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Farm biogas production in organic agriculture: System implications

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ABSTRACT

Current global energy needs and the effort to substitute fossil fuels have led to extensive production of biomass in agricultural systems for purposes of renewable and more sustainable energy. At the same time, large-scale industrialized energy crop production is criticized for various sustainability issues. Organic farming systems are said to alleviate the environmental burden of agricultural production by minimizing negative externalities and generating ecological benefits. However, organic agriculture is challenged for its lower productivity. Considering this food–energy–climate nexus, a large-scale conversion of agricultural land to organic management seems infeasible. Against this backdrop, this article presents the analysis of a combined system of organic farming and biomass energy production. With a systems approach, multiple agronomic effects caused by anaerobic digestion of residue and waste biomass in organic agriculture were reviewed and transferred into a conceptual diagrammatic model of a single farm. Dimensions reviewed include nitrogen dynamics, crop yield, product quality, crop rotations, weeds, plant health, and soil fertility. The systems analysis showed that farm biogas production bears potentials to enhance overall nitrogen supply and nitrogen use efficiency and to reduce labor and energy costs of the organic farm. System implications of these agronomical effects include changes in farm productivity, stability, and resilience. Through biogas integration organic farms may contribute to renewable energy supply without additional need for land, while simultaneously increasing food output and reducing greenhouse gas emissions from livestock manure. Therefore, this study indicates possibilities for the eco-functional intensification of organic farming systems that may contribute to solving the food–energy–climate nexus.

1. Introduction

Growing energy demand and the simultaneous need for a substitution of fossil fuels to curb global warming have led to rapid expansions of biomass utilization for energetic purposes. Driven by climate change mitigation policies, agricultural bioenergy systems in Germany have gained increasing importance since the early 2000s. Growing populations and increasing biomass demand on a global scale, however, have caused criticism and controversy concerning energy crop production.

The dedication of arable land to energy cropping is discussed ambivalently for ethical concerns such as food security. Furthermore, discussions are nourished by potential adverse effects, e.g. on biodiversity or soil fertility. In this regard, modern bioenergy systems have frequently been criticized for their intensive, high-input, and monoculture cropping practices (Altieri, 2009). Still, bioenergy will remain an important pillar in the renewable energy mix over the next 10 or 20 years in order to substitute fossil fuels and to mitigate greenhouse gas emissions (GHGE) (Cornelissen et al., 2012).

Organic farming systems (OFS) represent an alternative agricultural approach and provide certain environmental and social benefits. Organic practices are said to reduce negative external effects linked with conventional high-input systems (Maeder et al., 2002). However, OFS are associated with substantially lower yields per unit of land area (Ponisio et al., 2015). Since agricultural biomass utilization for energetic purposes will be imperative in the near future, organic agriculture may either have also to i) engage in bioenergy production or ii) become considerably more productive in order to maintain its legitimacy in a “world of hunger” and limited land-area.

In this article, we therefore analyze and discuss joint organic farming and bioenergy production. The present study through a systems approach conceptualizes possibilities of integrating anaerobic digestion (AD) into organic mixed farms under conditions in Germany. Thereby, implications of anaerobic digestion for organic agriculture are identified and analyzed at farm level.

1.1. Biogas systems

The focus of this study is on agricultural biogas technologies for combined generation of heat and power (CHP) which are prevalent in Germany. These bioenergy systems provide heat and power through internal combustion of gaseous bio-methane fuel which is produced through anaerobic fermentation of agricultural biomass. Although thermal and electrical energy are produced simultaneously, heat is still largely considered a by-product of the process and remains underutilized

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(Siegmeier et al., 2011). The primary product is the electricity which is fed into local power grids and subsidized via government payments. Thermal energy is marketed independently or used on the farm.

Biomass in this context can be defined as carbonaceous organic matter directly or indirectly derived from photosynthetical processes (Kaltschmitt et al., 2007). In continuously stirred tanks the biomass is decomposed through anaerobic bacterial activity. The result is a gaseous mixture with high contents of methane (CH_4; 50–75%) and carbon dioxide (CO_2; 25–45%) that may be used as fuel in gas turbines and combustion engines. After methanogenesis the fermented effluents from the biogas plant are particularly rich in mineral nutrients due to the degradation of organic compounds during the process. These digestates are applied to agricultural lands as fertilizer.

Suitable for farm biogas production are all primary and secondary agricultural biomasses containing degradable carbohydrates, e.g.:

- processed and unprocessed crops (fresh plants and plant parts, plant silages),
- their residues (e.g. straw),
- as well as all their derivatives resulting from technical processes (e.g. bio-waste, pomace/draff),
- other plant material (e.g. grass cuttings, landscape conservation biomass)
- animal feces (e.g. farmyard manure, slurry),
- other farm residues (e.g. fraction grain).

Materials with high contents of ligno-cellulosic compounds have a considerably lower methane potential and slow down the biochemical process (Thomsen et al., 2014). An overview on energy crops in conventional European agriculture and their characteristics for biogas production can be found in Amon et al. (2007). Detailed biological characteristics for the process of anaerobic digestion are given e.g. by Cirne et al. (2007).

In order to meet its climate protection goals and to give incentives for more sustainable, decentralized energy production from renewable resources, the German federal government issued the Renewable Energy Sources Act (EEG, 2012). The EEG regulates the structure and development of bioenergy production. Details on performance and basic structure of the German EEG are presented by Langniß et al. (2009) and Couture and Gagnon (2010).

Financial incentives provided by the EEG include high feed-in tariffs guaranteed for a 20 year period for electricity produced from renewable biofuels. As a result of the EEG, agricultural biogas technology in Germany has been rapidly expanding.[1] The number of farm biogas plants grew from approx. 1000 in the year 2000 to 7320 in 2011 and is estimated to have reached almost 8000 in 2014 (German Biogas Association, 2014). The total electrical capacity in CHP units fueled with farm biogas climbed from less than 100 $MW_{el.}$ in the year 2000 to nearly 3000 $MW_{el.}$ in 2011 and a forecasted 3750 $MW_{el.}$ by 2014 (German Biogas Association, 2014).

In general, anaerobic digestion of farm residues, especially farmyard manure (FYM) and slurry, is regarded to be an efficient and ecologically sustainable approach to renewable energy production (Holm-Nielsen et al., 2009; Shilton and Guieysse, 2010). In addition, there is evidence for positive effects of biogas technology on rural development (Plieninger et al., 2006). However, high-input energy crops instead of residues and wastes are increasingly used in German biogas production. Anaerobic co-digestion of silage maize in particular has become increasingly profitable due to its exceptionally high methane yields (Amon et al., 2007). Yet, conventional maize production is frequently associated with unsustainable farming practices and negative environmental impacts. Therefore, maize digestion bears the risk of jeopardizing benefits or outweighing positive effects of agricultural biogas systems (Herrmann, 2013).

Biogas production in general and intensive energy cropping in particular is challenged by increasing disapproval of stakeholders in society (e.g. neighbors, local administrations, environmental organizations, Small Farmer's associations). For this reason, increasing governance efforts are required from plant operators and project planners (Gold, 2010). Due to its relatively large land requirements and high CO_2 avoidance costs compared with other renewable energy options (Scholz et al., 2011), maize-based co-digestion will probably not play a major role in future energy scenarios. However, it does serve as a temporary bridging technology in the transition towards a resource-efficient renewable power system (Herrmann, 2013).

1.2. Organic farming systems

Organic agriculture is guided by the four constituent principles of i) health, ii) ecology, iii) fairness, and iv) care (Luttikholt, 2007). It has been legally defined in the European Union (EU) by Council Regulation (EC) No. 834/2007 (European Commission, 2007). Organic farming systems are low external input systems relying on natural internal sources of nutrients and utilizing ecological principles and processes for plant protection and pest management. Synthetic fertilizers and agrochemicals are banned. Weed management is limited to agronomical and mechanical measures. Leguminous crops through biological N_2-fixation (BNF) serve as main source of nitrogen. Livestock plays a fundamental role for nutrient cycling in OFS and husbandry systems strongly prioritize animal welfare.

OFS are striving for closed cycles with minimum use of external resources in order to reduce e.g. GHGE, eutrophication, and biodiversity loss often associated with conventional agricultural production (Matson et al., 1997). Although some benefits have been disputed (Leifeld and Fuhrer, 2010), organic agriculture has been widely acclaimed to reduce negative external effects of conventional high-input farming systems and to ease pressure on agro-ecosystems while generating positive external effects on soil fertility, biodiversity, landscape structure, and climate change (Maeder et al., 2002; Pacini et al., 2003; Norton et al., 2009; Scialabba and Müller-Lindenlauf, 2010). In addition, it has frequently been suggested that OFS contribute positively to rural development (Darnhofer, 2005) and the resilience of family farms (Darnhofer, 2010).

1.2.1. The situation in Germany

For its benefits – i.e. the reduction of negative externalities and the provision of ecosystem services – organic farming has been promoted and supported via agri-environmental policy schemes by the German government and co-financed through the EU. The political goal is to expand the area under organic cultivation in Germany to 20% of the total agricultural area “within the next years” (The Federal Government, 2012). Lower yields and increased costs are partly compensated for by higher prices for organic food products on the German market. Currently, about 23,500 organic farms in Germany manage over 1 million hectares. This accounts for 8.3% of all farms and 6.2% of the total agricultural area (BÖLW, 2014).

1.2.2. Performance of organic systems

Organic production systems have been claimed to be more energy efficient than comparable conventional systems (Lynch et al., 2011; Smith et al., 2014). However, regarding the energy needs modern OFS must not be underestimated. In most cases, especially in Europe where highly mechanized production and processing systems prevail, organic agriculture, too, is strongly dependent on fossil fuels (Dalgaard et al., 2001).

Although OFS are sometimes said to have the potential to be equally productive as conventional systems (Badgley et al., 2007) or even increase agricultural productivity in some regions (Pretty et al., 2005), the scientific basis shows a substantial crop yield gap between organic and conventional systems (de Ponti et al., 2012). Even though the differences in productivity are highly contextual (Seufert et al., 2012)

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[1] However, the government's latest amendment to the EEG in 2014 put an end to this expansion and biogas investments have almost been brought to a halt (Gawel and Lehmann, 2014).