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Cooperation in manure-based biogas production networks: An agent-based modeling approach

Devrim Murat Yazan*, Luca Fraccascia, Martijn Mes, Henk Zijm

Department of Industrial Engineering and Business Information Systems, Faculty of Behavioral, Management and Social Sciences, University of Twente, Enschede, The Netherlands

HIGHLIGHTS

- A distributed decision support for second-generation biomass markets is formulated.
- An Agent-Based Model is proposed defining various stakeholders as autonomous agents.
- Bioenergy production is investigated as a solution to manure disposal problem.
- The role of government is considered by investigating the role of external incentives.
- Findings provide a clear economic picture on conditions favoring profitable business.

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ABSTRACT

Biogas production from manure has been proposed as a partial solution to energy and environmental concerns. However, manure markets face distortions caused by considerable unbalance between supply and demand and environmental regulations imposed for soil and water protection. Such market distortions influence the cooperation between animal farmers, biogas producers and arable land owners causing fluctuations in manure prices paid (or incurred) by animal farmers. This paper adopts an agent-based modeling approach to investigate the interactions between manure suppliers, i.e., animal farmers, and biogas producers in an industrial symbiosis case example consisting of 19 municipalities in the Overijssel region (eastern Netherlands). To find the manure price for successful cooperation schemes, we measure the impact of manure discharge cost, dimension and dispersion of animal farms, incentives provided by the government for bioenergy production, and the investment costs of biogas plants for different scales on the economic returns for both actor types and favorable market conditions. Findings show that manure exchange prices may vary between −3.33 €/t manure (i.e., animal farmer pays to biogas producer) and 7.03 €/t manure (i.e., biogas producer pays to animal farmer) and thanks to cooperation, actors can create a total economic value added between 3.73 €/t manure and 39.37 €/t manure. Hence, there are cases in which animal farmers can profitably be paid, but the presence of a supply surplus not met by demand provides an advantage to arable land owners and biogas producers in the price contracting phase in the current situation in the Netherlands.

1. Introduction

The rapid growth of the human population (+20% since 2000) together with the growth in per capita energy use (+17% since 2000) has resulted in a sharply increasing demand for energy [1–3]. Currently, around 80% of energy is produced from fossil fuels [2]. However, fossil-fuel based energy production is one of the main causes of greenhouse gas (GHG) emissions [4]. With the growing concern about the impact of GHG emissions on climate change [5], the demand for renewable energy is increasing [6,7] and several technologies have been developed to produce energy from renewable resources. A well-known example is the production of energy from second-generation biomass (SGB) [8–10]. SGB refers to organic wastes and residues that are not used in food production, e.g., solid and liquid municipal waste, manure, lumber and pulp mill waste, and forest and agricultural residues, etc. [11–15]. In particular, the use of manure for energy production may offer significant opportunities at places where intensive livestock farming is practiced [16].

In the Netherlands, despite the fact that the amount of produced manure is substantial (about 68.6 M t/year), the potential of manure-

* Corresponding author.
E-mail addresses: d.m.yazan@utwente.nl (D.M. Yazan), l.fraccascia@utwente.nl (L. Fraccascia), m.r.k.mes@utwente.nl (M. Mes), w.h.m.zijm@utwente.nl (H. Zijm).

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Nomenclature

GHG	greenhouse gas
SGB	second-generation biomass
SC	supply chain
ABM	agent-based model
AD	anaerobic digestion
i	animal farmer
F	set of animal farmers
j	biogas producer
B	set of biogas producers
P_i	manure production capacity
P_j	biogas plant production capacity
PM	total amount of produced manure
RM	total amount of required manure
DC	manure discharge cost
Q	exchanged quantity of manure
CI	biogas plant investment costs
ROI	return on investment
CF	cash flow
R	actualization rate
RE	revenues from electricity sales
RH	revenues from heat sales
RI	revenues from incentives to energy production from manure
CT	manure transportation cost
CO	biogas plant operating cost
MEP	manure exchange price
MK	mark-up
EROI	energy return on investment

based energy production is currently not fully exploited because of obstacles in the cooperation between manure producers and waste-to-energy producers [17,18]. Producing energy from manure may offer significant opportunities for the country towards achieving the goal of European Energy Strategy, i.e., an 80–95% cut in GHG emissions up to 2050 when compared to the 1990 levels [19]. In fact, in Q4 of 2016, CO_2 emissions by the energy sector – about 30% of the total CO_2 emissions – increased by 5.5% over the previous year, due to the increase in electricity production at power stations [20]. Accordingly, coal consumption has increased in the last years, whilst all the European countries showed the opposite trend [21].

The lack of cooperation among actors in the manure-based energy supply chain (SC) forces animal farmers to discharge the manure as compost in arable lands in the Netherlands [18]. However, before being sent to arable lands, manure has to be collected from animal farmers and treated in manure treatment units. Manure collection costs are paid by animal farmers: the average price is 15 €/t – but the collection price raises 23 €/t in September-February during which manure-based fertilizer application to arable lands is forbidden – excluding transportation, which accounts for 4–6 €/t due to the high dispersion of arable lands and animal farms. Since the manure production highly exceeds the manure-based fertilizer demand, animal farmers have low contractual power and face difficulty to afford these prices [18].

Furthermore, since 2014, Dutch regulation reduced the amount of manure-based fertilizers that can be used in arable lands, hence obliging swine/cattle farmers to take a certain percentage of their manure out of the Dutch manure market. This regulation is enforced by limitations in the phosphate and nitrogen use (causing eutrophication). For swine farmers, at least 50% of the manure produced should be taken out the Dutch market by law [18]. However, with an average travel of 300 km to Germany or France, the average transportation cost of manure is almost 50 €/t, which is considerably high for animal farmers to sustain.

Having less contractual power caused by manure surplus and being constrained by the regulation, animal farmers have to cope with increased manure discharge cost. This leads to distortion in manure markets pushing animal farmers to accept the offered collection price by manure-treaters and arable land owners, i.e., animal farmers pay to discharge manure in arable lands. In turn, this causes an increase also in meat and dairy products' prices, thereby creating a drawback for the Dutch economy [18]. Such a drawback triggers stakeholders to look for alternative solutions for manure use, one of which is the production of biogas from manure to generate electric and heat energy.

However, implementing cooperation between animal farmers and potential biogas producers is not easy due to the above-mentioned market conditions. Also the spatial, operational, and technological variables might affect the potential cooperation benefits between animal farmers and biogas producers [22,23]. Few studies have investigated the cooperation dynamics among actors within the manure-based biogas SC and the need for further research on such a topic is recognized [24]. This paper aims at filling this gap by analyzing the impact of dynamic market conditions shaped by technological, operational, spatial, and regulatory variables on the cooperation schemes between animal farmers and biogas producers. We design an agent-based model (ABM) to simulate the dynamics of manure markets for biogas production aimed at producing electricity and heat. In particular, we aim at revealing the conditions which facilitate reciprocally sustainable cooperation between animal farmers and biogas producers. We particularly analyze the impact of five variables on the creation of cooperative relations between animal farmers and hypothetical biogas producers in a case example considering 19 municipalities in the province of Overijssel (eastern Netherlands). These variables are: (i) the total discharge cost of manure influenced by transportation distance from animal farm to arable land and seasonality in manure-based fertilizer application to arable lands; (ii) size, number, and geographical distribution of animal farms within the municipality; (iii) incentives for renewable energy; (iv) the threshold return on investment (ROI) for biogas production; and (v) the threshold cost reduction by farmers compared to the current situation. The impact of these variables is assessed on two performance measures: (i) manure exchange prices (MEPs) negotiated by the involved actors and (ii) the overall economic benefits created. Simulation results allow us to propose managerial and practical solutions to overcome market distortions.

Hence this paper is a seminal and novel study for analyzing the dynamics of manure markets for biogas production aimed at producing electricity and heat. All the policy variables are integrated to the proposed ABM as a game changer. Thus, the combination of operational and political conditions embedded in the ABM enables companies to foresee the costs and benefits of a potential cooperation and base their decisions upon these insights.

The remainder of this paper is structured as follows. Section 2 provides the theoretical background. Section 3 describes the generic ABM for the cooperation between animal farmers and biogas producers. Section 4 applies the ABM to the case example of Overijssel. Section 5 provides the results analysis, followed by the discussion in Section 6 and conclusions in Section 7.

2. Theoretical background

This section contains two sub-sections. The Section 2.1 provides a detailed and thorough review of the literature on bioenergy supply chains (SC), in particular on manure-based bioenergy production. The Section 2.2 focuses on Agent-based Modeling and its applications in the field of bioenergy production.