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Review

Improved power provision from biomass: A retrospective on the impacts of German energy policy

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ABSTRACT

Electricity generation from biomass in Germany is incentivised by the Renewable Energy Sources Act (German: EEG) since 2000. Since then, the EEG has been frequently altered. To assess the impacts of these amendments, we analyse power provision data from biomass sources between 2007 and 2015 with regard to the fuel type, the average remuneration paid, the electricity and heat production as well as the spatial distribution of power plants. The results show that the dynamics of power provision from biomass took effect all over Germany with two hotspot regions for biogas in the north-west and south of Germany. The development over time also indicates that the adjustments of the EEG premiums have been effective. Premiums for substrates such as for renewable sources and manure have been immediately accepted by the bioenergy sector. The premium for flexible electricity generation unfolds slowly but steadily its effect. In summary, it can be stated that financial incentives, as provided by the EEG, have the potential to lead the development of bioenergy power plants in the intended direction.

1. Introduction

The decarbonisation of the energy sector is one of the most important tasks of the global society in the 21st century [1]. As one option to face this challenge, the German government implemented the so-called “Energiewende” (energy transition) that aims at decarbonizing the Germany energy sector. The rapid development of renewable energy production in Germany was first initiated by the law for priority dispatch of renewable energies – Renewable Energy Sources Act (German: Erneuerbare-Energien-Gesetz or EEG) in the year 2000 [2]. Frequent amendments of the national energy legislation in the following years [3–5] aimed at further increasing the share of renewable energy sources in the electricity sector.

These substantial policies all support the use of renewable energy sources by guaranteed feed-in tariffs, summarized under the heading of the German Energiewende and have had already significant effects. The rapid introduction of new renewable energy technologies in Germany since the year 2000 resulted in a steep increase in installed capacities from renewable energy sources, especially from wind power, biogas and solid biomass as well as photovoltaic [3]. By the end of 2015, approximately 31.6% of the German gross electricity consumption was provided from renewable energies and 7% from biomass. The share of bioenergy was 1.8% for solid biofuels and 5.3% for biogas of the gross electricity consumption. Electricity from all renewable energy sources corresponded to an estimated emission reduction of 99 million tons of CO_2 equivalent in 2015 [6]. In Germany, power generation from biomass is usually carried out in cogeneration, so that useable heat is generated simultaneously.

When Germany decided to start integrating renewable energies into power markets, the related technologies were in different stages of development. Many technical and economic challenges needed to be solved for wind and photovoltaic but also for biomass. Consequently, at the beginning, the EEG focused on the support of dedicated technologies for an accelerated market introduction, especially on biogas and solid biomass conversion technologies. Initially, the provision of power from biomass was mainly based on residues and waste, such as waste wood and residues from food processing, but this resource base was limited. After this first phase of successful market introduction phase from 2000 to 2003, an extension of the resource base was intended. In these years, the agricultural sector was strongly under pressure due to overproduction and the regulation that envisaged taking arable land out of the food production [7–9].

From 2004 on, a dedicated support for the electricity provision form cultivated biomass (energy crops) was introduced [3]. During this time, the support of energy crops started not only for power generation from biomass but was also increased for biofuel generation by introducing

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Table 1
EEG and its amendments including most important changes regarding remuneration schemes for biomass.

EEG/year of amendment	
2000	• Priority feed-in of renewable energy power plants • Feed-in tariff guaranteed for 20 years
2004	• Substrate bonus system, i.e. for energy crops and manure • Technology bonus system for combined heat and power production (CHP)
2009	• Bonus waste and residues • Bonus biomethane upgrading • Manure bonus (30%) • Bonus for emission reduction
2012	• New simpler bonus system • New requirements on efficiency and ecology • Incentives for flexibilisation and direct marketing • New power category < 75 kW
2014	• Deletion of bonus, i.e. energy crops and manure • Deletion of bonus for biomethane upgrading
2017	• Tendering Model • Subsequent funding for existing plants possible (10 years)

biofuel quotas in the transportation sector [10].

In the two fields of application, electricity and transportation, technical and environmental requirements and incentives for a sustainable biomass provision and an efficient biomass use have been integrated into renewable energy support policies. Apart from technical requirements for emission reduction, measures to provide flexible power generation were introduced. The flexible generation of electricity is becoming increasingly necessary due to the increasing share of variable renewable energies, including electricity generation from wind and solar power. Concerning electricity generation, the decision was taken to (1) focus on biogas/biomethane and solid biofuels, (2) provide dedicated tariffs for biomass resources, whose energetic use does not compete with other forms of use (avoiding the food or feed question) and with higher provision or conversion costs and reducing emissions in agriculture (, i.e. manure, landscape management residues, straw etc.), (3) add requirements for heat recycling and (4) introduce additional incentives, if the plants can be operated in a flexible mode [5,11,12]. These amendments including most important changes regarding remuneration schemes for biomass in the EEG are summarized in Table 1.

This paper answers the key question how the quality and amount of power provision from biomass has been developed with regard to the intended targets of accelerated market introduction, improvements in energy efficiency, sustainability of the feedstock base and flexible power provision have been achieved under continuous adoption of remuneration systems.

The analysis carried out here is based on data provided by the German national regulatory authority, Bundesnetzagentur (BNetzA) [13–15]. The development of the different provision chains for power generation from biomass is our first indicator to describe the dynamics of the expansion. This data is enriched with additional information which enables to assess the environmental performance of biomass deployment over time. Thereby, we focus on (1) area specific power plant concentration, (2) share of residues and renewable resources for power provision, (3) the share of combined heat and power (CHP) generation, and (4) the share of flexible electricity generation. In addition, the average remuneration over time is evaluated as well to jointly assess economic and environmental impacts. With those six indicators we discuss the quality of the bioenergy provision incentivised by the EEG.

The remainder of this paper is organised as follows. Data that is used to perform this analysis is described in Section 2. Relevant indicators for measuring the success of biomass in the energy sector are presented in Section 3. Section 4 contains major results, which are further discussed in Section 5. Finally, conclusions for the further development of bioenergy policies in Germany are drawn in Section 6.

2. Data

Section 2.1 contains a description of the raw data that is the basis of this work. Section 2.2 describes the processing and completion of raw data.

2.1. Raw data

The German national regulatory authority (BNetzA) provides master and transaction data of bioenergy power plants. Originally, this data is collected by distribution and transmission system operators and further handed over to the BNetzA. The master data contains temporally unchangeable information about a power plant. This includes inter alia an identification key for each power plant, information about the location of bioenergy power plants (federal state, postal code, city, street), installed electrical power, responsible distribution and transmission system operator, voltage level of the grid connection and the date of commissioning. The transaction data comprises time-varying information with an annual resolution. This data set contains all remuneration categories for each bioenergy power plant including the amount of electricity produced in kWh, the amount of received remuneration and avoided network charges in the very year. It can be linked to the master data by joining identical identification keys.

Most power plants have at least two different remuneration keys, depending on the size and bonuses they receive. When bioenergy power plants use direct marketing of electricity, the remuneration keys change and provide no more information about the specific remuneration, e.g. bonus for manure, but only for the energy fed into the grid. Additional information about historical and current remuneration keys can be found in Ref. [13]. For the analysis of the land use of biogas and biomethane power plants in chapter 4.3 it is also necessary to include the biogas upgrading plants as well. As gas upgrading itself is not incentivised by the EEG, these facilities cannot be found in the master or transaction data of the BNetzA. Instead a list of all upgrading plants including gas upgrading capacities from the association of "Biogaspartner" was used [16].

2.2. Data processing and assignment of fuel types

The capability of differentiating between different biomass fuel types is pivotal for this study. However, fuel types are included neither in the master data nor in the transaction data. For a certain part of power plants, the fuel type can be identified by analysing the remuneration key. For all remuneration keys we have determined whether they allow conclusions on a specific biomass fuel type (see Table 5 in Annex A). For example, the bonus for the use of manure can be received from biogas plants but not from wood-fired biomass power plants. Thus, this bonus gives only an indication whether the manure is used exceeding at least 30% mass related, but not how much manure is used. There are no unique remuneration keys for liquid biomass and just a few unique keys for solid biomass, e.g. for the use of waste wood. By combining remuneration keys with the date of commissioning, additional fuel types can be assigned. Power plants found within localities and a commissioning year before 2012 were normally classified as liquid biomass. In some cases it is known that some of these CHP plants switched to biomethane [14]. With the amendment of the EEG in 2012, new power plants using liquid biomass were no longer eligible for receiving remuneration [5]. Hence, power plants found within localities and with a commissioning year starting from 2012 are assigned to biomethane. The only exceptions are power plants within the power class from 30 to 180 kW, which can be also wood gasifiers. Power plants with a commissioning year before 2012 and remuneration keys for