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# Biogas plants and surplus generation: Cost driver or reducer in the future German electricity system?

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ABSTRACT

The proportion of (intermittent) renewable energy in the German electricity system is set to continuously increase over the next decades. This brings along with it the challenge of balancing demand and supply. For this paper, we analyzed the cost efficiency of reducing surplus generation to reduce greenhouse gas emissions in the German electricity system for the period of 2016–2035 through (flexible) biogas plants, taking into consideration different biogas extension paths and modes of operation. We assessed flexible power generation in biogas plants using a quotient of remuneration and surplus generation called the average integration costs of surplus generation (AICSG). We defined the AICSG, which can be interpreted as a new approach to assess and to compare the cost efficiency of flexibility options. Increasing the capacities of flexible biogas plants decreases future surplus generation by up to 35% compared to if these installments were phased out. The best AICSG value was generated in a scenario that had a low rate of constructing new biogas plants. In conclusion, the system integration of intermittent renewable energies requires further technologies that result in additional costs. Therefore, biogas plants are one option for improving the system integration of intermittent renewable energies.

## 1. Introduction

The Paris Agreement, signed in December 2015, emphasizes the international need to reduce greenhouse gas (GHG) emissions and to halt the increase in average global temperatures (UN, 2015). In order to mitigate negative impacts on climate change, the German government's energy concept aims to reduce GHG emissions by at least 80% by 2050 (BMWi, 2012). As a consequence, and in accordance with the Renewable Energy Act (EEG) (i) the gross electricity consumption should be significantly reduced and (ii) the proportion of renewable energy in the electricity sector should make up 40–45% of gross electricity consumption by 2025 and 55–60% by 2035 (BMWi, 2014). In 2015, 31.6% of electricity was generated from renewable resources and the largest proportion of renewable electricity production came from onshore wind, biomass (especially biogas) and photovoltaics (PV) (BMWi, 2016a). According to (BMWi, 2014) and (NEP, 2016) the future development of renewable energy focuses on renewable power generation technologies with the lowest levelized cost of electricity (LCOE). These are currently onshore wind and PV. The LCOE is defined as the sum of fixed and variable costs [€] of a power generation technology over its full life cycle divided by the electricity that is generated [MWh] (Ueckerdt et al., 2013). This measure was developed after an intensive debate on household electricity prices in Germany (WSJ, 2014). In order to slow down the rise in electricity prices, EEG reforms limited the expansion of biomass plants, including all biomass techniques based on solid, liquid and gaseous biofuels (BMWi, 2014). Beyond 2020, the future role of biogas plants is being currently discussed in Germany, e.g. in (BMWi, 2016b). Without the consideration of the phase out of existing biogas plants, the 2017 EEG limited the expansion to a maximum of 150 MW per year for the period of 2017–2019 (BMWi, 2017); between 2004 and 2014 the average installation of biogas plants was about 350 MW per year (Scheftelowitz et al., 2015). This means that the maximum expansion of new biogas plants is in place and that existing plants do not have a clear perspective at the end of their remuneration period (from around 2025). As a consequence, the supply of new plants will not be sufficient, in other words, the installed capacity will go down. In 2014, over 7800 biogas plants with an installed capacity of 4500 MW generated around 27.6 TWh of electricity in Germany (Scheftelowitz et al., 2015). When it comes to a reduction in the electricity generated by biomass plants, this gap has to be filled by additional renewable energies to reach the targeted percentage of renewables. The draft of the 2017 EEG clearly shows that onshore wind, which has the lowest LCOE, is how the government plans to compensate for this

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gap (BMWi, 2016c). Electricity production from wind and PV is intermittent and depends on local weather conditions. This increased proportion of intermittent renewable energies brings with it the challenge of balancing demand and supply (IEA, 2011). This requires further technologies to ensure there is a sufficient power supply. These include flexible power plants, demand side management (DSM), storage technologies and grid extension (Alizadeh et al., 2016). The integration of intermittent renewable energies is also accompanied by additional costs (e.g. DeCarolis and Keith, 2005; Hirth et al., 2015). Flexible power generation from biogas offers the possibility of flexible as well as controllable electricity generation (Szarka et al., 2013) and may therefore reduce electricity system transformation costs. One example is reducing surplus generation events when the supply of (intermittent) renewable energies exceeds current electricity demand.

Evaluating the cost of the transformation towards a renewable energy system is the topic of an increasing number of publications. (DeCarolis and Keith, 2005) show that the LCOE of wind power generation does not represent the effective cost of wind because, due to other grid operations, the cost of intermittency also has to be taken into account. (Ueckerdt et al., 2013) define a new concept to assess the total cost of integrating intermittent renewable energy into the energy system. This is called system LCOE. They argue that the LCOE overestimates the economic efficiency of energy systems with a high penetration of intermittent renewable energies. System LCOE also includes the costs of variability, thus the integration costs of wind can equal the generation costs of wind power (Ueckerdt et al., 2013). (Hirth et al., 2015) define the integration cost of wind as the reduction in market value caused by the variability of renewable energies and the interaction with the rest of the (inflexible) energy system. Whereas, due to external effects, (Zipp, 2016) argues that hourly whole sale prices do not express the real value of the system integration of intermittent renewable energies. As a consequence, integration costs are not negligible for policymaking and for calculating the future costs of system transformation.

(Brouwer et al., 2016) find that increasing the percentage of renewable energies in the western European power system (in 2050) will increase overall system costs. Four options can reduce the integration costs of renewable energies at a higher level: demand response, natural gas-fired plants with carbon capture and storage (CCS), grid extension, and curtailment. (Batalla-Bejerano and Trujillo-Baute, 2016) estimate the cost of balancing service as a consequence of intermittent renewable energies making up an increasing proportion of the Spanish energy system. Due to the geographic location of Spain and the low cross-border interconnection capacity associated with this, flexible power generation from combined cycle plants is the most competitive flexibility option compared to other conventional plants. (Becker et al., 2015) determine the optimal combination of PV and wind for the USA to minimize backup energy requirements. By reducing surplus generation through the optimal mix of wind and PV, they demonstrate that a mixed portfolio of renewables becomes economically feasible with regard to total costs instead of choosing one technology with the lowest generation costs. A similar case study was done for China by (Huber and Weissbart, 2015). To summarize, (Papaefthymiou and Dragoon, 2016) emphasize that diversifying renewable energies leads to a reduction in variability and a cost-optimal system integration.

However, the consideration of the optimal mix of renewable energies often neglects biomass and biogas plants as a way of reducing the total costs of integrating intermittent renewable energies into the system. (Schill, 2014) calculates residual load, surplus generation and storage demand for Germany in 2022, 2032 and 2050. Surplus generation appears in 5% of all hours of the year in 2032 when biomass generation is flexible and thermal must-run capacities are removed. However, inflexible biomass generation and a thermal must-run capacity of 20 GW increase this value to 40%. (Tafarte et al., 2015) model power generation from flexible biogas and solid biomass plants to minimize the residual load variance on a regional scale in Germany. Compared to inflexible systems, the daily variance in the residual load is reduced by at least 50% due to the flexibilization of biomass plants. (Holzhammer, 2015) compares the additional costs of flexibilizing biogas plants in Germany with the saved costs of conventional power plants for flexible power generation in 2030. Biogas plants can reduce total costs in the energy system by lowering the amount of fuel and the start-stop operation of conventional power plants.

The above-mentioned studies reflect the fact that the LCOE does not identify the total costs of integrating intermittent renewable energies. In order to assess total costs of renewable energy integration, several factors should be incorporated, such as the share of renewable energies, the combination of diverse technologies and the consideration of different options for balancing supply and demand. Additional costs arise from other flexibility requirements in the form of investments in higher interconnection capacities, (conventional) flexible power plants, DSM or storage technologies. With regard to the cost-efficient transformation of the energy system, the future role of (flexible) biogas plants has yet to be adequately assessed. The present analysis intends to fill this gap by using different extension paths that have a lower as well as a higher proportion of (flexible) electricity generated from biogas plants in their renewable generation portfolios.

In this paper, we assess the cost efficiency of surplus generation reduction by biogas plants depending on three extension paths varying the installed capacity, electricity amount and mode of operation of biogas plants in Germany for the period 2016–2035. Our approach can be used to assess and compare the cost-efficiency of flexibility options.

The objectives can be defined as follows:

i. To describe options for the installed capacity of biogas with different extension paths by estimating the ongoing transition of the German energy system towards renewables; considering the transition pathways formulated in the EEG;
ii. To calculate residual load and surplus generation in a context of decrease of gross electricity consumption for the period of 2016 – 2035 for the different biogas extension paths;
iii. To optimize flexible electricity generation from biogas plants to reduce surplus generation; through: three different modes of biogas operation and
   a. by considering existing flexible and non-flexible biogas plants;
iv. To consider total premiums[1] and to economically assess the scenarios by using the average integration costs of surplus generation.

## 2. Methodology

According to the set objectives, we defined three biogas extension paths and future capacities of other renewable energies (Section 2.1), calculated surplus generation and residual load for the period of 2016–2035 (Section 2.2), optimized flexible power generation from biogas plants (Section 2.3) and assessed the scenarios by considering total premiums and by using the average integration costs of surplus generation (Section 2.4). The methodology is also shown in Fig. 1.

### 2.1. Defining three biogas extension paths and the future capacities of other renewable energies

In order to reach the target values of the EEG, which are oriented towards a percentage of renewable energies in gross electricity consumption, the lower generation of electricity from biogas plants has to be compensated for by other renewable energies. Based on current debates in Germany, onshore wind is used as a “adjustment screw” to fulfil the goals

[1] Total premiums are part of the German remuneration system for renewable energies which is described in Section 2.4.