Applied Energy 212 (2018) 820–833

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

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.

ARTICLE INFO

Keywords:
Biogas production networks
Manure markets
Agent-based modeling
Sustainable supply chains
Industrial symbiosis

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).

https://doi.org/10.1016/j.apenergy.2017.12.074
Received 10 July 2017; Received in revised form 27 November 2017; Accepted 17 December 2017
0306-2619/ © 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/BY-NC-ND/4.0/).

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.

2.1. Manure-based bioenergy production and supply chains

The need to reduce fossil fuel consumption and greenhouse gas (GHG) emissions triggered the production of bioenergy from various types of feedstock of organic origin, such as food crops, agricultural residues, forestry residues or municipal solid waste [25]. However, the application of food crops for energy purposes, so-called first-generation bioresources, has been criticized, since it is recognized to be responsible for increases in prices of food and animal feeds. Such critics have turned the attention to alternative organic feedstocks, the so-called second-generation bioresources, which are not sourced from dedicated plantations directly competing for agricultural land. The production of second-generation biofuels has been largely investigated from a technical, environmental, and economic point of view [16,26–34]. Within the field of second-generation biomass (SGB) processing, the energy production from animal manure has been particularly explored. From a technical point of view, manure-based bioenergy can be produced in two different ways: (i) producing biogas by anaerobic digestion (AD) and (ii) producing biochar, bio-oil, and gases through pyrolysis [35–38]. AD seems to be the most used technology, since it ensures the highest performance from both environmental and economic perspectives [39].

From an operational perspective, the technical conditions of the AD plant (e.g., [40–42]) and the joint use of different types of feedstocks and manure (e.g., [43,44]) influence the stability and performance of biogas production. From an environmental point of view, Hamelin et al. [45] claim that producing biogas from manure causes lower CO_2 emissions than producing biogas from other types of feedstocks. Furthermore, several studies explore the economic and financial viability of biogas production from manure in different countries. Some examples are Sweden [46], Ireland [23], Spain [47], Portugal [48], Italy [16], Germany and France [49], China [50], the Netherlands [38], and Canada [51]. In particular, the economic impact of market conditions (e.g., amount of feedstock available, renewable electricity tariff) was investigated. Whilst in some cases market conditions can ensure high profitability for bioenergy production, in other cases they have a negative impact on the economic viability of bioenergy production.

Biogas produced through AD may be used for electricity, heat and steam generation or to produce biomethane, which in turn can be injected into the natural gas grid or be used as fuel for transportation [52,53]. In this regard, some studies claim that, in order to maximize GHG mitigation, production of electricity from biogas is the best option [54,55]. The environmental benefits of producing electricity from biogas instead of from fossil fuels are widely acknowledged [53,56,57].

Recently, instead of focusing on the production phase only, several studies started to address the bioenergy supply chain (SC) as a whole, i.e., all processes related to biomass production, collection, transport, conversion into energy, and final use of the produced energy. Designing bioenergy SCs includes technical (e.g., selection of feedstock, process technologies, bioenergy plant size, amount of feedstock used by the plant), operational (e.g., centralized vs. decentralized production, bioenergy plant location, biomass collection schedule and transportation), and economic (e.g., market competitiveness of bioenergy against fossil-based energy) variables, in order to minimize production costs or maximize profits for the entire SC. In this regard, Yazan et al. [58] investigated the sustainable design of a regional bioenergy SC processing lignocellulosic biomass in the province of Overijssel (Eastern Netherlands). In particular, they compared the economic performance of four scenarios shaped by spatial and technological variables: (i) a mobile pyrolysis plant processes the locally available biomass on-site into pyrolysis oil which is sent to a regional biofuel production unit for upgrading to marketable biofuel; (ii) local biomass is collected and transported to a regional pyrolysis-based biofuel production unit for upgrading to a marketable biofuel; (iii) a mobile pyrolysis plant performs the on-site conversion to pyrolysis oil which is transported to an oil refinery outside the region; and (iv) collected biomass is sent to the nearest electricity production unit to generate electricity. Their findings show that mobile biomass processing is economically feasible for the Overijssel region while for larger regions its economic convenience depends on how many times the mobile plant is set-up in different locations within the region. De Jong et al. [59] used a geography-explicit cost optimization model to analyze the impact of four cost reduction strategies for second-generation biofuel production: (i) economies of scale; (ii) intermodal transport; (iii) integration with existing industries; and (iv) distributed SC configurations (i.e. the adoption of intermediate pre-treatment steps to reduce biomass transport cost). Furthermore, several optimization models for bioenergy SC design have been proposed. Jonker et al. [60] designed a linear optimization model to determine the optimal location and scale of bioenergy plants given the projected spatial distribution of the expansion of biomass production between 2012 and 2030 in the state of Goiás (Brazil). D'Amore and Bezzo [61] used mixed integer linear programming model to simultaneously maximize economic and environmental benefits of a bioethanol SC in Northern Italy. The model allows to optimize the variables such as geographical location of biomass to be collected, biomass production rate and feedstock mix, technology selection, and facility location and scale. Babazadeh et al. [62] proposed an integrated hybrid approach based on data envelopment analysis and mathematical programming techniques for the strategic design of a biodiesel SC in Iran based on jatropha and waste cooking oil. The model optimizes the numbers, locations, and capacities of feedstock cultivation centers and waste cooking oil collection centers, as well as bio-refineries and distribution centers. Mayerle and Neiva de Figueiredo [63] developed a methodology to design a SC that maximizes the economic performance and minimizes the biomass transportation distances from numerous small-scale farms to the AD plant serving the region. The model allows to identify: (i) the optimal schedule for biomass collection from each farm; (ii) the optimal logistics and transportation system; and (iii) the optimal position of a digestion plant relative to the farm locations. Miret et al. [64] proposed a mixed integer linear programming model for determining the optimal SC design, facility location, process selection and inventory policy. Their model is able to account for biomass seasonality, geographical availability, biomass degradation, conversion technologies, and final product demand.

Most of the above-mentioned optimization models assume nominal parameter values, leading to solutions that perform well only in the most likely scenario or in a specific location, whilst in reality unexpected changes in the market conditions can occur over time. Since such changes can strongly affect the economic performance of SCs (e.g., [65–67]), recently some studies claim that the optimization of biomass SCs should take into account the uncertainty in market conditions. In this regard, Santibañez-Aguilar et al. [68] proposed a mathematical programming model for the optimal planning of a bioenergy SC that considers explicitly the uncertainty associated with the SC operations as well as the associated risk. Similarly, Hu et al. [69] developed a cyberGIS approach to optimize biomass SCs under uncertainty caused by a number of factors such as biomass yield, procurement prices, market demand, transportation costs, and processing technologies. In particular, 7000 scenarios are evaluated by Monte Carlo simulation to quantify the uncertainty and sensitivity impact of the above-mentioned factors on bioenergy production costs and optimal biomass SC configurations in Illinois (USA). However, these studies do not consider SCs composed of different business entities, i.e., SCs where biomass production and bioenergy production reside to different companies. In this regard, it is widely acknowledged that SCs composed of different business entities can be implemented only if all involved entities have shown willingness to cooperate [70–72]. Such a willingness highly depends on adequate economic gaining induced by economic agreements (e.g., the internal exchange price of intermediate products) favorable for all involved companies [73–76].

For bioenergy SCs, the feedstock supply price is recognized as the most important factor allowing the chain to be created, along with a number of political and spatial factors [77]. If a market for a particular type of biomass does not exist, the exchange price has to be negotiated between biomass producers and bioenergy producers. However, to the best of our knowledge, no studies have investigated the cooperation dynamics among actors within the manure-based biogas SC to compute the manure exchange price (MEP) under different operational scenarios. In particular, no studies have been carried out to understand how the supply-demand mismatch for manure influences potential business deals between manure suppliers and biogas producers. Therefore, this paper proposes an Agent-based Model (ABM) that considers the business strategy of each SC actor influenced by a combination of the above-mentioned variables and provides decision support to the practitioners to reveal the conditions for an economically sustainable business practice. The ABM proposed in this paper is a globally applicable model that takes into account multiple variables and yields different results for the combination of different geographical locations, discharge regulations, subsidies, adopted technologies, and market conditions.

2.2. The agent-based modeling approach

Agent-based modeling is a suitable approach to study complex systems consisting of autonomous decision-making entities, such as production networks and SCs. Accordingly, each entity is modeled as an independent agent, which is provided with: (i) a set of goals it has to accomplish through the interaction with other agents and the environment; and (ii) a set of rules of social engagement, driving such interactions [78,79]. The system behavior spontaneously emerges from the interactions between the agents, and between the agents and the environment, rather than to be defined by the modeler [80]. The interactions between agents are often complex and nonlinear; therefore, patterns, structures, behaviors, and phenomena that are not explicitly programmed in the model can emerge spontaneously [80]. Accordingly, through these models, researchers are able to consider aspects which cannot be investigated by analytical models [81]. In an ABM, decision rules must be as realistic and accurate as possible, otherwise simulations may lead to misconceived results [82].

Applications of ABM span a broad range of disciplines such as marketing [83], economic systems [84,85], finance [86,87], manufacturing [88,89], SCs [90–92], and energy production and management [93–95]. The dynamic nature of ABM makes it suitable for studying the outcomes of collaborative relationships among agents [96]. In this regard, relationships among firms involved in the same SC have been investigated, with the aim to design the contractual clauses that are able to optimize the SC performance [88] or to equally share benefits from cooperation between firms [76,97].

ABM is recognized as an appropriate methodology to investigate cooperation among actors in bioenergy SCs as it considers the heterogeneity of the actors (i.e., agents) and proposes a self-organizing system [80,98]. Several contributions can be found in the literature. Shastri et al. [99] analyzed the dynamics of the adaptation of *Miscanthus* as an agricultural crop and its impact on biorefinery capacity in Illinois. Alexander et al. [100] modeled the UK perennial energy crop market, including the contingent interaction of supply and demand, to understand the spatial and temporal dynamics of energy crop adoption. Sorda et al. [101] investigated how changes in the support scheme may affect electricity generation from agriculture-based combined heat and power biogas plants in Germany. Singh et al. [102] simulated the corn markets in Illinois, to investigate the dynamic corn prices arising from the interactions between producers and users. Mertens et al. [103] explored the effect of market context on the purchase of local biomass for anaerobic digestion (AD) in Belgium. Moncada et al. [92] investigated the effect of institutions on the emergence of biofuel SCs in Germany. However, up to the best knowledge of the authors, no studies exist adopting the ABM approach for manure-based bioenergy SCs. Our paper fills this gap in the literature from a methodological perspective and provides a decision support framework to the actors of manure-based biogas SCs.

3. The agent-based model for cooperation among animal farmers and biogas producers

Cooperation among animal farmers (manure producers) and biogas producers (manure users) aims at exploiting the manure for biogas production. Such a cooperation can generate economic benefits for both actors: the animal farmer benefits from reduction in manure disposal costs and the biogas producer benefits from electric energy and heat sales. However, the cooperation may arise only if characterized by a *win-win* condition, i.e., both parties should achieve an economic benefit that at least offsets the costs of cooperation. In particular, biogas producers have to sustain relevant investment costs [104] and the obtained economic benefits should counterbalance such costs. Moreover, monetary flows might exist between animal farmers and biogas producers, depending on the contractual clauses associated with the manure exchange. In particular, three different clauses can be adopted [76]: (i) biogas producer pays animal farmer to purchase the produced manure; (ii) animal farmer pays biogas producer to dispose of the manure; and (iii) the exchange is for free. In absence of a manure exchange market, the manure exchange price (MEP) has to be negotiated for each specific relationship. In this regard, cooperation between animal farmers and biogas producers arises only if the actors reach a mutually beneficial agreement.

The ABM presented in this section simulates the interaction between two kinds of agents, animal farmers $i \in F$ and biogas producers $j \in B$, with F and B representing the sets of farmers and biogas producers, respectively. Let us assume that $|F| = N$ farmers and $|B| = M$ biogas producers exists in a given area. Each farmer i is characterized by manure production capacity P_i, standing for the amount of manure generated per year. Each biogas producer j is characterized by the production capacity P_j, standing for the maximum amount of manure that it can yearly process to produce electric energy and heat via anaerobic digestion (AD). Accordingly, the total amount of produced manure by farmers (PM), as well as the total amount of required manure by biogas producers (RM), are computed by:

$$PM = \sum_{i=1}^{N} P_i \tag{1}$$

$$RM = \sum_{j=1}^{M} P_j \tag{2}$$

In the absence of cooperation (basic scenario), each farmer has to dispose of the produced manure. Hence, the generic farmer i pays manure discharge cost $DC(i) = d_c \cdot P_i$, where d_c is the unit discharge cost per ton of manure. Moreover, in the basic scenario, biogas producers do not obtain revenues from selling electric energy and heat. For this reason, the generic biogas producer j is interested in using the manure produced by farmers to generate energy: accordingly, its ultimate goal is to obtain economic benefits from the cooperation. To achieve this goal, j can cooperate with $n \le N$ farmers; in turn, each farmer can cooperate with $m \le M$ biogas producers.

When j tries to establish cooperation with i, the quantity of manure to be potentially exchanged is defined as the minimum between the current manure demand by j, i.e., R_j, and the current amount of manure that i is able to send to j, i.e., R_i.

$$Q(i \to j) = \min\{R_j; R_i\} \tag{3}$$

Obviously $R_j = P_j - \sum_{i=1;i \neq j}^{N} Q(i \to j)$. Accordingly, R_j is equal to P_j if j is currently not receiving manure from other farmers, whereas it is lower than P_j if j is currently cooperating with other farmers. Similarly, it results that $R_i = P_i - \sum_{j=1;j \neq i}^{N} Q(i \to j)$. Accordingly, R_i is equal to P_i if i is not sending manure to other biogas producers, whereas it is lower than P_i if i is currently cooperating with other biogas producers.

In order to cooperate with i, j has to sustain investment costs CI(j → i) [22,104], and its economic return on investment ROI(j → i), is computed as follows [105]:

$$ROI(j \rightarrow i) = \frac{1}{CI(j \rightarrow i)} \cdot \left[\sum_{t=1}^{15} \frac{CF(j \rightarrow i,t)}{(1+r)^t} - CI(j \rightarrow i) \right] \quad (4)$$

where 15 years of investment life time is assumed [104]. The parameter r stands for the actualization rate, while CF(j → i, t) is the cash flow at year t resulting from the cooperation with F(i). In particular, such a cash flow is computed by using the following equation [105]:

$$CF(j \rightarrow i,t) = [RE(j \rightarrow i,t) + RH(j \rightarrow i,t) + RI(j \rightarrow i,t)] \\ -[CT(j \rightarrow i,t) + CO(j \rightarrow i,t)] - MEP(j \rightarrow i,t) \cdot Q(j \rightarrow i) \quad (5)$$

All revenues and costs in Eq. (5) are defined in Table 1 [22].

We assume that all costs, except for the MEP, are sustained by j in case of cooperation. On the other hand, the MEP stems from contractual clauses related to the manure exchange and is representative for how the overall economic benefits from the transaction are shared between the agents. MEP(j → i, t) is higher than zero if j pays i to purchase the manure. On the contrary, MEP(j → i, t) is lower than zero if i pays j to dispose of its manure. Finally, MEP(j → i, t) is equal to zero if the manure exchange is for free. j is interested to cooperate with i only if it realizes a sufficient return on investment (ROI), i.e., if the ROI is higher than a threshold value. In the opposite case, such an investment is evaluated as not rewarding by j; accordingly, j is not interested to cooperate with i and it will try to cooperate with another farmer.

To reveal the role of five variables highlighted in the introduction, scenarios are constructed based on the combination of these variables. Hence, the Agent-Based Simulation is conducted to evaluate the conditions for forming the SGB market. When the simulation starts, j proposes to i to exchange $Q(i \rightarrow j)$ units of manure and a MEP that would make the relationship beneficial for itself, allowing to guarantee the threshold ROI by j. The MEP proposed by j affects the benefits for i stemming from cooperation with j. These benefits are computed by i in the form of a mark-up MK(i, t) on its costs associated to the case of no-cooperation (Eq. (6)). This is a comparative approach between cooperation and non-cooperation cases because if the farmers cannot achieve business with biogas producers, then the current market conditions apply for them, i.e., DC must be paid. The ABM considers the biogas producers as the first proposers because animal farmers are already facing the drawback of existing regulations on DC. Relative mark-up values are specifically considered in the ABM as each farmer has the autonomy of defining a threshold to be engaged in business with biogas producers.

$$MK(i,t) = \frac{DC(i,t) - \{d_c \cdot [R_i - Q(i \rightarrow j)] + MEP(j \rightarrow i,t) \cdot Q(i \rightarrow j)\}}{DC(i,t)} \quad (6)$$

DC(i, t) is the cost that i sustains in the absence of cooperation, while $\{d_c \cdot [R_i - Q(i \rightarrow j)] + MEP(j \rightarrow i,t) \cdot Q(i \rightarrow j)\}$ is the cost sustained by i when it is cooperating with j. This is the summation of the saved discharge costs and the MEP paid/requested by j. i is interested to cooperate with j only if it obtains a sufficient mark-up on its costs associated to the basic scenario, i.e., if MK(i, t) is higher than a threshold value. In the opposite case, i will prefer to not cooperate with j and it will wait for the offer of another biogas producer, hoping to obtain better conditions. In this case, j looks for another farmer and tries to establish a cooperation with it, whereas i becomes available to receive proposals from other biogas producers, hoping to obtain better conditions. The generic biogas producer j tries to establish cooperation with farmers until it reaches the production capacity P_j.

4. The Overijssel case example

This section is divided into two sub-sections, one providing the description of the case example and the latter explaining the scenario design.

Table 1
Revenues obtained and costs sustained by the biogas producer in case of cooperation in year *t*.

Revenue or cost	Description	Formula	Parameter description
RE (j → i, t)	Revenues in year t from electric energy sales produced from the manure obtained from *i* by biogas producer *j*	$RE(j \rightarrow i,t) = by \cdot Q(i \rightarrow j) \cdot cre \cdot ep$	by = biogas yield [m^3 biogas/t manure] cre = conversion rate electricity-biogas [kW h/m^3] ep = electricity price [€/kW h]
RH (j → i, t)	Revenues in year t from heat sales produced from the manure obtained from *i* by biogas producer *j*	$RH(j \rightarrow i,t) = by \cdot Q(i \rightarrow j) \cdot crh \cdot ep$	by = biogas yield [m^3 biogas/t manure] crh = conversion rate heat-biogas [kW h/m^3] hp = heat price [€/kW h]
RI (j → i, t)	Revenues in year t from incentives to energy production from the manure obtained from *i* by biogas producer *j*	$RI(j \rightarrow i,t) = by \cdot Q(i \rightarrow j) \cdot cre \cdot gi$	by = biogas yield [m^3 biogas/t manure] cre = conversion rate electricity-biogas [kW h/m^3] gi = government incentive for energy production [€/kW h]
CT (j → i, t)	Transportation costs in year t related to the manure exchanged between *j* and *i*	$CT(j \rightarrow i,t) = \frac{Q(i \rightarrow j) \cdot di(i \rightarrow j) \cdot ct}{tl \cdot av}$	d(i → j) = distance from farmer i to biogas producer j [km] av = average velocity [km/h] ct = transportation cost per hour [€/h] tl = truck load [t]
CO (j → i, t)	Operating costs of biogas plant *j* in year *t* due to electricity and heat production from the manure exchanged with *i*	$CO(j \rightarrow i,t) = by \cdot Q(i \rightarrow j) \cdot cre \cdot rc$	by = biogas yield [m^3 biogas/t manure] cre = conversion rate electricity-biogas [kW h/m^3] rc = running cost [€/kW h]
CI(j → i)	Investment in the biogas plant *j* to process the manure supplied by animal farmer *i*	$CI(j \rightarrow i,t) = Q(i \rightarrow j) \cdot by \cdot cre \cdot cc$	by = biogas yield [m^3 biogas/t manure] cre = conversion rate electricity-biogas [kW h/m^3] cc = capital cost of the biogas plant [€/kW h]
MEP (j → i, t)	Manure exchange price paid by *j* to *i* in year t	The value of MEP stems from negotiation between farmers and biogas producers	

4.1. Case description

Overijssel is located in the eastern Netherlands (Fig. 1) and is one of the regions where animal farming is highly intensive. In Overijssel, there are 19 municipalities with swine manure surplus (Table 2). The Bioenergy Atlas of the Overijssel Region provides the quantities of swine manure surplus at municipality level [106]. In this section, the potential use of the excess manure in biogas production is evaluated. It is assumed that each municipality employs the available surplus in one biogas plant within the municipality and the manure is dispersed among animal farms with different scales. The distance between a farm and biogas plant implemented within the same municipality is a random value between 0 and 15 km, in line with the region's territorial size. We aim to understand whether biogas production is economically feasible for different scales of hypothetical biogas plants receiving manure from dispersed farmers within the municipality with different distances.

To design the agent-based model (ABM), we consider a generic municipality where *N* farmers produce manure and one biogas producer is available to use it for electric energy and heat production. In line with the current situation in the Dutch manure market as explained in Section 1, we assume no manure transportation between municipalities as the manure processing capacity of one biogas plant is assumed to be equal to the manure surplus of the municipality where it is located. This means that in each municipality, one biogas plant absorbs the manure surplus and accordingly we can evaluate the impact of plant scale on the sustainability of the business. Such a model allows us also to understand the effect of manure regulations in case there is no manure supply-demand mismatch. Contrary to the generic ABM, the presence of only one biogas producer in one municipality does not allow the farmers to receive offers from biogas producers located in other municipalities. This is motivated by the fact that the capacity of a biogas plant is designed based upon the available surplus within the municipality. Accordingly, we can also understand how the economies of scale influence the one-to-one cooperation conditions.

4.2. Scenarios design

In this subsection, we present the spatial, economic, and regulatory factors that influence the cooperation among farmers and biogas producers. These factors affect the economic benefits for each agent in case of cooperation as well as their willingness to cooperate. We investigate the impact of five factors: (i) governmental incentives for energy production by manure; (ii) the threshold return on investment (ROI) by biogas producers; (iii) manure discharge cost; (iv) the threshold markup by farmers; and (v) the geographical distribution of farmers within the municipality.

For the biogas producers, revenues from electricity sales are affected by the subsidy provided by the government to renewable energy producers. Biogas production receives an incentive of 7–15 eurocents/kW h depending on the efficiency of technology used in the plant and it is an important economic parameter for the biogas plant to compete with fossil energy markets [18]. *Ceteris paribus*, the higher the obtained subsidy, the higher the revenues from selling electric energy will be. We investigate cooperation for three different levels of incentives: 0.07 €/kW h, 0.11 €/kW h, and 0.15 €/kW h. Moreover, the economic performance of biogas producers is also affected by the threshold ROI of energy production from manure. This parameter is representative for the minimum benefit that biogas producers want to obtain from the cooperation: the higher the threshold ROI, the higher the threshold economic return will be. We consider three levels of ROI: 10%, 20%, and 30%, in line with the fact that agents are autonomous in decision-

Table 2
Swine manure surplus in 19 municipalities of Overijssel [106].

Municipality	Manure surplus [tons/year]	Municipality	Manure surplus [tons/year]
Zwolle	11,959	Deventer	12,768
Dalfsen	60,411	Rijssen-Holten	28,441
Ommen	39,009	Hof van Twente	160,709
Olst-Wijhe	26,978	Borne	3231
Raalte	117,211	Denekamp	68,892
Hellendoorn	52,713	Losser	3171
Wierden	29,045	Oldenzaal	1739
Almelo	34,291	Haaksbergen	54,373
Vriezenveen	1583	Hengelo	2143
Tubbergen	84,990		

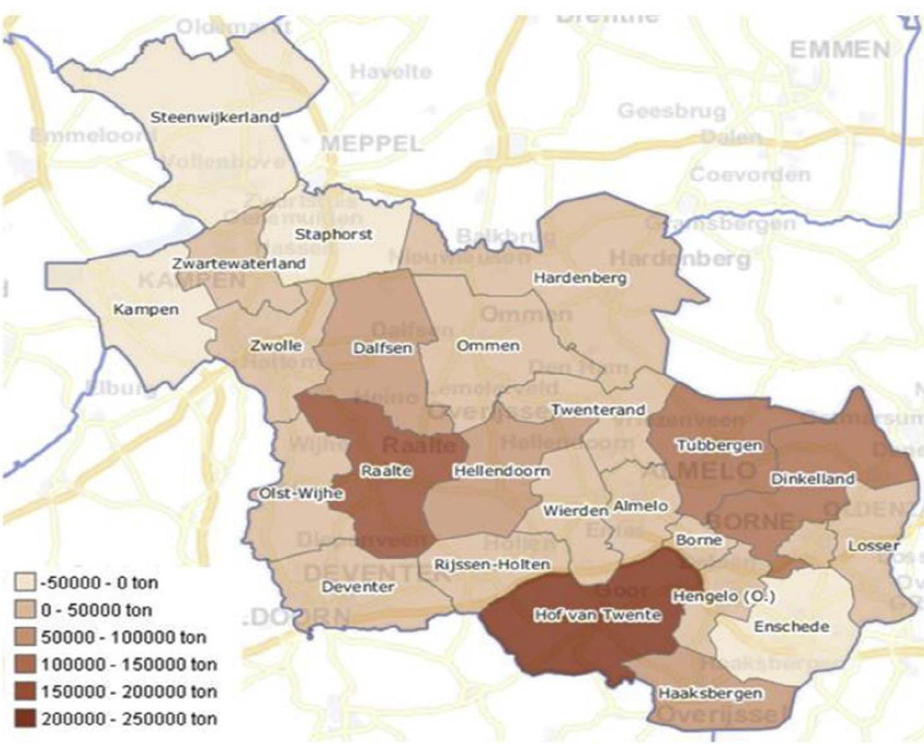

Fig. 1. Map of the Overijssel region and manure quantities per each municipality [106].

making and each of them might have different profit expectations.

For the farmers, the manure discharge cost affects their economic performance. Caused by environmental regulations for surplus manure discharge, manure discharge cost to arable lands might reach to 30 €/t, depending on the distance between farmers and arable lands where the manure is discharged, as well as on the seasonality in manure-based fertilizer application to arable lands. In fact, manure discharge cost usually increases during the period of 1 September till 30 January when the manure application to arable land is prohibited [107]. We consider three levels of manure discharge cost: 0 €/t, 15 €/t, and 30 €/t. Using a minimum discharge cost of 0 €/t helps us to understand the role of the manure discharge regulation in the market, while 30 €/t is the extreme case when the manure is transported over long distances during the period of 1 September till 30 January. In turn, the manure discharge cost is decisive for the threshold mark-up for farmers. Similar to the threshold ROI for biogas producers, this parameter is representative for the minimum economic benefit that farmers want to obtain from the cooperation: the higher the minimum mark-up desired by farmers, the higher the economic benefit will be if the cooperation is implemented. We investigate the cooperation conditions when the threshold mark-up is equal to 5%, 10%, and 15% of the discharge cost in arable lands incurred in the no-cooperation scenario. In addition, the number and spatial distribution of the farmers with different scales within a municipality are also critical factors influencing the cooperation decisions. Hence, we address the role of transportation for both non-cooperation and cooperation cases, combined with other factors. Numerical values of the investigated parameters are displayed in Table 3.

Referring to the spatial distribution of farmers, the manure can be produced by only one big farm (producing all the manure of the municipality) or conversely by many small farms (each of them producing a small percentage of the total produced manure) or by a combination of different scale farms within a given municipality. We consider nine farm sizes, each of which produces a different percentage of the total manure generated within the municipality (Table 4).

Thus, 2909 different combinations of farm dispersion are possible, ranging from one farmer producing 100% of the total manure to 40 small farmers each producing 2.5% of the total manure generated within a municipality. In particular, to simulate the spatial dispersion of these farms within the municipality, each farm has a random distance to the biogas plant ranging from 0 to 15 km.

By combining the above-mentioned parameters, 3 subsidy values for electricity production from renewable sources times 3 threshold ROI values by biogas producers times 3 manure discharge cost values times 3 threshold mark-up values by farmers times 2909 combinations of farm dispersion results in 235,629 different scenarios for each municipality. Within a scenario, the locations of the farms are generated randomly, i.e., the distance between each farm and the biogas producer is random. To provide accurate results, we perform 30 replications for each scenario, which is sufficient to reach a relative error of at most 0.1% with a confidence level of 99%. The simulation was coded in Matlab and simulations were performed using Matlab R2015a. Two outcomes are computed in each simulation: (i) the annual economic benefit (per ton manure exchanged) for animal farmer and biogas producer resulting from each cooperation between an animal farmer and a biogas producer; and (ii) the manure exchange price (MEP) for each relationship. The first outcome is representative for the overall benefits obtainable from cooperation. The overall economic benefits are computed as the sum of the benefits for the biogas producer (stemming from the gains on the investment) and the benefit for farmers (stemming from the savings on manure disposal costs and additional revenues, i.e., when the biogas producer pays farmers to receive the manure). The second outcome provides information about how these benefits are shared among the agents: the higher the MEP, the higher the economic benefit for farmers, *ceteris paribus*. In addition to the total economic benefits and MEP, also the Energy Return on Investment (EROI) is computed for a combination of transportation distances and processed manure quantities. Nine scenarios are evaluated and an EROI for each scenario is computed. Table 5 summarizes the operational parameters used for the computations. Results are presented in the next section.

5. Results

In this section, we provide the results under four sub-sections. In the Section 5.1, we summarize the conditions that enable market formation for manure destined to bioenergy production. Manure exchange price (MEP), total economic benefits created, and energy return on investment (EROI) are respectively provided in the Sections 5.2–5.4.

5.1. Conditions for the implementation of manure markets

For each municipality, the overall amount of economic benefits created by the cooperation mainly depends on the amount of manure surplus in that municipality, *ceteris paribus*: the higher the exchanged manure quantity, the higher the overall economic benefits created by cooperation. For this reason, we present the economic benefits stemming from cooperation per unit of exchanged manure.

The effect of different combinations of farm dispersion varies among municipalities, depending on their manure surplus quantities. In particular, we find different results for quantities lower than 10,000 t (i.e., small-scale plant), between 10,000 t and 20,000 t (i.e., medium-scale plant), or higher than 20,000 t (i.e., large-scale plant). This effect is due to the economies of scale in biogas plant investments.

All the investigated factors, except for the threshold mark-up for farmers, affect at least one outcome. This means that when the cooperation takes place, the mark-up on costs obtained by farmers always exceeds 15% (i.e., the cooperation is always convenient for farmers), whereas when the cooperation does not occur, the mark-up is always lower than 5% (i.e., the cooperation is never convenient for farmers).

Results (Tables 6 and 7) show that in some scenarios not even one relationship is created, meaning that the manure market cannot be established. In particular, the market is not created under the following conditions: (i) manure discharge cost is 0 €/t, incentives for energy production are 0.07 €/kW h, and the amount of available manure is lower than 10,000 t/y; (ii) manure discharge cost is 0 €/t, incentives for energy production are 0.07 €/kW h, the threshold ROI by biogas producers is 30%, and the amount of available manure is lower than 20,000 t/y: (iii) manure discharge cost is 0 €/t, incentives for energy production are 0.11 €/kW h, the threshold ROI by biogas producers is 30%, and the amount of available manure is lower than 10,000 t/y. In these scenarios, the market is not realized because the highest MEP the biogas producer is willing to offer is lower than the lowest MEP that farmers are willing to accept. Therefore, since agents do not agree on the MEP, no cooperation is created among them.

In all other scenarios, the manure market is created and the exchanged manure quantity is equal to the available quantity within the municipality.

Table 3
Factors whose impact on the cooperation between farmers and biogas producers is investigated.

Agent	Factor	Values
Biogas producers	Incentive for energy production by manure [€/kW h]	0.07; 0.11; 0.15
	Threshold ROI (fraction)	0.1; 0.2; 0.3
Animal farmers	Manure discharge cost [€/t]	0; 15; 30
	Threshold mark-up (fraction)	0.05; 0.1; 0.15
	Distribution within the municipality	Ranging from many small farmers to one large farmer

Table 4
Swine farm compositions according to their contribution to the total supply in a municipality.

Dimensional classification of farms	% of manure produced
Big farms	100
	50
	25
Medium farms	20
	15
	10
Small farms	7.5
	5
	2.5

Table 5
Operational parameters used for computations.

Biogas yield	by	36.9 [m^3/t]
Conversion rate electricity-biogas	cre	1.7 [kW h/m^3]
Electricity price	ep	0.056 [€/kW h]
Conversion rate heat-biogas	crh	2138 [kW h/m^3]
Heat price	hp	0.0033 [€/kW h]
Average velocity	av	60 [km/h]
Transportation cost per hour	ct	75 [€/h]
Truck load	tl	30 [t]
Running cost	rc	0.019 [€/kW h]
Capital cost of the biogas plant	cc	6510 [€/kW h] if Q(i) < 10,000 t 4976 [€/kW h] if 10.000 t ≤ Q(i) < 20,000 t 3441 [€/kW h] if Q(i) ≥ 20,000 t
Hours of activity per year	h	7200 [h]

5.2. Manure exchange price

Table 6 shows the MEP resulting from the negotiation between farmers and biogas producers and the variables affecting the price.

Depending on the specific environmental conditions, the MEP ranges from −3.33 €/t (farmers pay the biogas producer) to 7.03 €/t (biogas producer pays farmers). In particular, farmers pay the biogas producer under the following conditions: (i) manure discharge cost is not lower than 15 €/t, incentives for energy production are 0.07 €/kW h, the amount of exchanged manure is lower than 20,000 t/y, and the threshold ROI by the biogas producer is not lower than 20%; (ii) manure discharge cost is at least 15 €/t, incentives for energy production are 0.11 €/kW h, the threshold ROI by the biogas producer is not lower than 20%, and the amount of exchanged manure is lower than 10,000 t/y; (iii) manure discharge cost is at least 15 €/t, incentives for energy production are 0.07 €/kW h, the threshold ROI by the biogas producer is 10%, and the amount of exchanged manure is lower than 10,000 t/y. Under all the other conditions, the biogas producer pays the farmers. The MEP is mainly affected by the threshold ROI of the biogas producer, the incentive to the energy production from manure, and the manure exchanged quantity. In particular:

– The higher the threshold *ROI of the biogas producer*, the lower the MEP is, *ceteris paribus* (Fig. 2a). In fact, a higher ROI means that the biogas producer wants to obtain higher economic benefits from the cooperation; hence, it is able to pay a lower price to farmers (when MEP > 0), or in some cases it wants to be paid to receive the manure (when MEP < 0);
– The higher the *incentive to the energy production from manure*, the higher the MEP is, *ceteris paribus* (Fig. 2b). Since economic incentives increase the revenues for the biogas producer, *ceteris paribus*, it will be able to pay a higher price to farmers to receive their manure;

Table 6
Manure exchange price for different scenarios (Gray cells display scenarios where the market is not created; green cells display scenarios where biogas producer pays farmers; blue cells display scenarios where farmers pay biogas producer).

SCENARIOS			MANURE EXCHANGE PRICE [€]		
manure discharge cost [€/t]	threshold ROI for biogas producers	incentives for electricity production from manure [€/kWh]	Q<10,000	10,000≤Q<20,000	Q≥20,000
0	0.3	0.07			€ 1.22
		0.11		€ 1.44	€ 3.73
		0.15	€ 1.67	€ 3.95	€ 6.24
	0.2	0.07		€ 0.06	€ 1.61
		0.11	€ 0.26	€ 2.01	€ 4.12
		0.15	€ 2.41	€ 4.52	€ 6.63
	0.1	0.07		€ 0.35	€ 2.00
		0.11	€ 0.65	€ 2.58	€ 4.51
		0.15	€ 3.16	€ 5.09	€ 7.03
15	0.3	0.07	-€ 3.32	-€ 1.06	€ 1.21
		0.11	-€ 0.83	€ 1.43	€ 3.70
		0.15	€ 1.65	€ 3.92	€ 6.19
	0.2	0.07	-€ 2.58	-€ 0.49	€ 1.60
		0.11	-€ 0.09	€ 1.99	€ 4.09
		0.15	€ 2.40	€ 4.48	€ 6.58
	0.1	0.07	-€ 1.85	€ 0.07	€ 1.99
		0.11	€ 0.64	€ 2.56	€ 4.48
		0.15	€ 3.13	€ 5.05	€ 6.97
30	0.3	0.07	-€ 3.33	-€ 1.06	€ 1.21
		0.11	-€ 0.84	€ 1.43	€ 3.70
		0.15	€ 1.65	€ 3.92	€ 6.19
	0.2	0.07	-€ 2.58	-€ 0.50	€ 1.60
		0.11	-€ 0.09	€ 1.99	€ 4.09
		0.15	€ 2.39	€ 4.48	€ 6.58
	0.1	0.07	-€ 1.85	€ 0.07	€ 1.99
		0.11	€ 0.64	€ 2.56	€ 4.47
		0.15	€ 3.13	€ 5.05	€ 6.96

– The higher the *exchanged manure quantity*, the higher the MEP is, *ceteris paribus* (Fig. 2c). This is because the investment costs for the biogas producer are affected by economies of scale. Hence, when the amount of exchanged manure is high, the biogas producer is able to pay a higher price to farmers to receive the manure, *ceteris paribus*. In particular, when the manure quantity is higher than 20,000 t, the MEP is always positive, i.e., the biogas producer pays farmers to purchase their manure.

Furthermore, we find that the manure discharge cost only affects the decision of agents to start the cooperation but it does not affect the MEP. In fact, when the manure discharge cost is higher than zero (presence of manure discharge regulation), the cooperation starts only if the biogas producer is willing to pay farmers to receive the manure. In the opposite case, farmers will prefer to dispose of the manure. Moreover, no differences in the MEP are found between scenarios characterized by manure discharge cost equal to 15 €/t and 30 €/t, *ceteris paribus*.

5.3. Economic benefits of the cooperation

Table 7 shows the economic benefits stemming from the cooperation between farmers and biogas producers, as well as the variables affecting these benefits.

The economic benefits created by the cooperation mainly depend on the manure discharge cost, the exchanged manure quantity, and the incentives for energy production from manure. In particular:

Table 7
Yearly economic benefits created per ton of exchanged manure (the symbol "–" means that no cooperation arises in the correspondent scenario).

Scenarios			Economic benefit generated per unit of exchanged manure [€]		
Manure discharge cost [€/t]	Desired ROI for biogas producers	Incentives for electricity production from manure [€/kW h]	Q < 10,000	10,000 ≤ Q < 20,000	Q ≥ 20,000
0	0.3	0.07	–	–	€ 4.35
		0.11	–	€ 5.97	€ 6.86
		0.15	€ 7.59	€ 8.48	€ 9.37
	0.2	0.07	–	€ 4.02	€ 4.35
		0.11	€ 5.44	€ 5.97	€ 6.86
		0.15	€ 7.59	€ 8.48	€ 9.37
	0.1	0.07	–	€ 3.73	€ 4.35
		0.11	€ 5.07	€ 5.96	€ 6.86
		0.15	€ 7.58	€ 8.48	€ 9.37
15	0.3	0.07	€ 17.57	€ 18.46	€ 19.35
		0.11	€ 20.08	€ 20.97	€ 21.86
		0.15	€ 22.59	€ 23.48	€ 24.37
	0.2	0.07	€ 17.57	€ 18.46	€ 19.35
		0.11	€ 20.08	€ 20.97	€ 21.86
		0.15	€ 22.59	€ 23.48	€ 24.37
	0.1	0.07	€ 17.57	€ 18.46	€ 19.35
		0.11	€ 20.08	€ 20.97	€ 21.86
		0.15	€ 22.59	€ 23.48	€ 24.37
30	0.3	0.07	€ 32.57	€ 33.46	€ 34.35
		0.11	€ 35.08	€ 35.97	€ 36.86
		0.15	€ 37.58	€ 38.48	€ 39.37
	0.2	0.07	€ 32.57	€ 33.46	€ 34.35
		0.11	€ 35.07	€ 35.97	€ 36.86
		0.15	€ 37.58	€ 38.48	€ 39.37
	0.1	0.07	€ 32.57	€ 33.46	€ 34.35
		0.11	€ 35.08	€ 35.97	€ 36.86
		0.15	€ 37.58	€ 38.48	€ 39.37

- The higher the *manure discharge cost*, the higher the economic benefits generated per ton of manure are, *ceteris paribus* (Fig. 3a). These benefits are mainly in favor of the farmers, in form of higher reduction in manure discharge cost, *ceteris paribus*;Fig. 4
- The higher the *incentive for energy production* from manure, the higher the economic benefits generated per ton of manure are, *ceteris paribus* (Fig. 3b). These benefits are mainly in favor of the biogas producers, in form of higher revenues from selling electric energy;
- The higher the *amount of exchanged manure* between one farmer and the biogas producer, the higher the economic benefits generated per ton of manure are, *ceteris paribus* (Fig. 3c). These benefits are for both farmers and biogas producers.

Finally, we find that the threshold ROI for the biogas producer only affects the decision of agents to start the cooperation but it does not affect the total economic benefit stemming from such a cooperation.

Fig. 4 summarizes the effect of each investigated parameter, *ceteris paribus*, on the performance measures.

5.4. Energy return on investment

Following Yazan et al. [22], the Energy Return on Investment (EROI) is also computed. Plant scale and transportation distances are two main factors influencing the EROI of a scenario. Hence, we apply sensitivity analysis to these variables. Three values for transportation distance (2, 10, and 30 km) and three values for plant-scale (5000, 20,000, and 100,000 tons) lead to nine combinations as shown in Table 8. Expectedly, when the transportation distance increases, the EROI decreases. On the other hand, when plant-scale increases, the EROI increases as well. However, results fluctuate in a small range with a minimum EROI of 1.75 and a maximum EROI of 2.10. Therefore, EROI values are satisfactory even for the worst scenario where the farms are dispersed and provide low quantity of manure to the small-scale plant.

6. Discussion

Manure has an economic value of 8–10 €/t in terms of mineral organic value and 4–6 €/t in terms of energy value. So, unless a noticeable supply-demand unbalance occurs, animal farmers might recover an average value of 14 €/t from manure [18]. Our findings show that manure can locally be priced between −3.33 €/t (farmers pay a biogas producer) and 7.03 €/t (biogas producer pays farmers), which is in line with the economic energy value of manure. However, in the current situation, the huge supply-demand unbalance and regulations imposed on animal farmers cause a double disadvantage for animal farmers who are currently paying prices between 15 and 23 €/t for manure discharge in the Netherlands. Indeed, we observe that regulation for manure discharge already causes a significant increase of manure prices that are paid as discharge cost by animal farmers. However, if the demand can absorb the supply, also the animal farmers may have economic benefits in terms of profit rather than cost reductions.

Our case study design is implemented without considering the supply-demand unbalance to observe what would happen in case the demand absorbs the supply. Accordingly, we can notice the differences between the scenarios analyzed and the current state. Summarizing the effects of the analyzed factors, the presence of incentives provides economic contributions not only for biogas producers but also indirectly for animal farmers. In fact, when the incentive is high, also animal farmers obtain benefits in terms of cost reduction or profit. When the threshold ROI for biogas producers increases, the economic benefit for farmers reduces. However, this can be compensated by using more efficient technology, which means higher incentives (Table 3). The exchanged manure quantity is decisive for launching the cooperation as we notice from our findings that cooperation is hardly achieved when the manure quantity is lower than 10,000 t. Higher discharge cost for animal farmers causes loss of power in contracting,

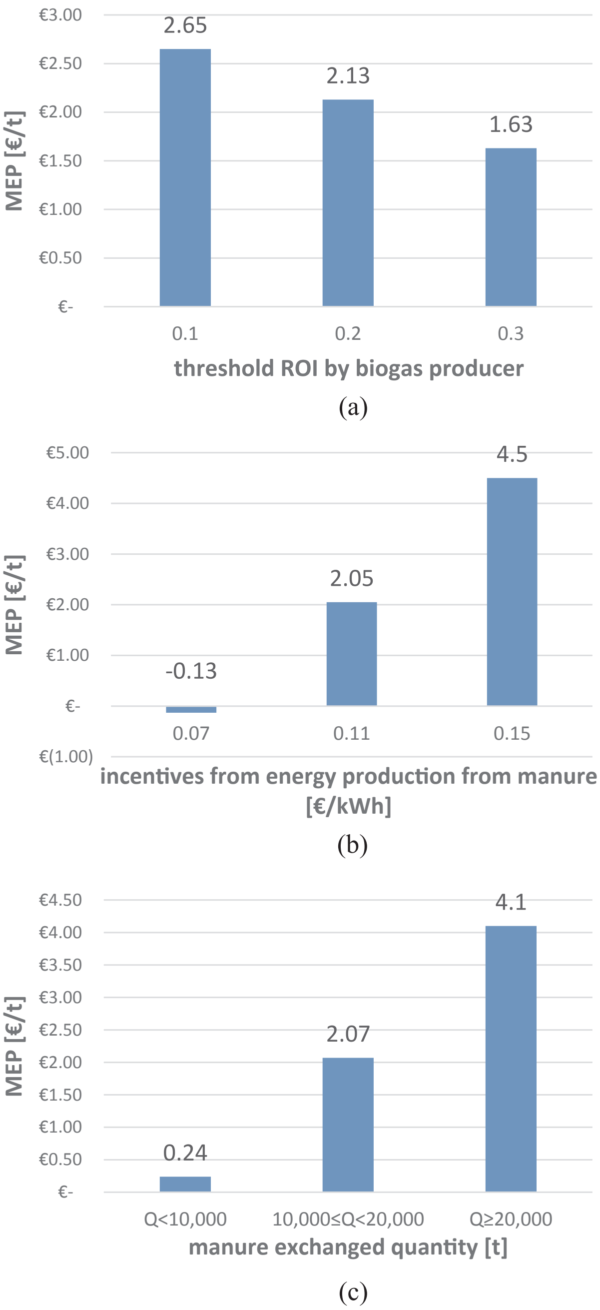

Fig. 2. Average manure exchange price, computed from all the simulated scenarios, as a function of different levels of threshold ROI by the biogas producer (a), incentives for energy production from manure (b), and amount of exchanged manure between one farmer and the biogas producer (c), *ceteris paribus*.

leading to a lower manure exchange price (MEP).

The impact of transportation on cooperation is embedded in the manure discharge cost and in the dispersion of farmers. If there is no supply-demand mismatch then, under the presence of environmental regulations for manure discharge, the higher the distance to the arable land, the higher the benefit for animal farmers in case of cooperation, i.e., other factors provide economic benefits. If the other factors do not provide an economically convenient situation, the transportation distance to the arable land has a negative impact on the implementation of the cooperation. Furthermore, in the case of cooperation, a short distance between 0 and 15 km allows the farmers and the biogas producer to create higher benefits within a municipality. We can observe that such short distances do not matter for the total economic benefits

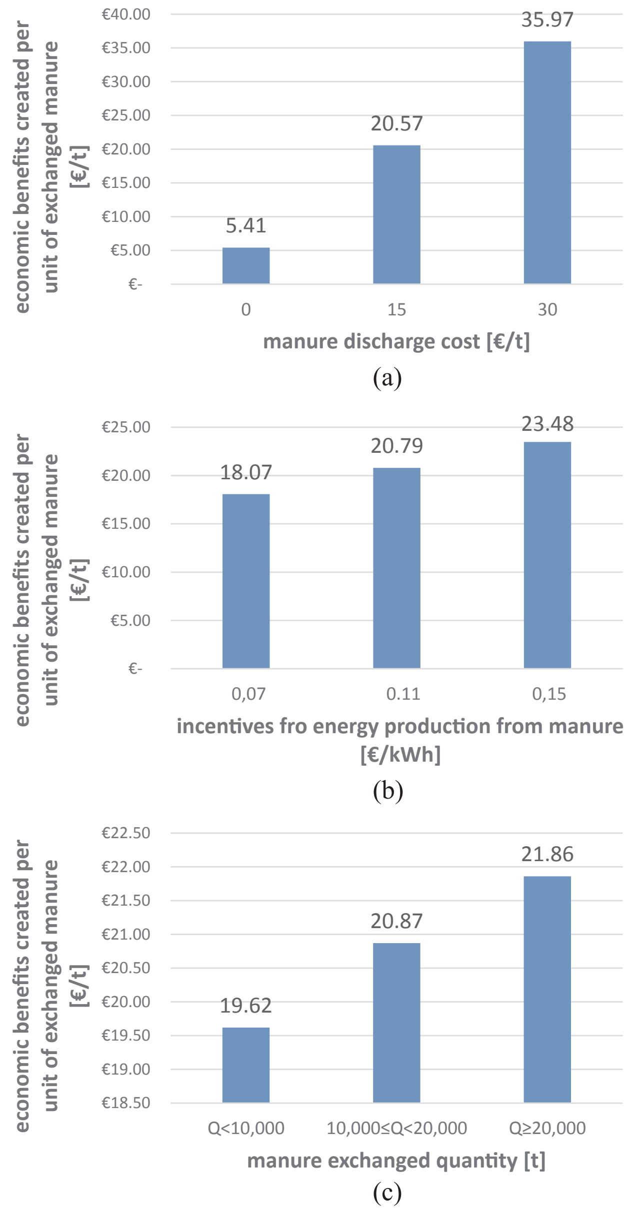

Fig. 3. Average amount of economic benefits created per ton of exchanged manure, computed from all the simulated scenarios, as a function of different levels of manure discharge cost (a), incentives for energy production from manure (b), and amount of exchanged manure between one farmer and the biogas producer (c), *ceteris paribus*.

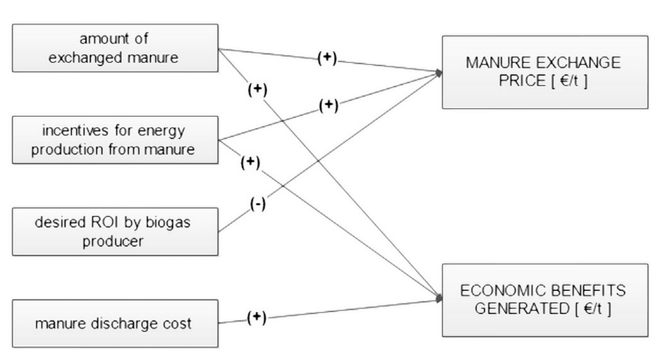

Fig. 4. Impact of the investigated parameters on the manure exchange price and the economic benefits generated per ton of exchanged manure. The symbol (+) stands for a positive effect whereas the symbol (−) stands for a negative effect.

Table 8
Energy return on investment (EROI).

Biogas plant scale [tons of manure]	Transportation distance [km]	Energy output [GJ]	Energy input [GJ]	Energy return on investment
100,000	30	69,087	34,969	1.98
	10	69,087	33,506	2.06
	2	69,087	32,921	2.10
20,000	30	13,817	7287	1.90
	10	13,817	6887	2.01
	2	13,817	6728	2.05
5000	30	3454	1978	1.75
	10	3454	1822	1.90
	2	3454	1759	1.96

created but only cause small changes in MEP. Hence, if there was no supply-demand mismatch, transportation costs would not be a significant obstacle to implement cooperation at a local level between animal farmers and biogas producers. However, such a significant supply-demand mismatch currently causes a considerable increase in transportation movements between the Netherlands, Germany, and France. Although it is a serious challenge for the Netherlands to overcome such a supply surplus, our results are replicable for other geographical locations where a supply-demand mismatch does not exist, i.e., positive revenues for both supply and demand sides are possible at a local level.

This paper provides a novel business insight into manure-based bioenergy production, proposing a globally applicable ABM that takes into account the critical factors influencing the economic viability of the case. These factors are selected based on their impact on the business-making strategy of each actor. There exist, however, several factors that might influence the technical outcomes, although they do not directly influence the generalizability of the economic findings. These factors are discussed below.

Properties of biomass type. Anaerobic digestion (AD) is applicable to different biomass types such as fruit waste, garden waste, grain silage, olive pulp, etc. Several factors such as organic content, dry matter or volatile solids existing in the biomass might influence the amount and content of biogas produced. Following Yazan et al. [22], we consider a dry content of 12% and an organic content of 85% for pig manure in this paper. Changes in these values might influence the production outcome and hence the economic conditions of cooperation for each actor. However, this is simply addressable in the ABM proposed in this paper via different levels of mark-up for animal farmers and ROI values for biogas producers. For example, if an animal farmer supplies manure with higher organic and dry content, then she can expect a higher mark-up in the negotiation phase. Vice versa, if a biogas producer receives manure with low organic and dry content, then she can expect a lower ROI and offer a lower MEP to the animal farmer. In this way, the ABM is flexible and able to economically take into account other factors, e.g., the above-mentioned biomass characteristics, which are not investigated in this paper.

Biomass conversion and biogas generation technology. As with many biomass types, manure can also be processed by other technologies such as pyrolysis, as an alternative to AD, and the obtained biogas can be purified and upgraded under different conditions. Depending on the biomass type, various upgrading technologies can be appropriate, such as in the case of biogas production from micro-algae [108,109]. Depending on the technology adopted, technical characteristics of produced biogas might vary, which in turn influences the energy outcome in terms of heat and electricity. As we deal with the economic aspects of implementing a market for manure to be used in bioenergy production, we take into account the economic impact of different technology levels in the ABM via different levels of incentives. This is perfectly in line with a government's incentive policy reflecting higher subsidies for higher technology levels (0.07, 0.11, and 0.15 €/kW h produced). Accordingly, any fluctuations on technical outcomes or governmental incentives in different geographical areas do not influence the working of the ABM proposed in this paper (but it does influence the outcomes). In contrast, the model is applicable to any geographical and technological context to enhance the cooperation between animal farmers and biogas producers and support the creation of second-generation biomass (SGB) markets adopting different technologies.

Uncertainty associated to modeling. The most relevant uncertainty issue might technically appear because of the seasonality of manure use. However, the seasonality impact is also addressed in the ABM by considering different levels of manure discharge cost, i.e., 0–30 €/ton. Considering the case- and site-specificity of SGB, we simulate all the factors taken into account in a range, e.g., 0–15 km of transportation distance and 0–160,709 tons of manure. Indeed, a practitioner should first locate itself in one of the combination scenarios and then reflect on the proposed pricing strategy, which significantly reduces the uncertainty in the negotiation phase.

The presence of natural gas in the market. As biogas is capable of substituting natural gas, it can be a good alternative for countries that do not possess natural gas reserves. However, producing biogas from manure becomes economically viable only if incentives are provided and technical issues are solved regarding the injection of biogas to natural grids. This is an issue beyond the scope of this paper, which concentrates on proposing a global decision support framework to facilitate the implementation of SGB markets.

Potential conflict of interest among actors. The ABM proposed in this paper takes into account the competitive nature of liberal markets by modeling each agent as autonomous. This means that, triggered by competitiveness, each actor has the chance of accepting or declining a MEP offer based on its own interest. Such an interest is reflected in mark-up values for animal farmers and ROI values for biogas producers. Indeed, a cooperation might economically be feasible for one actor while it does not pay-off for the other one. In fact, our findings confirm the formation of a liberal market where some potential cooperation opportunities do not realize due to the autonomous moves of the actors while there are also cases that pay-off for both sides leading to a mature market. Potential conflict of interests might also emerge caused by the presence of other actors in the (potential) market such as bioenergy producers adapting pyrolysis for manure processing or the ones using other technologies employing other types of biomass. This would trigger further research on the regional competition of bioenergy supply chains (SC) aimed to be conducted by the authors of this paper.

7. Conclusions

This paper provides two novel contributions to the domain of bioenergy production and one novel contribution to the domain of manure-based biogas production. First, it provides a globally valid ABM that facilitates the negotiation between suppliers and producers within non-mature second-generation biomass (SGB) markets. 235,629 different scenarios per each municipality are analyzed via using the proposed ABM. Considering the similar nature of other SGB types, in particular the ones emerging as the residues of forestry, agricultural, or food-processing activities, the model has a vast field of applicability. In particular, the logical reasoning on negotiation phase proposed in the ABM is globally applicable to the business models based on such SGB types. The model is also appropriate for the bio-based businesses operating in the form of industrial symbiosis, i.e., wastes of a company are used as substitutes of traditional primary resources of another company.

Second, it reveals the conditions that allow the creation of mature SGB markets. This is an important issue because SGB is not produced upon demand but emerge as a secondary output from other primary activities, e.g., agricultural residues as a secondary output of agriculture or manure as a secondary output of animal farming. Such a characteristic is a challenge to economically value the SGB and implement profitable business. The case of manure is an appropriate example which is not analyzed in the literature from economic perspective by considering different business entities. Therefore, this paper provides a novel practical contribution to animal farmers and (potential) biogas producers about how to implement a profitable business based on manure processing.

Overall, manure can be better exploited if the supply surplus problem is solved and economic gains for all actors are possible by minimizing environmental impacts. From practical and managerial perspectives, increased quantities of manure lead to higher exchange prices, which is an advantage for large-scale farms. In the Netherlands, this advantage turns into a disadvantage for large scale farmers in the current situation of manure surplus causing high discharge cost. Hence, considering the current market situation, investing in biogas production at locations where large scale farms are located would be advantageous until the manure surplus is met by demand. Furthermore, existing relationships between swine farmers with arable land owners are also critical in the contracting phase with biogas producers. If the arable land is too distant, accordingly, the collection price requested by arable land owners is also too high. This increases the chance of cooperation between a swine farmer and a biogas producer to make a mutually profitable business.

This paper addresses the case of energy recovery from manure. As mentioned before, manure has a higher added value thanks to its mineral content compared to its energy-based added value. Triggered by market distortions and environmental regulations, the Netherlands have been seeking to implement a manure-based refinery that would simultaneously produce biogas, heat, and electricity and process manure into its minerals. This initiative, which is a demo-plant project, is supported by the EU Commission [18]. The goal is to create an alternative fertilizers market in which mineral recovery, e.g., fats, trace elements, undigested starch or protein [110], is 100% possible. The main advantages of such a refinery are the reduction of artificial fertilizers, increased crop productivity in arable lands, and added value creation within the Netherlands. In addition, the methane reduction and manure upgrading are strong motivations to provide incentives to implement small-scale biogas digesters which currently do not pay off.

Future research should also address a fair distribution of incentives through the manure-based bioenergy SCs, which in turn may be helpful to achieve the supply-demand balance for manure in the Netherlands without damaging the livestock farming. After discovering that mutually beneficial agreements are possible between animal farmers and biogas producers, the authors aim at extending the ABM proposed in this paper in a manure exchange network where farmers can receive offers from multiple biogas producers. This is particularly relevant as large-scale biogas plants might offer better conditions to the animal farmers located in locations farther than the small-scale biogas producers located nearby animal farms. Similarly, a small-scale biogas plant adopting better technology might offer better conditions to an animal farm farther away than a big-scale biogas plant adopting less qualified technology. Hence, an ABM analyzing M-to-N manure-biogas markets in which animal farmers can form coalitions would better reveal cooperation conditions.

Acknowledgements

The authors of this article greatly acknowledge Davide Cafagna for his contributions to the initial computations of this study.

References

[1] International Energy Agency. Key World Energy Statistics 2014. Paris; 2014.
[2] The World Bank. World Bank open data; 2017. <https://data.worldbank.org/>.
[3] United Nations. World population prospects. The 2017 revision. New York; 2017. <https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf>.
[4] Soytas U, Sari R, Ewing BT. Energy consumption, income, and carbon emissions in the United States. Ecol Econ 2007;62:482–9. http://dx.doi.org/10.1016/j.ecolecon.2006.07.009.
[5] IPCC. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge, UK, and New York: Cambridge University Press; 2014.
[6] González MOA, Gonçalves JS, Vasconcelos RM. Sustainable development: Case study in the implementation of renewable energy in Brazil. J. Clean. Prod. 2017;142:461–75. http://dx.doi.org/10.1016/j.jclepro.2016.10.052.
[7] Yang L, Wang J, Shi J. Can China meet its 2020 economic growth and carbon emissions reduction targets? J. Clean. Prod. 2017;142:993–1001. http://dx.doi.org/10.1016/j.jclepro.2016.08.018.
[8] Albino V, Fraccascia L, Savino T. Industrial symbiosis for a sustainable city: technical, economical and organizational issues. Procedia Eng 2015;118:950–7. http://dx.doi.org/10.1016/j.proeng.2015.08.536.
[9] McKendry P. Energy production from biomass (part 2): conversion technologies. Bioresour Technol 2002;83:47–54. http://dx.doi.org/10.1016/S0960-8524(01)00119-5.
[10] Schievano A, D'Imporzano G, Adani F. Substituting energy crops with organic wastes and agro-industrial residues for biogas production. J Environ Manage 2009;90:2537–41. http://dx.doi.org/10.1016/j.jenvman.2009.01.013.
[11] Ariunbaatar J, Panico A, Esposito G, Pirozzi F, Lens PNL. Pretreatment methods to enhance anaerobic digestion of organic solid waste. Appl Energy 2014;123:143–56. http://dx.doi.org/10.1016/j.apenergy.2014.02.035.
[12] César AdaS, Werderits DE, de Oliveira Saraiva GL, Guabiroba RCdaS. The potential of waste cooking oil as supply for the Brazilian biodiesel chain. Renew Sustain Energy Rev 2017;72:246–53. http://dx.doi.org/10.1016/j.rser.2016.11.240.
[13] Haatanen A, den Herder M, Leskinen P, Lindner M, Kurttila M, Salminen O. Stakeholder engagement in scenario development process – bioenergy production and biodiversity conservation in eastern Finland. J Environ Manage 2014;135:45–53. http://dx.doi.org/10.1016/j.jenvman.2014.01.009.
[14] Hall DO, House JI. Trees and biomass energy: carbon storage and/or fossil fuel substitution? Biomass Bioenergy 1994;6:11–30. http://dx.doi.org/10.1016/0961-9534(94)90081-7.
[15] Viana H, Cohen WB, Lopes D, Aranha J. Assessment of forest biomass for use as energy. GIS-based analysis of geographical availability and locations of wood-fired power plants in Portugal. Appl Energy 2010;87:2551–60. http://dx.doi.org/10.1016/j.apenergy.2010.02.007.
[16] Massaro V, Digiesi S, Mossa G, Ranieri L. The sustainability of anaerobic digestion plants: a win–win strategy for public and private bodies. J Clean Prod 2015;104:445–59. http://dx.doi.org/10.1016/j.jclepro.2015.05.021.
[17] De Korte F. Exploring the potential of manure-based energy production in Salland. The Netherlands: TU Delft; 2012.
[18] Veenstra AJ. Manure digestion expert in Groengas. Personal interview; 2015.
[19] European Commission. Energy roadmap 2050; 2011. <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0885&from=EN>.
[20] Centraal Bureau voor de Statistiek. Higher CO2 emissions in Q4 2016; 2017 [WWW Document]. <https://www.cbs.nl/en-gb/news/2017/07/higher-co2-emissions-in-q4-2016>.
[21] PBL Netherlands Environmental Assessment Agency. Trends in global CO2 emissions: 2015 Report; 2015.
[22] Yazan DM, Cafagna D, Mes M, Fraccascia L, Pontrandolfo P, Zijm H. Economic sustainability of biogas production from animal manure: a regional circular economy model. In: 4th GIN conference 2015, 11st–13rd November, Mexico City; 2015.
[23] Dennehy C, Lawlor PG, Gardiner GE, Jiang Y, Shalloo L, Zhan X. Economic viability of farm-based co- digestion of pig manure and food waste. Appl Energy 2017;205:1–10. http://dx.doi.org/10.1016/j.apenergy.2017.08.101.
[24] Pierie F, Dsouza A, van Someren C, Benders R, van Gemert W, Moll H. Improving the sustainability of farming practices through the use of a symbiotic approach for anaerobic digestion and digestate processing. Resources 2017;6:50. http://dx.doi.org/10.3390/resources6040050.
[25] International Energy Agency. Technology roadmap – bioenergy for heat and power; 2012.
[26] Chandra R, Takeuchi H, Hasegawa T. Methane production from lignocellulosic agricultural crop wastes: a review in context to second generation of biofuel production. Renew Sustain Energy Rev 2012;16:1462–76. http://dx.doi.org/10.1016/j.rser.2011.11.035.
[27] Elliott DC, Neuenschwander GG, Hart TR, Butner RS, Zacher AH, Engelhard MH, et al. Chemical processing in high-pressure aqueous environments. 7. Process development for catalytic gasification of wet biomass feedstocks 2004. doi: 10.1021/IE034303O.
[28] Mathioudakis V, Gerbens-Leenes PW, Van der Meer TH, Hoekstra AY. The water footprint of second-generation bioenergy: a comparison of biomass feedstocks and conversion techniques. J Clean Prod 2017;148:571–82. http://dx.doi.org/10.1016/j.jclepro.2017.02.032.
[29] Naik SN, Goud VV, Rout PK, Dalai AK. Production of first and second generation biofuels: a comprehensive review. Renew Sustain Energy Rev 2010;14:578–97. http://dx.doi.org/10.1016/j.rser.2009.10.003.
[30] Osaki MR, Seleghim P. Bioethanol and power from integrated second generation biomass: a Monte Carlo simulation. Energy Convers Manage 2016. http://dx.doi.org/10.1016/j.enconman.2016.08.076.
[31] Steubing B, Zah R, Ludwig C. Heat, electricity, or transportation? The optimal use of residual and waste biomass in Europe from an environmental perspective. Environ Sci Technol 2012;46:164–71. http://dx.doi.org/10.1021/es202154k.

[32] You F, Wang B. Life cycle optimization of biomass-to-liquid supply chains with distributed–centralized processing networks. Ind Eng Chem Res 2011;50:10102–27. http://dx.doi.org/10.1021/ie200850t.
[33] Jonker JGG, van der Hilst F, Junginger HM, Cavalett O, Chagas MF, Faaij APC. Outlook for ethanol production costs in Brazil up to 2030, for different biomass crops and industrial technologies. Appl Energy 2015;147:593–610. http://dx.doi.org/10.1016/j.apenergy.2015.01.090.
[34] van Eijck J, Batidzirai B, Faaij A. Current and future economic performance of first and second generation biofuels in developing countries. Appl Energy 2014;135:115–41. http://dx.doi.org/10.1016/j.apenergy.2014.08.015.
[35] Guo J, Dong R, Clemens J, Wang W. Thermal modelling of the completely stirred anaerobic reactor treating pig manure at low range of mesophilic conditions. J Environ Manage 2013;127:18–22. http://dx.doi.org/10.1016/j.jenvman.2013.04.026.
[36] Namuli R, Jaumard B, Awasthi A, Pillay P. Optimisation of biomass waste to energy conversion systems for rural grid-connected applications. Appl Energy 2013;102:1013–21. http://dx.doi.org/10.1016/j.apenergy.2012.06.011.
[37] Pöschl M, Ward S, Owende P. Evaluation of energy efficiency of various biogas production and utilization pathways. Appl Energy 2010;87:3305–21. http://dx.doi.org/10.1016/j.apenergy.2010.05.011.
[38] Van Dael M, Van Passel S, Pelkmans L, Guisson R, Reumermann P, Luzardo NM, et al. A techno-economic evaluation of a biomass energy conversion park. Appl Energy 2013;104:611–22. http://dx.doi.org/10.1016/j.apenergy.2012.11.071.
[39] Miller JO, Moyle J. Manure as a natural resource: alternative management opportunities; 2014. doi: 10.13016/M2GD04.
[40] Zareei S, Khodaei J. Modeling and optimization of biogas production from cow manure and maize straw using an adaptive neuro-fuzzy inference system. Renew. Energy 2017;114:423–7. http://dx.doi.org/10.1016/j.renene.2017.07.050.
[41] Dennehy C, Lawlor PG, Gardiner GE, Jiang Y, Cormican P, McCabe MS, et al. Process stability and microbial community composition in pig manure and food waste anaerobic co-digesters operated at low HRTs. Front Environ Sci Eng 2017;11:4. http://dx.doi.org/10.1007/s11783-017-0923-9.
[42] Lebranchu A, Delaunay S, Marchal P, Blanchard F, Pacaud S, Fick M, et al. Impact of shear stress and impeller design on the production of biogas in anaerobic digesters. Bioresour Technol 2017;245:1139–47. http://dx.doi.org/10.1016/j.biortech.2017.07.113.
[43] Zheng Z, Liu J, Yuan X, Wang X, Zhu W, Yang F, et al. Effect of dairy manure to switchgrass co-digestion ratio on methane production and the bacterial community in batch anaerobic digestion. Appl Energy 2015;151:249–57. http://dx.doi.org/10.1016/j.apenergy.2015.04.078.
[44] Tsapekos P, Kougias PG, Treu L, Campanaro S, Angelidaki I. Process performance and comparative metagenomic analysis during co-digestion of manure and lignocellulosic biomass for biogas production. Appl Energy 2017;185:126–35. http://dx.doi.org/10.1016/j.apenergy.2016.10.081.
[45] Hamelin L, Naroznova I, Wenzel H. Environmental consequences of different carbon alternatives for increased manure-based biogas. Appl Energy 2014;114:774–82. http://dx.doi.org/10.1016/j.apenergy.2013.09.033.
[46] Lantz M. The economic performance of combined heat and power from biogas produced from manure in Sweden – a comparison of different CHP technologies. Appl Energy 2012;98:502–11. http://dx.doi.org/10.1016/j.apenergy.2012.04.015.
[47] Flotats X, Bonmati A, Fernandez B, Magri A. Manure treatment technologies: on-farm versus centralized strategies. NE Spain as case study. Bioresour Technol 2009;100:5519–26. http://dx.doi.org/10.1016/j.biortech.2008.12.050.
[48] Ferreira S, Moreira NA, Monteiro E. Bioenergy overview for Portugal. Biomass Bioenergy 2009;33:1567–76. http://dx.doi.org/10.1016/j.biombioe.2009.07.020.
[49] Nguyen TLT, Hermansen JE, Mogensen L. Fossil energy and GHG saving potentials of pig farming in the EU. Energy Policy 2010;38:2561–71. http://dx.doi.org/10.1016/j.enpol.2009.12.051.
[50] Qiao W, Yan X, Ye J, Sun Y, Wang W, Zhang Z. Evaluation of biogas production from different biomass wastes with/without hydrothermal pretreatment. Renew Energy 2011;36:3313–8. http://dx.doi.org/10.1016/j.renene.2011.05.002.
[51] Morin P, Marcos B, Moresoli C, Laflamme CB. Economic and environmental assessment on the energetic valorization of organic material for a municipality in Quebec, Canada. Appl Energy 2010;87:275–83. http://dx.doi.org/10.1016/j.apenergy.2009.07.007.
[52] Hijazi O, Munro S, Zerhusen B, Effenberger M. Review of life cycle assessment for biogas production in Europe. Renew Sustain Energy Rev 2016;54:1291–300. http://dx.doi.org/10.1016/j.rser.2015.10.013.
[53] Ullah Khan I, Hafiz Dzarfan Othman M, Hashim H, Matsuura T, Ismail AF, Rezaei-DashtArzhandi M, et al. Biogas as a renewable energy fuel – a review of biogas upgrading, utilisation and storage. Energy Convers Manage 2017;150:277–94. http://dx.doi.org/10.1016/j.enconman.2017.08.035.
[54] Labutong N, Mosley J, Smith R, Willard J, Resources N. Life-cycle modeling and environmental impact assessment of commercial scale biogas production. University of Michigan. School of Natural Resources and Environment; 2012.
[55] Thyö K, Wenzel H. Life cycle assessment of biogas from maize silage and from manure-for transport and for heat and power production under displacement of natural gas based heat works and marginal electricity in northern Germany. Institute for Product Development. Report 2007; 2007. 86 p. ID: 46e36c70-e6de-11dc-9a76-000ea68e967b.
[56] Rehl T, Lansche J, Müller J. Life cycle assessment of energy generation from biogas – attributional vs. consequential approach. Renew Sustain Energy Rev 2012;16:3766–75. http://dx.doi.org/10.1016/j.rser.2012.02.072.
[57] Mezzullo WG, McManus MC, Hammond GP. Life cycle assessment of a small-scale anaerobic digestion plant from cattle waste. Appl Energy 2013;102:657–64. http://dx.doi.org/10.1016/j.apenergy.2012.08.008.
[58] Yazan DM, van Duren I, Mes M, Kersten S, Clancy J, Zijm H. Design of sustainable second-generation biomass supply chains. Biomass Bioenergy 2016;94:173–86. http://dx.doi.org/10.1016/j.biombioe.2016.08.004.
[59] de Jong S, Hoefnagels R, Wetterlund E, Pettersson K, Faaij A, Junginger M. Cost optimization of biofuel production – the impact of scale, integration, transport and supply chain configurations. Appl Energy 2017;195:1055–70. http://dx.doi.org/10.1016/j.apenergy.2017.03.109.
[60] Jonker JGG, Junginger HM, Verstegen JA, Lin T, Rodríguez LF, Ting KC, et al. Supply chain optimization of sugarcane first generation and eucalyptus second generation ethanol production in Brazil. Appl Energy 2016;173:494–510. http://dx.doi.org/10.1016/j.apenergy.2016.04.069.
[61] d'Amore F, Bezzo F. Strategic optimisation of biomass-based energy supply chains for sustainable mobility. Comput Chem Eng 2016;87:68–81. http://dx.doi.org/10.1016/j.compchemeng.2016.01.003.
[62] Babazadeh R, Razmi J, Rabbani M, Pishvaee MS. An integrated data envelopment analysis–mathematical programming approach to strategic biodiesel supply chain network design problem. J Clean Prod 2017;147:694–707. http://dx.doi.org/10.1016/j.jclepro.2015.09.038.
[63] Mayerle SF, Neiva de Figueiredo J. Designing optimal supply chains for anaerobic bio-digestion/energy generation complexes with distributed small farm feedstock sourcing. Renew Energy 2016;90:46–54. http://dx.doi.org/10.1016/j.renene.2015.12.022.
[64] Miret C, Chazara P, Montastruc L, Negny S, Domenech S. Design of bioethanol green supply chain: comparison between first and second generation biomass concerning economic, environmental and social criteria. Comput Chem Eng 2016;85:16–35. http://dx.doi.org/10.1016/j.compchemeng.2015.10.008.
[65] Tomlin B. On the value of mitigation and contingency strategies for managing supply chain disruption risks. Manage Sci 2006;52:639–57. http://dx.doi.org/10.1287/mnsc.1060.0515.
[66] Giunipero LC, Aly Eltantawy R. Securing the upstream supply chain: a risk management approach. Int J Phys Distrib Logist Manage 2004;34:698–713. http://dx.doi.org/10.1108/09600030410567478.
[67] Fraccascia L, Giannoccaro I, Albino V. Rethinking resilience in industrial symbiosis: conceptualization and measurements. Ecol Econ 2017;137:148–62. http://dx.doi.org/10.1016/j.ecolecon.2017.02.026.
[68] Santibañez-Aguilar JE, Guillen-Gosálbez G, Morales-Rodriguez R, Jiménez-Esteller L, Castro-Montoya AJ, Ponce-Ortega JM. Financial risk assessment and optimal planning of biofuels supply chains under uncertainty. BioEnergy Res 2016;9:1053–69. http://dx.doi.org/10.1007/s12155-016-9743-1.
[69] Hu H, Lin T, Wang S, Rodriguez LF. A cyberGIS approach to uncertainty and sensitivity analysis in biomass supply chain optimization. Appl Energy 2017;203:26–40. http://dx.doi.org/10.1016/j.apenergy.2017.03.107.
[70] Crook TR, Combs JG. Sources and consequences of bargaining power in supply chains. J Oper Manage 2007;25:546–55. http://dx.doi.org/10.1016/j.jom.2006.05.008.
[71] Fawcett SE, Magnan GM, McCarter MW. Benefits, barriers, and bridges to effective supply chain management. Supply Chain Manage An Int J 2008;13:35–48. http://dx.doi.org/10.1108/13598540810850300.
[72] McCarter MW, Northcraft GB. Happy together? Insights and implications of viewing managed supply chains as a social dilemma. J Oper Manage 2007;25:498–511. http://dx.doi.org/10.1016/j.jom.2006.05.005.
[73] Cao M, Zhang Q. Supply chain collaboration: impact on collaborative advantage and firm performance. J Oper Manage 2011;29:163–80. http://dx.doi.org/10.1016/j.jom.2010.12.008.
[74] Narayanan VG, Raman A. Aligning incentives in supply chains. Harv Bus Rev 2004;82(94–102):149.
[75] Simatupang TM, Sridharan R. Design for supply chain collaboration. Bus Process Manage J 2008;14:401–18. http://dx.doi.org/10.1108/14637150810876698.
[76] Albino V, Fraccascia L, Giannoccaro I. Exploring the role of contracts to support the emergence of self-organized industrial symbiosis networks: an agent-based simulation study. J Clean Prod 2016;112:4353–66.
[77] De Laporte AV, Weersink AJ, McKenney DW. Effects of supply chain structure and biomass prices on bioenergy feedstock supply. Appl Energy 2016;183:1053–64. http://dx.doi.org/10.1016/j.apenergy.2016.09.049.
[78] Bonabeau E. Agent-based modeling: methods and techniques for simulating human systems. Proc Natl Acad Sci USA 2002;99:7280–7. http://dx.doi.org/10.1073/pnas.082080899.
[79] Weiss G. Multiagent systems: a modern approach to distributed artificial intelligence. Cambrigde, MA, London, UK: The MIT Press; 1999.
[80] Macal CM, North MJ. Tutorial on agent-based modelling and simulation. J Simul 2010;4:151–62. http://dx.doi.org/10.1057/jos.2010.3.
[81] Axelrod R. The complexity of cooperation: agent-based models of competition and collaboration. Princeton University Press; 1997.
[82] Zenobia B, Weber C, Daim T. Artificial markets: a review and assessment of a new venue for innovation research. Technovation 2009;29:338–50. http://dx.doi.org/10.1016/j.technovation.2008.09.002.
[83] Rand W, Rust RT. Agent-based modeling in marketing: guidelines for rigor. Int J Res Mark 2011;28:181–93. http://dx.doi.org/10.1016/j.ijresmar.2011.04.002.
[84] Deissenberg C, van der Hoog S, Dawid H. EURACE: a massively parallel agent-based model of the European economy. Appl Math Comput 2008;204:541–52. http://dx.doi.org/10.1016/j.amc.2008.05.116.
[85] Tesfatsion L. Agent-based computational economics. Artif Life 2002;8:55–82. http://dx.doi.org/10.1162/106454602753694765.
[86] Lebaron B. Agent-based computational finance. In: Tesfatsion L, Judd T, editors. Handbook of computational economics. Elsevier; 2006. p. 1187–233.

[87] Samanidou E, Zschischang E, Stauffer D, Lux T. Agent-based models of financial markets. Reports Prog Phys 2007;70:409–50. http://dx.doi.org/10.1088/0034-4885/70/3/R03.

[88] Jiao J, You X, Kumar A. An agent-based framework for collaborative negotiation in the global manufacturing supply chain network. Robot Comput Integr Manuf 2006;22:239–55. http://dx.doi.org/10.1016/j.rcim.2005.04.003.

[89] Shen W, Norrie DH. Agent-based systems for intelligent manufacturing: a state-of-the-art survey. Knowl Inf Syst Int J 1999;1:129–56.

[90] Giannoccaro I, Pontrandolfo P. Supply chain coordination by revenue sharing contracts. Int J Prod Econ 2004;89:131–9. http://dx.doi.org/10.1016/S0925-5273(03)00047-1.

[91] Fraccascia L, Giannoccaro I, Albino V. Efficacy of Landfill tax and subsidy policies for the emergence of industrial symbiosis networks: an agent-based simulation study. Sustainability 2017;9:521. http://dx.doi.org/10.3390/su9040521.

[92] Moncada JA, Lukszo Z, Junginger M, Faaij A, Weijnen M. A conceptual framework for the analysis of the effect of institutions on biofuel supply chains. Appl Energy 2017;185:895–915. http://dx.doi.org/10.1016/j.apenergy.2016.10.070.

[93] Kuznetsova E, Li Y-F, Ruiz C, Zio E. An integrated framework of agent-based modelling and robust optimization for microgrid energy management. Appl Energy 2014;129:70–88. http://dx.doi.org/10.1016/j.apenergy.2014.04.024.

[94] Li G, Shi J. Agent-based modeling for trading wind power with uncertainty in the day-ahead wholesale electricity markets of single-sided auctions. Appl Energy 2012;99:13–22. http://dx.doi.org/10.1016/j.apenergy.2012.04.022.

[95] Zhao J, Kucuksari S, Mazhari E, Son Y-J. Integrated analysis of high-penetration PV and PHEV with energy storage and demand response. Appl Energy 2013;112:35–51. http://dx.doi.org/10.1016/j.apenergy.2013.05.070.

[96] Holmstrom B, Milgrom P. Multitask principal-agent analyses: incentive contracts, asset ownership, and job design. J Law Econ Organ 1991;7:24–52.

[97] Giannoccaro I, Pontrandolfo P. Negotiation of the revenue sharing contract: an agent-based systems approach. Int J Prod Econ 2009;122:558–66. http://dx.doi.org/10.1016/j.ijpe.2009.02.014.

[98] Kempener R, Beck J, Petrie J. Design and analysis of bioenergy networks a complex adaptive systems approach. J Ind Ecol 2009;13:284–305. http://dx.doi.org/10.1111/j.1530-9290.2009.00120.x.

[99] Shastri Y, Rodríguez L, Hansen A, Ting KC. Agent-based analysis of biomass feedstock production dynamics. Bioenergy Res 2011;4:258–75. http://dx.doi.org/10.1007/s12155-011-9139-1.

[100] Alexander P, Moran D, Rounsevell MDA, Smith P. Modelling the perennial energy crop market: the role of spatial diffusion. J R Soc Interface 2013;10. http://dx.doi.org/10.1098/rsif.2013.0656. 20130656-20130656.

[101] Sorda G, Sunak Y, Madlener R. An agent-based spatial simulation to evaluate the promotion of electricity from agricultural biogas plants in Germany. Ecol Econ 2013;89:43–60. http://dx.doi.org/10.1016/j.ecolecon.2013.01.022.

[102] Singh A, Chu Y, You F. Biorefinery supply chain network design under competitive feedstock markets: an agent-based simulation and optimization approach. Ind Eng Chem Res 2014;53:15111–26. http://dx.doi.org/10.1021/ie5020519.

[103] Mertens A, Van Meensel J, Mondelaers K, Lauwers L, Buysse J. Context matters—using an agent-based model to investigate the influence of market context on the supply of local biomass for anaerobic digestion. Bioenergy Res 2016;9:132–45. http://dx.doi.org/10.1007/s12155-015-9668-0.

[104] Navaratnasamy M, Edeogu I, Papworth L. Economic feasibility of anaerobic digesters. Agri-Facts Agdex 2008:768–76.

[105] Phillips JJ. Return on investment in training and performance improvement programs. Butterworth-Heinemann; 2003.

[106] Provincie Overijssel. Energie Atlas Provincie Overijssel [WWW Document]; 2011. <http://gisopenbaar.overijssel.nl/viewer/app/energieatlas/v1>.

[107] Smit H. Dutch manure policy; 2013. <https://www.holanda.es/media/52510/present.%20h.%20smit%20pdf.pdf>.

[108] Yan C, Zhu L, Wang Y. Photosynthetic CO_2 uptake by microalgae for biogas upgrading and simultaneously biogas slurry decontamination by using of microalgae photobioreactor under various light wavelengths, light intensities, and photoperiods. Appl Energy 2016;178:9–18. http://dx.doi.org/10.1016/j.apenergy.2016.06.012.

[109] Yan C, Munoz R, Zhu L, Wang Y. The effects of various LED (light emitting diode) lighting strategies on simultaneous biogas upgrading and biogas slurry nutrient reduction by using of microalgae *Chlorella* sp. Energy 2016;106:554–61. http://dx.doi.org/10.1016/j.energy.2016.03.033.

[110] Wageningen UR Livestock Research. Manure: a valuable resource; 2014.