Biomass and Bioenergy 86 (2016) 105–119

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Economics of anaerobic digestion in organic agriculture: Between system constraints and policy regulations

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ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form
20 January 2016
Accepted 22 January 2016
Available online xxx

Keywords:
Anaerobic digestion
Organic agriculture
Economic assessment
Investment
Bioenergy

ABSTRACT

During its pioneer-stage in Germany, the generation of power and heat from anaerobic digestion (AD) was predominantly developed on organic farms. However, biogas production in organic agriculture (OR) never expanded to the same extent as in conventional farming (CV). Besides various other aspects, this appears to be mainly due to economic reasons related to system-specific production requirements. Therefore, this article analyses the framework conditions of organic biogas generation and assesses its monetary implications on production economics. The structural and economic comparison of organic and conventional generation of power from biogas displays systematic constraints for AD in OR and identifies advantages of conventional biogas plants, particularly concerning lower capital and biomass input costs. Moreover, frequently changing policy regulations, further aggravating the economic situation for biogas production in both farming systems, are reflected. Our study shows that the recent developments of political frameworks will inhibit biogas investments for nearly all types of biogas plants in Germany. Finally, an alternative evaluation approach for organic AD systems, considering monetary benefits from agronomic effects of an integrated biogas generation in organic agriculture is discussed.

1. Introduction

In Germany, the financial incentives under the German Renewable Energy Act [1] have led to a major increase in the deployment of renewable electricity technologies including the installation of agricultural biogas plants that primarily feed on energy crops as well as animal wastes [2,3]. Since the enactment of the renewable energy regulation in Germany in the year 2000, the total number of biogas plants has increased from 1050 (in 2000) to 7850 (in 2013) with increases in the installed electrical performance from approx. 100 MW to 3543, respectively [4]. On a much smaller scale, the proportion of biogas production associated with organic farms has undergone a similar development over the past years. Based on regular surveys amongst organic farms with biogas production since 2007 [5] as well as additional estimations [6], the total number of biogas plants on organic farms accounts for about 180–200 in Germany with an installed electrical production capacity of at least 30.8 MW. Even though the integration of anaerobic digestion (AD) into organic farming systems promises various agronomic benefits, the proportion of organic farms engaging in biogas production is distinctly lower (0.8%) than the proportion of conventional farms producing biogas (2.9%) [4,7–9]. Reasons for this relatively small share of AD in organic agriculture become evident in several differing structural conditions inherent to organic farming systems if compared to biogas production associated with conventional farms.

1.1. Research objectives

Against this background, the aim of this study was to outline the diverse conditions of production for biogas systems in OR compared to conventional biogas systems and to display the impact of these apparent differences (as described in chapter 1.2) on the economic performance of organic AD systems. As comparative reference scenarios, conventional AD systems were calculated. Hence, economic assessments for six organic and six conventional biogas systems were conducted. The study focused on German framework conditions concerning payments for electricity as well as production costs. The impact of policy changes on biogas plant economics was illustrated by integrating two amendments of the German Renewable Energy Sources Act (EEG) [1,10] into the calculations. Profitability calculations as well as the comparison of economic key figures and interactions of changing framework conditions on economics by

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http://dx.doi.org/10.1016/j.biombioe.2016.01.015
0961-9534/

sensitivity and break even analysis were carried out. Finally, alternative evaluation approaches for organic AD systems that integrate a holistic economic view on the associated organic farming and AD systems are discussed. The performed analyses aim at the provision of decision support both for practitioners' investment decisions as well as for political decision makers in the debate of future adjustments of bioenergy policies.

Even though the study considered German regulations (feed-in tariffs) and biogas production structures, the particularities of integrating biogas into organic farming systems are transferable to other regions with similar climatic and/or agricultural production conditions for OR.

1.2. Biogas in organic agriculture

The biogas systems referred to in this study are characterised by the combined generation of heat and power (CHP). In continuously stirred tanks biomass such as energy crops, animal wastes and other residue material is fermented. Through anaerobic digestion a methane-rich gaseous mixture is generated, which is then converted to power and heat by CHP combustion units. The fermented effluents can be used to fertilise agricultural lands.

The development of anaerobic digestion in Germany was driven especially by environmentally concerned farmers. With their opposition towards nuclear power [11] and their striving for energy self-sufficiency, organic farmers were pioneering the development of biogas production. As AD became more common in both organic and conventional agriculture, the discriminative structural conditions of OR and CV biogas production became obvious. These systematic differences as well as their implications are displayed and elaborated below. They illustrate the potential to crucially affecting AD plant economics:

1. Lower biomass yields in organic (OR) compared to conventional (CV) agricultural systems
2. Low availability of organically produced energy crops
3. Impact of organic biomass characteristics on biological performance potential
4. Implications of organic biogas production on investment and operating costs

1.2.1. Lower biomass yields in organic compared to conventional agricultural systems

Organic agricultural systems can be characterised as low-input systems, attempting to accomplish preferably closed farming cycles. This implies a sensible use of resources as well as an efficient nutrient management in order to maintain or increase soil fertility and biodiversity [12–14]. By keeping external resources as limited as possible, low-input agricultural systems are able to reduce negative external effects often associated with intensive systems, such as nutrient leaching or biodiversity losses. In addition, negative climate effects can be mitigated through increased carbon sequestration and reduced losses of soil organic matter [15,16]. Nitrogen (N) leaving the farm cycle with agricultural products is usually not replaced by purchased external nutrient sources but incorporated into the farming cycle through biological symbiotic N_2-fixation of leguminous cover crops. Incorporating leguminous leys and other organic fertilisation measures can lead to adequate amounts of N to meet cash crop demands. However, the availability of N is often limited due to the characteristics of organic fertilising measures, i.e. a difficult synchronisation of N-availability and crop N-demand or often low mineralisation rates [17]. Therefore, organic fertilisation regimes as well as non-chemical weed and pest management measures on average lead to lower crop yields in organic farming compared to intensive agricultural systems [18,19]. Even though it was recently shown that this yield gap has been overestimated [20], the cultivation of organic energy crops for the purpose of anaerobic digestion is still more costly than conventionally grown energy crops. Hence, the high biomass input costs of predominantly using organically produced energy crops in a biogas plant will inevitably lead to economic inefficiencies.

1.2.2. Low availability of organically produced energy crops

While organic cash crops usually generate a premium price on the organic markets, electricity produced with organically grown energy crops usually does not (with very few exceptions of ”green” power trading companies, selling organic biogas to consumers who are willing to pay a premium prize for sustainably produced energy). Therefore, for energy crop production high opportunity costs have to be considered. Eventually, besides the high production (and opportunity) costs of organic energy crops, the comparatively low earnings through AD compared to organic cash crop sales severely impede the use of organic energy crops in OR biogas production.

In addition, the mostly missing spatial proximity of organic farms further impairs the use of organic energy crops. Transportation costs are usually too high to transport energy crops from an organic farm to an organically fed biogas plant – let alone bulky biomasses such as animal manures or waste materials with low energy and high water contents [21]. Therefore, AD plants mainly based on feeding with certified organic materials are restricted in size, which means that *economies of scale* (specific investment costs, cost degression) only apply to a very limited extent.

Due to self-imposed restrictions concerning biomass and nutrient import as well as the use of conventionally produced energy crops, the small- and micro-scale pioneer plants in organic farming were mainly operated on the basis of animal manure and other waste materials. Yet, with increasing biogas plant capacity the use of herbal substrates such as clover-grass but also energy crops solely grown for the purpose of AD became ever more prominent [22]. Because on-farm production or import of organically produced energy crops is too costly, a number of organic AD enterprises “feed” a certain amount of less expensive co-materials produced with conventional farming practices to ensure AD plant profitability. This causes great disputes amongst organic farmers and consumers about the principles of organic agriculture. While this practice is still permitted, a number of organic farmers' associations in Germany will ban the use of conventional biomass input by the year 2020 [23,24].

1.2.3. Impact of input biomass characteristics on biological performance potential

Referring to fresh or dry matter (FM; DM) weight, many substrates used in organic biogas systems (cover crops, residual plant materials) have a lower methanogenetic potential than most energy crops particularly grown for AD [22]. In addition, since the mix of employed substrates can be quite versatile in organic AD [5,6,22], it is very challenging to achieve a stable fermentation process, since bacteria have to adjust more often to new substances than in more homogeneously fed AD reactors using only one or two energy substrates [25,26]. Both aspects can result in a lower degree of capacity utilisation and therefore lower power and heat yields in organic AD systems.

1.2.4. Implications of organic biogas production on investment and operating costs

Plant substrates used in organic biogas production such as grass, clover-grass or crop residues often have a higher fibre (or lignocellulose) content than energy crop silages. This can both influence the choice of technical equipment and machines used as well as its lifetime, and therefore has a distinct impact on investment and operating costs [27]. For instance, substrates with higher ligno-