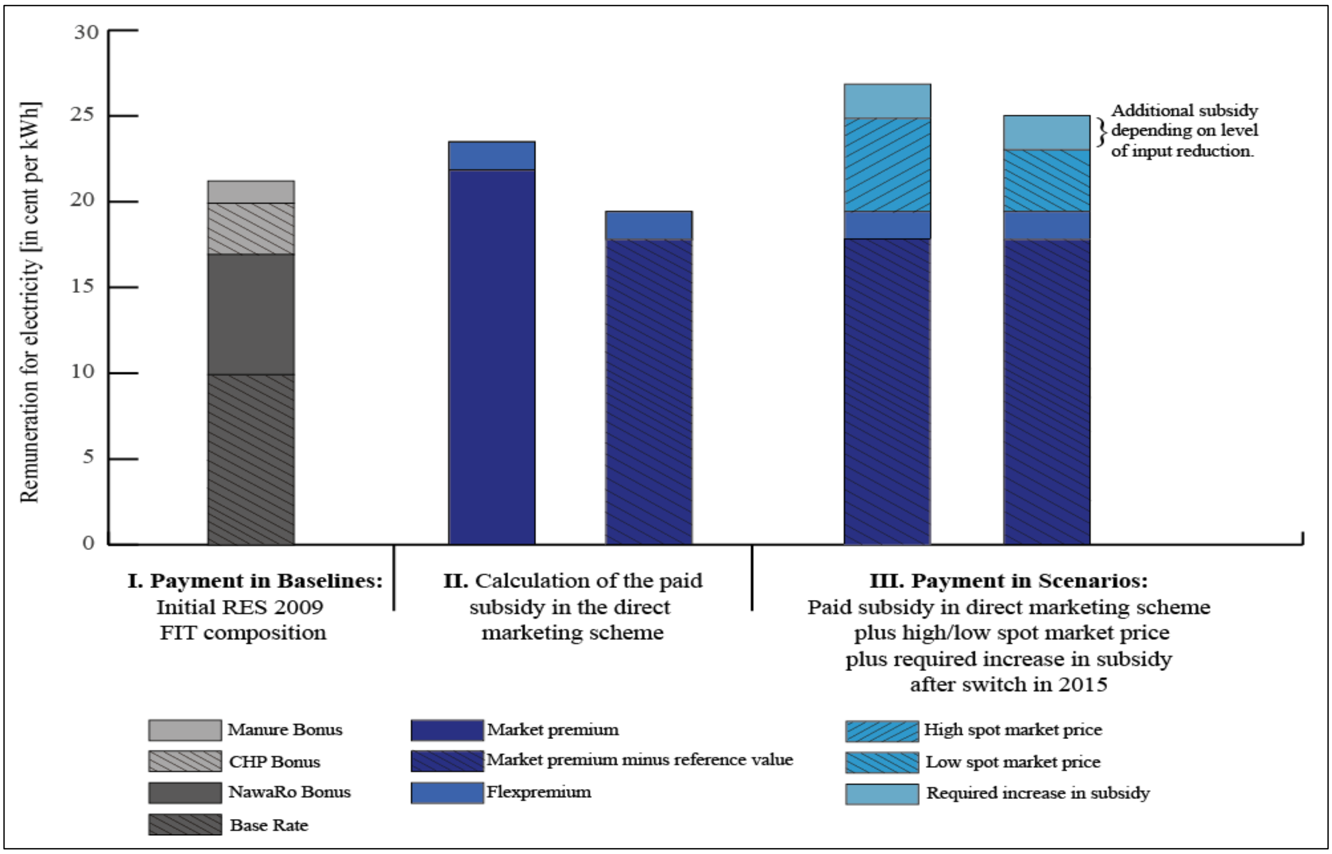
The payment in the baseline (I) shows the composition of the initial FIT in the RES 2009. The initial FIT determines the level of the market premium and serves as the basis for the calculation of the subsidy (II). The market premium minus the reference value, which is given by the monthly average spot market price, and the flexibility premium sum up the subsidy received by the biogas operator in the direct marketing scheme. The payment in the scenarios (III) are thus the initial subsidy plus the received spot market price plus the required increase in subsidy for a given input reduction level. In the study at hand, we consider input reduction levels from 5% to 50% in steps of 5%. The payment schemes of the four scenarios and their baselines are shown in Figure 3. The subsidy increases reflect risk neutral behavior, i.e. sole changes in costs and revenues. Figure 3 below shows that under flexible energy production the vast share of the payments is still made of guaranteed subsidies. Thus, we conclude that a further increase in subsidies to cover a risk premium when considering risk adverse behavior is probably small.

Figure 1. Strategic decision implementation in FarmDyn



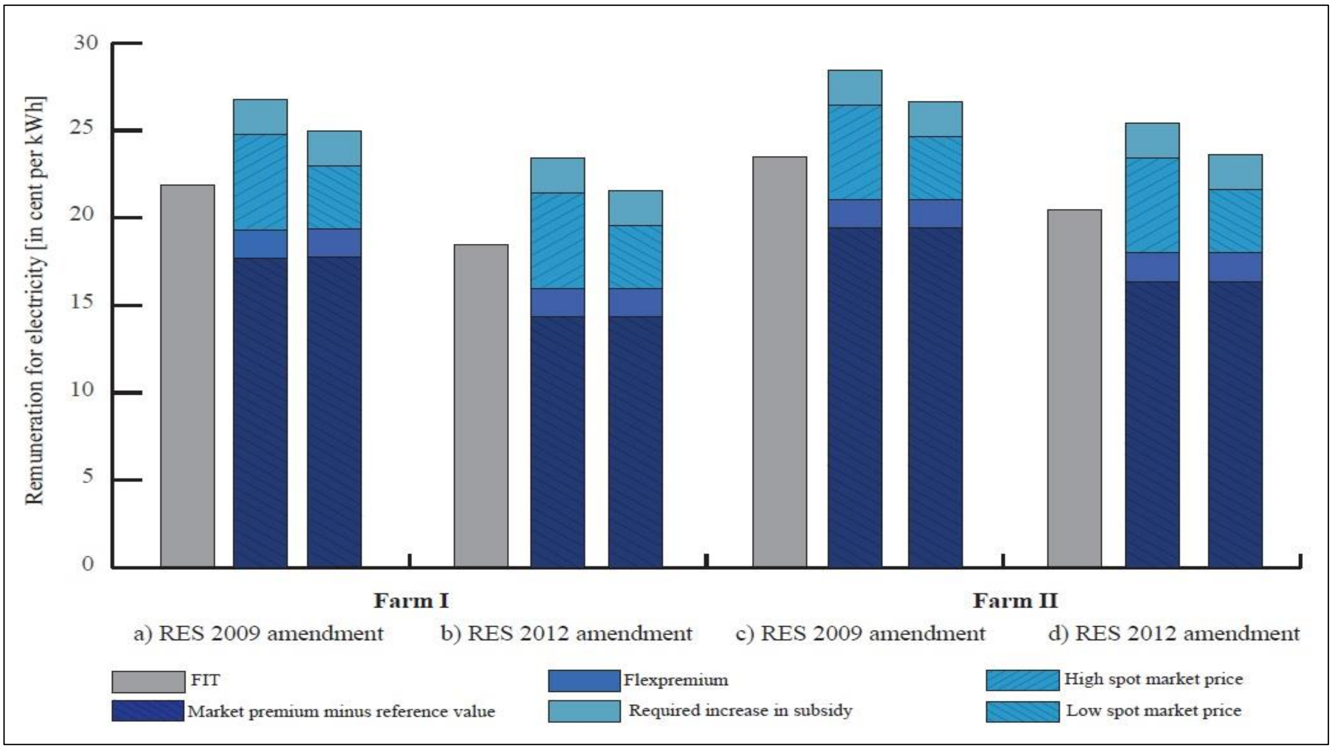
Source: own depiction

Figure 2. Composition of payment scheme in the baseline and the scenario – Farm I RES 2009 amendment



Source: own depiction using data from KTBL (2013)

Figure 3. Composition of payment scheme in baselines and scenarios for all four scenarios



Source: own depiction using data from KTBL (2013), EPEX SPOT (2015)

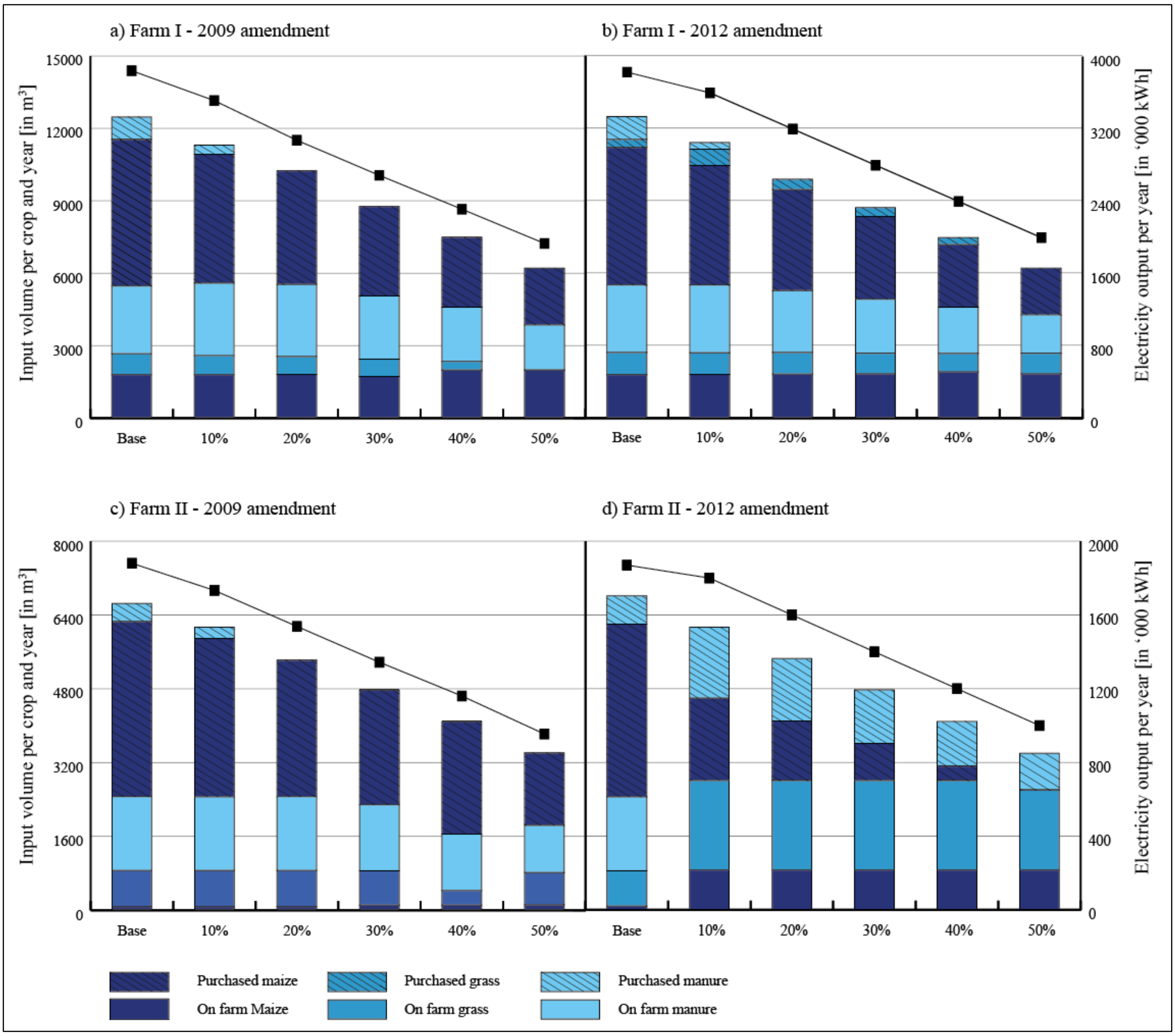
3 Results and Discussion

3.1 Farm Management: Environmental and Economic Implications

The simulations show that purchased maize is the primary biomass source reduced in all scenarios when average power output is decreased (cf. Figure 4). Legislation limits the flexibility of the farmer in the input mix considerably: in order to receive the sizable manure bonus in the RES 2009, 30% of input mass must consist of manure. Furthermore, the RES 2012 prescribes that silage maize cannot exceed 60% of input volume, such that farmers have to add other feedstocks; for the farms with grasslands considered in the paper, that is grass silage. That result reflects the fact that permanent grass land, in accordance with the German implementation of the Greening component of the CAP 2014 (EUROPEAN COMMISION, 2013; BGBL, 2014b), cannot be converted to arable land in the model without compensation areas, making grass silage profitable as a feedstock for the farms under investigation. Consequently, reducing the average power load of the engine translates into a reduction of the bought silage maize. Thus, the share of grass silage in the fermenter increases with the simulated reduction of the average fermenter load.

This tendency of reducing maize input and increasing the share of grass silage can alleviate negative environmental externalities related to biogas production such as potential nutrient leakage, soil run-off and pesticide input. Further, negative effects on biodiversity could be reduced especially in regions with high shares of maize (DESTATIS, 2015; SACHVERSTÄNDIGEN RAT FÜR UMWELTFRAGEN, 2007;

Figure 4. Input volume and composition for input reduction levels



Source: own calculation with FarmDyn

DEUKER et al., 2012; BUNZEL et al., 2014). However, we cannot exclude that maize bought into the farm does not find another demand, e.g. as feed in livestock production in other farms, such that the environmental benefit could be even zero.

Several authors recognized positive effects of biogas digestates with respect to emission reduction and ecological benefits for soils compared to untreated slurry (AMON et al., 2014; VANEECKHAUTE et al., 2013). However, the regions under investigation are characterized by both high biogas plant and animal densities and thus experience high nitrogen and phosphor loads (WÜSTHOLZ et al., 2014) with undesired environmental threats such as eutrophication and contaminated groundwater. That fact is partially due to the lack of accounting plant based digestate in the nitrogen application limit of the German Fertilizer Directive (BGBL, 2007) and the lack of enforcement of the allowed maximum nitrogen surplus on farm (OSTERBURG and TECHEN, 2012b).

For the larger Farm I, all simulated input reduction levels under both amendments do not entail any significant farm management changes with respect to cow herd size and cropping pattern as seen in Table 2. Only a relatively minor increase in off farm work can be observed, otherwise used in biogas production. The smaller Farm II, however, experiences a drastic change in its farm management under the RES 2012 amendment. With already a 10% input reduction, the farm almost completely withdraws from dairy production and only concentrates on biogas production on farm and distributes 90% of its labor force to off farm work. Using the manure from the herd and economies of scope and scale from producing feedstock, both for the cows and the biogas plant, render a smaller dairy herd attractive as long as the biogas plant is fully utilized. Once feedstock and labor demand from the biogas plant drop, especially indivisibilities in labor use render it attractive to work mostly off farm. The withdrawal of the dairy branch can also be seen in the input mix of the fermenter in which primarily on farm produced grass silage is used. Even if farms, which give up on dairy farming, could alleviate some negative environmental effects, a widespread withdrawal from dairy farming might trigger far-reaching negative economic consequences at regional level, e.g. on employment and in up- and downstream industries such as dairies (EMMANN et al., 2014).

3.2 Additional Required Subsidy for Decreased Biomass Demand

A more demand-driven electricity production could allow a biogas operator to reap benefits of increasingly volatile electricity prices on the EPEX SPOT market (PARASCHIV et al., 2014), while contributing to a more stable electricity grid in the energy transition. HOCHLOFF and BRAUN (2014) found that with optimal direct marketing of produced electricity the participa-

Table 2. Key farm characteristics in baseline and after a 50 percent input reduction for all scenarios

	Unit	Farm I			
		RES 2009		RES 2012	
		Base	50% Red.	Base	50% Red
On farm work	*[hours]*	9,678	8,323	9,658	7,902
Off farm work	*[hours]*	71	1,117	91	1,597
Cows	*[count]*	105	105	105	105
Grassland used for dairy	*[ha]*	33.6	60	34.1	34.2
Grassland used for biogas	*[ha]*	26.4	0	27.9	26
Arable land used for dairy	*[ha]*	39.2	34.3	39.6	38.8
Arable land used for biogas	*[ha]*	40.8	45.7	40.4	41.2
		Farm II			
		RES 2009		**RES 2012**	
		Base	**50% Red.**	**Base**	**50% Red**
On farm work	*[hours]*	5,921	5,524	5,911	1,228.7
Off farm work	*[hours]*	2,578	2,975	2,588	7,271
Cows	*[count]*	60	60	60	0
Grassland used for dairy	*[ha]*	34.2	36.8	46.13	0
Grassland used for biogas	*[ha]*	23.9	21.4	10.14	53
Arable used for dairy	*[ha]*	18.0	17.1	17.84	0
Arable used for biogas	*[ha]*	1.7	2.5	1.86	19.7

Source: own calculations with FarmDyn

tion on the electricity spot market is profitable under the subsidy scheme of the RES 2012. BARCHMANN and LAUER (2014) showed that an increase of 100% of the installed capacity of the power engine is the most beneficial option to switch from a FIT based payment scheme to direct marketing scheme. In contrast, with our proposed biogas plant setup in which the average fermenter load and electricity production is reduced, results show that sizeable increases in FITS are necessary to let farmers switch to flexible marketing. The additional subsides per unit of electricity needs to cover to a larger extent the reduced returns to farm own factors due to the output reduction. These results are consistent for both farms and RES amendments considered. Figure 5 show that the RES 2009 amendment requires the highest increase in FITs.

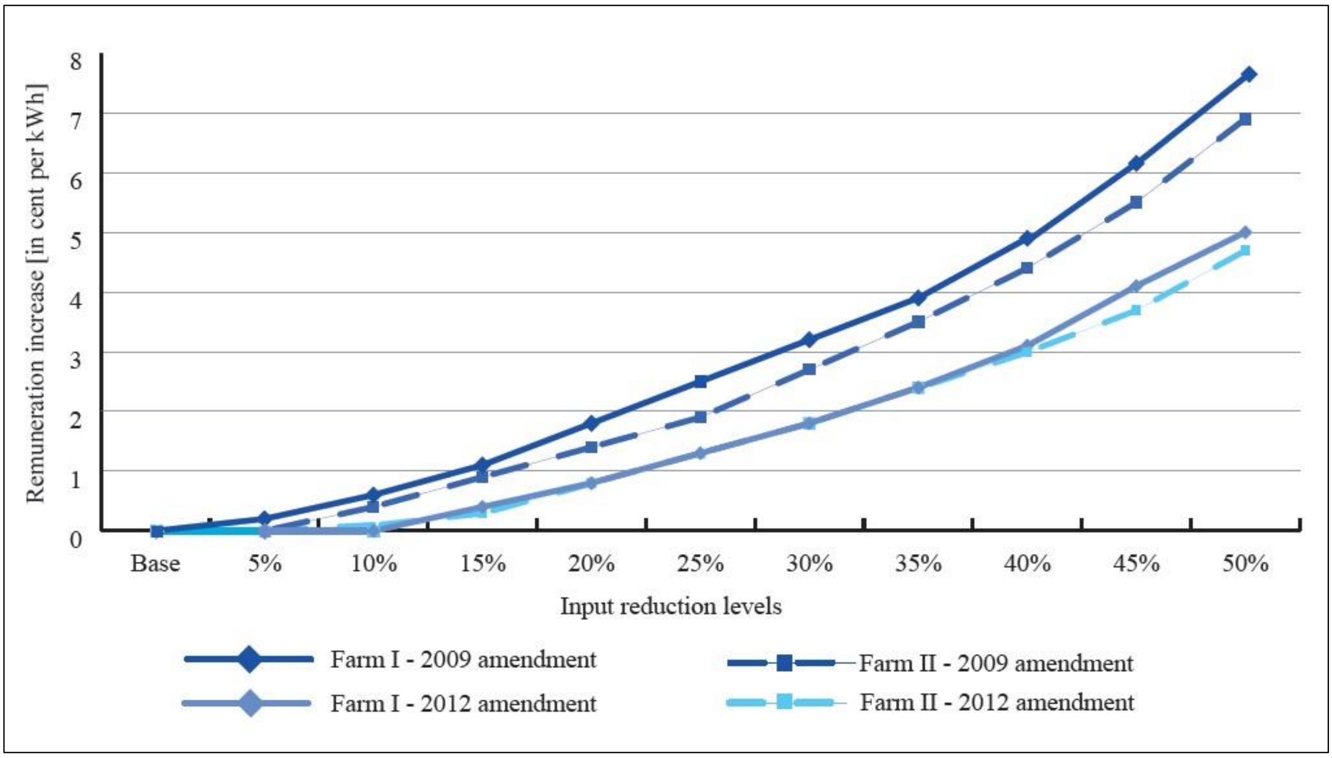
The additional payments for a 10% to 50% input reduction range from 0.6 up to 7.4 Euro cents per kWh, respectively. The lowest additional subsidy has to be paid in the RES 2012 amendment for Farm II. However, at an input reduction of 50% the required increase in FITs is still 4.7 Euro cents per kWh, i.e. 135% of the average market value of hourly contracts at the EPEX SPOT prices in 2012 (EPEX SPOT, 2015). As electricity produced by biogas plants already have the highest production costs among renewable energies (KOST et al., 2013) such an increase in subsidies would be politically hard to enact. In particular, additional subsidies paid to producers of renewable based electricity are directly driving up consumers' bills.

However, this study only investigates direct marketing based on participation on the EPEX Spot market. Other marketing options, such as secondary control reserves and minute reserves (THRÄN et al., 2015), might generate higher per unit revenues and thus require lower additional subsidies for the proposed biogas plant setup. In addition, shifting from the base load setup to a more flexible setup can lead to a reduction in GHG emissions as biogas is competing against flexible fossil fuels, such as coal-fired and gas-steam power stations, instead of the average energy mix (LAUER et al., 2016).

4 Summary and Conclusion

Various studies have shown that the expansion of biogas plants with the primary use of energy maize in Germany poses threats to the environment (EUROPEAN ENVIRONMENT AGENCY, 2007: 54; OSTERBURG and RÖDER, 2012) as well as for existing agricultural production and its value chains (RAUH, 2010; EMMANN et al., 2012; EMMANN et al., 2014). Simultaneously, the German government tries to foster flexible electricity production for biogas plants in order to

Figure 5. Necessary increase in FITs for different input reduction levels



Source: own calculations with FarmDyn

offset fluctuating electricity generation of wind and solar energy and thus stabilize the electricity grid (STRUNZ, 2014). While most recent studies on flexible electricity production had a focus on biogas setups with the highest economic viability (BARCHMANN and LAUER, 2014; HOCHLOFF and BRAUN, 2014; HAHN et al., 2014), we proposed to have an extended view and to integrate environmental and agricultural sector concerns into the biogas setup by reducing biomass demand.

In this investigation, the aim was to quantify the required additional subsidies for two typical farms operating biogas plants under the German Renewable Energy Sources Act (RES) to switch from continuous biogas production to flexible marketing. For this purpose we used the highly detailed single farm model FarmDyn in combination with a newly developed biogas module. The flexible electricity load is assumed to be available from using the existing fermenter as gas storage by reducing the average fermenter and engine load. Our results indicate that even for moderate levels of flexible load such as 30%, sizeable additional subsidies of 1.8-3.2 ct/kWh, i.e. around 52% to 91.9% of typical average spot prices, would be required to let farmers switch to flexible marketing.

The required changes in farm management are quite small, as the main impact are reduced purchasing of feedstock for the biogas plants. Such a reduction would be desirable as the main feedstock of biogas plants is energy maize whose cultivation is linked to negative environmental externalities such as increased soil erosion, loss of bio-diversity and increased nutrient loads. Equally, reducing feedstock demand would ease pressure on land markets and maintenance of permanent grass land.

We conclude that the consequences for Germany's farming sector and the environment of a flexibilization of existing biogas plants are probably positive and a realization based on using existing fermenters as additional gas storage relatively simple from a technical viewpoint. Enforcing this option is, however, unlikely as the legislation under which existing plants were erected guaranteed subsidies for twenty years. We, therefore, see a wide-spread application as rather unlikely due to relatively high additional subsidies required to let farmers opt for it and the already considerable share of costs for renewable energy in the electricity bill of German households.

However, being limited by the computational restrictions in the modelling framework of this study, the results have to be viewed with caution as aspects such as risk attitude or multiple objectives could not be implemented. Further, the study focuses on the participation on the electricity spot market, while providing positive or negative balancing energy might be another possible payment opportunity for biogas plant operators in future studies.

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Contact author:
DAVID SCHÄFER
Institute for Food and Resource Economics,
Chair of Production Economics
University of Bonn
Nußallee 19, 53115 Bonn, Germany
e-mail: david.schaefer@ilr.uni-bonn.de

Appendix

Appendix A. Investment costs by investment horizon and credit rates

	150 kW	250 kW	500 kW
Investment horizon - 20 years ['000 Euro]	554	721	1,246
Investment horizon - 10 years ['000 Euro]	173	252	359
Investment horizon - 7 years ['000 Euro]	214	290	372
Credit rate - 2 years [%]		3.5	
Credit rate - 5 years [%]		4	
Credit rate - 10 years [%]		4.5	
Credit rate - 20 years [%]		5	

Source: KTBL (2013, 2014); FNR (2013)

Appendix B.1. Production related biogas plant specific parameters

	250 kW	500 kW
Electric conversion efficiency [%]	37	40.1
Heat conversion efficiency [%]	44	43.2
Net-Volume fermenter [m^3]	1,800	3,400
Digestion load [$\frac{kg}{day*m^3}$]	2.5	2.5
Dwelling time [day]	97	97

Source: KTBL (2013); FNR (2013)

Appendix B.2. Substrate specific parameters

	Manure	Grass silage	Maize silage
Dry matter content [%]	10	35	33
Organic dry matter content [%]	80	90	95
Methane yield [$\frac{Nm^3}{t}$]	14	98	106

Source: KTBL (2013); FNR(2013)

Appendix B.3. Parameter for variable cost calculation

Required electricity [$\%$ *of el. production*]	7
Electricity purchasing price [$\frac{cent}{kWh}$]	19
Maize silage [$\frac{€}{ton}$]	36
Gras silage [$\frac{€}{ton}$]	33

Source: KTBL (2013); FNR (2013)