NJAS - Wageningen Journal of Life Sciences 57 (2010) 109–115

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

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

Economic analysis of anaerobic digestion—A case of Green power biogas plant in The Netherlands

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ARTICLE INFO

Article history:
Received 1 April 2009
Accepted 20 July 2009

Keywords:
Anaerobic digestion
Biogas plant
Methane yield
Reverse osmosis
Linear programming

ABSTRACT

One of the key concerns of biogas plants is the disposal of comparatively large amounts of digestates in an economically and environmentally sustainable manner. This paper analyses the economic performance of anaerobic digestion of a given biogas plant based on net present value (NPV) and internal rate of return (IRR) concepts. A scenario analysis is carried out based on a linear programming model to identify feedstocks that optimize electricity production and to determine the optimal application of digestate. In addition to a default scenario, management and policy scenarios were investigated. Economic evaluations of all scenarios, except no subsidy scenario, show positive NPV. The highest NPV and IRR values are observed under reverse osmosis (RO) as a green fertilizer scenario. Our findings show that treating RO as a green fertilizer, as opposed to manure (default scenario), is not only lucrative for the plant but also lessens environmental burden of long distance transportation of concentrates. This paper also concludes that given the uncertainty of regulations concerning RO and the currently low values of digestate and heat, high investment and operating costs limit feasibility of anaerobic digestion of wastes of farm origin and other co-substrates unless subsidies are provided.

1. Introduction

Manure residues from livestock industries have long been identified as a major source of environmental pollution. Traditionally, these wastes have been disposed of, directly or after composting, as soil amendments in the agricultural industry. Since this practice has resulted in degradation of air, soil, and water resources, new regulations for protecting the environment have been promulgated to control land application of animal manure [1]. The nitrate-directive, 91/676/EEC [2], regulates input of nitrate on farmland, aiming to protect ground and surface water environments from nitrate pollution, and includes rules for the use of animal manure and chemical fertilizers [3]. In principle, not more than 170 kg of animal manure N may be applied per ha per year, as long as this is not in conflict with application standard for total P [4]. Implementation of these environmental measures entails a high cost of manure disposal for livestock farmers, which impairs profitability of farming. As such, livestock industries and regulatory agencies are seeking alternatives for managing manure residues in an economically feasible and environmentally friendly manner. Several studies have shown that anaerobic digestion (AD) of organic wastes has the potential to manage these problems in a cost effective and environmentally sustainable manner [10,11,16,20].

Interest has recently been growing in using the AD of organic waste of farm origin, such as manure, crop residues and organic residues from food and agro-industries, to generate renewable energy [5,6]. Processing manure to biogas through AD recovers energy that contributes no net carbon to the atmosphere [7] and reduces the risk from pathogens from land spreading, as thermophilic or mesophilic AD with a sanitization step destroys all or virtually all pathogens [8].

Besides biogas, AD produces digestate, which consists of a mixture of liquid and solid fractions. Applying digestate to land is the most attractive option in terms of environmental issues, because it allows nutrients to be recovered and reduces loss of organic matter suffered by soils under agricultural exploitation [9]. A reliable and generally accepted means of disposing of the comparatively large amounts of digestate produced is of crucial importance for the economic and environmental viability of a biogas plant [10]. Murphy and Power [11] investigated biogas production utilizing three different crop rotations to optimize energy production and performed a sensitivity analysis for a change in price of digestate. Georgakakis et al. [12] developed an economic evaluation model based on the concept of NPV to

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doi:10.1016/j.njas.2009.07.006

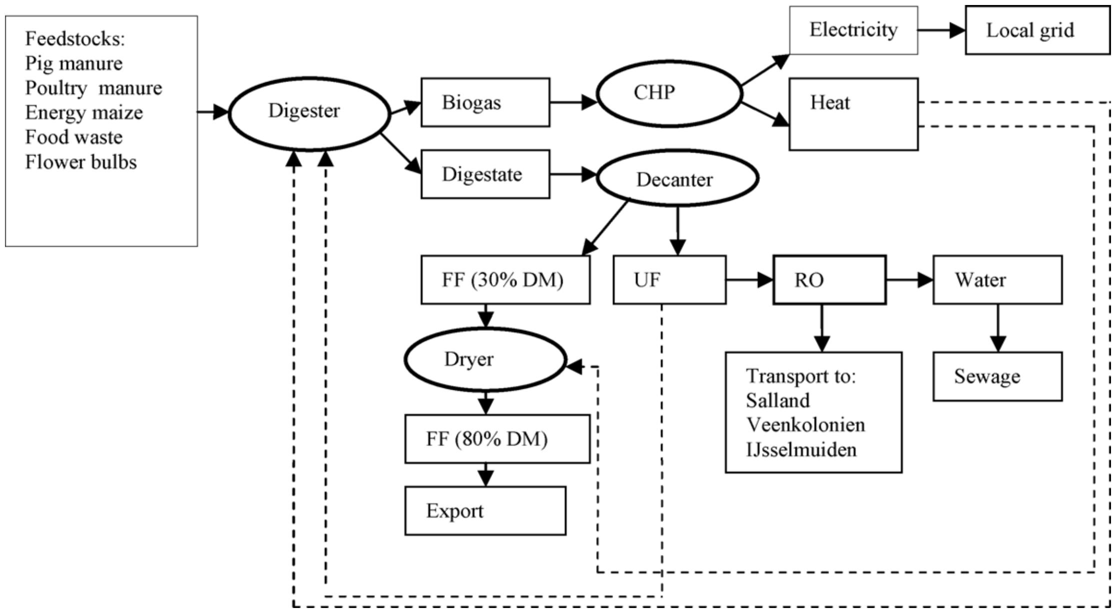

Fig. 1. Schematic overview of Green power anaerobic digestion process. CHP = combined heat–power unit; FF = fixed fraction; DM = dry matter; UF = ultra filtration; RO = reverse osmosis.

assess cost-effectiveness of biogas production systems fed with pig manure. However, a complete economic analysis of AD, incorporating outcomes from production and application of digestates is still lacking.

The aim of this study is to analyze economic performance of AD of a given biogas plant. A scenario analysis is carried out on the basis of a linear programming (LP) model to identify feedstocks that optimize electricity production and to determine optimal application of digestate. Green power biogas plant located in northern part of Netherlands forms the basis for our analysis. The plant is a relatively large plant with an installation capacity of 70,000 tons of input on an annual basis. The plant produces electricity, heat, and three types of digestates, namely fixed fraction (FF), ultra filtration (UF), and reverse osmosis (RO).

The paper is structured as follows. Section 2 introduces case study and will elaborate on general framework, data used, and assumptions made for developing an optimization model. Section 3 will analyze model results and scenarios assessed. The final section contains discussion and major conclusions.

2. Materials and methods

2.1. Case study description

Green power biogas plant was established in 2007 by 50 swine farmers, with an installation capacity of 70,000 tons of input on an annual basis. The important starting point for the plant was its commitment to process a contracted amount of pig manure from its member farmers. The installation, in addition to pig manure, uses other co-digestion materials, such as poultry manure, energy maize, food waste, and flower bulbs. A schematic overview of Green power AD process is given in Fig. 1.

The input materials are mixed, grinded, and pumped to 2 prefomenters of 600 m^3 each. Fermentation starts, and mixture stays a week in these silos. This pre-fermented product flows to main fermentor of 1800 m^3 and stays there for 40 days at 40°. Biogas is burned in a combined heat and power (CHP) unit to generate electric power and heat. Electricity produced is sold to local grid at a market price of €0.06 kwh^{-1}. Additionally, the plant receives an MEP[1] subsidy of €0.097 kwh^{-1} for a duration of 10 years, after which it is estimated that it will receive about half of current tariff (personal communication with plant manager). The plant is limiting electricity production to a total of 2 MW $year^{-1}$, amount for which subsidy is provided.

Market for heat is currently non-existent. Heat is utilized within the plant for heating digester and drying digestate. Besides biogas, the plant produces digestate, which is separated into a solid and a liquid fraction via pressing. Solid fraction (80% dry matter), rich in phosphate, contains NPK of 9.3, 19.2 and 5.9 kg ton^{-1}, respectively and is targeted for export to EU countries with a phosphate deficiency. The plant intends to sell FF concentrate at zero price, but transportation cost will be fully paid by buyers. Ultra filtration is recycled to digestion process, guaranteeing sufficient dilution of substrate fed into digester. Reverse osmosis, also referred to as green fertilizer, contains NPK of 6.8, 0.6 and 11.5 kg ton^{-1}, respectively. It is to be used as a supplement to animal manure on plots with low K qualities. Currently, RO is treated as animal manure, competing with other types of manure with an application rate limited to 170 kg (or 250 kg on grassland) N per ha per year from animal manure. However, pilot projects are underway to test fertilizing value and treatment of RO as a replacement to artificial fertilizer.

For biogas plants, the first consideration in digestate management is adhering to hygiene requirements and certification of digestate. Organic waste can contain infectious matters, which can result in new spreading of pathogens and transmission of disease between animals, humans, and environment. Many countries, therefore, enforce their legislation regarding pathogen control in digestate. At the same time, European Council has implemented rules and regulations that are mandatory for all Member Countries [13]. These regulations include European regulations (EC) No. 208/2006 and (EC) No. 1774/2002. In Netherlands, Food and Consumer Product Safety Authority (VWA) deals with monitoring of the production and certification of digestates.

[1] The MEP (Environmental quality of electricity production) is a kwh subsidy paid to domestic producers of electricity from renewable sources and CHP who feed into the national grid. The state guarantees the subsidy for a maximum of 10 years.

2.2. Description of target regions for RO

RO concentrate is to be transported to Salland, Veenkolonien, and IJsselmuiden, regions that are relatively near the plant. Key decision parameters for target regions are land availability, land usage, soil type, crops grown, and distance from the plant. Salland, a region with a total surface land area of 51,621 ha, 10–15 km from the plant, consists mostly of sandy soil [14]. Arable land comprises of only 7% of total utilized agricultural area, with grains holding the greatest share of arable land.

Veenkolonien, unlike Salland, is comprised mostly of arable land, which makes up 76% of total agricultural land. Approximately 60% of soil in Veenkolonien is peat, and most of the area is used for starch potatoes. Veenkolonien, 60 km from the plant, is characterized as a region with a net deficiency in mineral availability, with around 80% of fertilizable land in year 2006 using nutrients [14].

IJsselmuiden, 35 km from the plant, covers an area of 14,140 ha [14]. Like Salland, the region is a typical cattle region with a lot of grassland (91%). Conventional arable crops (potato, sugar beet, wheat) play quite a small role as shares of total fertilizable arable land. A relatively large part of fertilizable ground is occupied by horticulture; horticulture in greenhouses in particular accounts for around 30%.

2.3. Model description

2.3.1. Linear programming (LP)

After specifying a set of decision variables and constraints, linear programming is used to maximize profit of the plant from sales of electricity and digestate application. A standard LP model with a profit-maximizing objective can be expressed as

$$\text{Maximize}\, Z = \sum_{j=1}^{m} c_j X_j$$

Subjected to:

$$\sum_{j=1}^{m} a_{ij} X_j \le b_i \quad i = 1 \ldots N$$
$$X_j \ge 0 \quad j = 1 \ldots M$$

where X = vector of activities; c_j = gross margin per unit of activity j; a_{ij} = technical coefficients; and b_i = availability of resource i.

Since digestate comprises of a large percentage (by volume) of the final product from AD, sustainability of the plant will depend on not only maximizing profits from electricity but also on effective management of digestate. Activities that were identified as being relevant are classified as producing and selling electricity and digestates, transporting biomass to plant, hiring people, transporting RO to target regions, and storing digestates.

Constraints relate to treatment capacity of the plant and digestate application. Capacity constraint is that total biomass processed should not exceed maximum treatment capacity of the plant. Total quantity of digestate transported to regions must be less than or equal to the amount of digestate available. Moreover, the model will assume cognizance of nutrient content of concentrate as well as nutrient uptake of crops per each type of soil in each region, and hence total amount of nutrients transported to a certain region should be less than or equal to maximum nutrient uptake of that region. Total digestate storage at the end of each time period is the difference between digestate available and total digestate applied to regions. We assume that all concentrates will be transported and thus there is no digestate in storage.

To analyze profitability of the system, net present value (NPV) and internal rate of return concepts are used as valuation criteria. NPV is sum of expected net cash flows measured in today's currency and is given by

$$\text{NPV} = -I + \sum_{t=0}^{n} \frac{\text{CF}_t}{(1+r)^t}$$

and

$$\text{CF}_t = p_t O_i - v_t X_t - \text{FC}$$

where CF is expected cash flow at time t, r is discount factor, and I is initial capital investment cost. CF is a function of income p_t from i outputs (O) where output relates to electricity, heat, and digestate; variable costs (X_t) include feedstock prices, operating and maintenance costs, and disposal costs of digestate and water; and FC is all fixed costs such as labor cost, interest expense, and overhead cost. IRR is discount rate for which total present value of future cash flows equals cost of investment. Total investment cost is €6.75 million, which accounts for CHP unit, decanter, dryer, land, and silos. Investment is paid from own equity capital (15%), investment grant (15%), and remainder is financed from debt whereby a 6% interest rate is charged. It was assumed that average life-span of the plant is 20 years. Economic analysis is based on subsidy level of €0.097 kwh^{-1} for 10 years and half the current subsidy for the remaining 10 years. It was assumed that discount rate is 10%. Total labor cost, RO transportation cost, operating and maintenance cost, and overhead costs are subjected to an average annual increase of 2%. Operating and maintenance costs include maintenance of digester, CHP unit, and decanter. Overhead cost includes indirect costs such as salary of management, insurance cost and accountancy. Income tax is not considered in our analysis.

2.4. Model parameterization and assumptions

Table 1, derived from the plant's records, depicts labor allocated to final products and current proportion and cost of each feedstock in total biomass digestion of 67,500 tons year^{-1}. Substrate composition is a major factor affecting methane yield. Biogas can be produced from a broad range of feedstocks that may be solid, slurries, and both concentrated and dilute liquids. However, in the current study, model will only consider feedstocks currently used by the plant, but it will vary proportion of feedstocks in total blend to see how methane yield varies with substrate mixture. Fees received are designated as a reduction to costs and are therefore negative.

Specific characteristics and methane yield of feedstocks are estimated from literature. Potential production of biogas is directly related to volatile solids content. For the purpose of this study, methane productivity of pig manure, 0.356 m^3 kg^{-1} VS (Table 2), was taken from a study done by Moller et al. [15]. Amon et al. [16] developed methane energy value model, which estimates methane yield from nutrient composition of energy crops via regression models. Although different studies show different methane yields, in this study methane yields, 0.39 m^3 kg^{-1} VS of energy maize and food waste of 0.5 m^3 kg^{-1} VS, were taken from a study done by Amon et al. [17].

One of the most important parameters describing plant efficiency is organic degradation rate [18], which is assumed to be 80% of VS-input for Green power due to the plant's short retention time. Design of a biogas plant is directly linked to its hydraulic retention time (HRT), which may be defined as time period during which mixture of feedstocks stays in digester to produce biogas [19]. Green power maintains a short retention time of 40 days to ensure that continuous supply of pig manure from its member farmers is accommodated. Average retention time for similar digesters is 72 days (personal communication with plant operator). Typical retention time of biogas plants which treat energy crops together with manure and organic wastes are between 60 and 90

Table 1
Input data and cost associated with each input (default scenario).

	Input (ha $year^{-1}$ or tons $year^{-1}$)	Biomass proportion (%)	Fee received (€ ton^{-1})	Input cost including transportation (€ ton^{-1})	Net cost (€ ha^{-1} or € ton^{-1})
Labor allocation:					
Electricity	3,182				22.50
Digestate	562				22.50
Pig manure	49,275	73	−14	2.5	−11.5
Energy maize	7,425	11		38	38
Food waste	3,375	5		40	40
Poultry manure	6,075	9	−14	0	−14
Flower bulbs	1,350	2	0	0	0
Total biomass	67,500				

days [20]. Calorific value of biogas depends on its CH_4 content, and it is assumed that 1 m^3 CH_4 = 10 kwh (Dubbel (1987) cited by Amon et al. [16] while electrical efficiency is assumed to be 37% [21].

With the given digestion process, total feedstocks yield about 60,750 tons of digestate that is further processed to produce FF, UF and RO concentrate. These concentrates account for about half the total volume, whereas remaining fifty percent becomes water that is expelled into sewage at a cost of €1 m^{-3}. Composition of digestate depends on feedstocks and can therefore vary. However, the plant provides tailor-made concentrates as per the needs of farmers. Composition of RO concentrate therefore stays the same in absolute values, whereas composition of FF varies. There are three types of mineral application standards: one for total P (sum of mineral fertilizer and organic manure), one for plant available N (sum of mineral fertilizer and N becoming available after application of manure) and one for N in the form of animal manure [4]. When RO is treated as animal manure, application rate is limited to 170 kg ha^{-1} (250 kg on grassland). When RO is treated as a green fertilizer, application standard for mineral fertilizers will apply. Plant experts expect that RO will be applied in combination or in addition to animal manure at an acceptance level of 75%, that is, 75% of total nitrogen needs of crops will be supplied from mineral fertilizer (RO) and remaining 25% from animal manure. The expected price of RO as a mineral fertilizer is €5 ton^{-1} (excluding transportation costs); otherwise, the plant will pay €20 ton^{-1} for its disposal as animal manure. In addition to transportation and sampling cost, the plant pays €20 to farmers for applying digestate. This is because, the plant is based on digestion of pig manure and most pig farms do not have sufficient land to apply the digestate and hence the plant pays to get rid of the digestate.

Feedstock and digestate transport have a significant effect on the economy of the system. Some authors indicate a viable maximum distance of 15–25 km [22]. Logistics of feedstocks and digestate are important determinants for biogas system to be economically, environmentally, and socially viable. Long distance transportation will not only be costly in terms of transportation cost but also entails environmental costs such as GHG emissions and odor noises. The impact of these transport movements should, therefore be minimized. Biogreen is a relatively large plant producing large quantity of digestate. The plant is situated in an area with mostly pig farms, which do not have sufficient land to apply the digestate on. The plant, therefore, transports digestate to as near-by farms as possible but at the same time taking nutrient uptake capacity of the regions into consideration. Total transportation and sampling cost of RO to Salland, Veenkolonien and IJsselmuiden is €3, €4, and €4 ton^{-1}, respectively.

Table 2
Methane yields of feedstocks specified as dry matter (DM) and volatile solid (VS) content.

Input	DM (%)	VS (%) of DM	Methane yield m^3 kg^{-1} VS
Pig manure	5–8	80	0.356
Energy maize	35–39	96	0.390
Poultry manure	10–30	80	0.410
Food waste	10	80	0.500
Flower bulbs	10	80	0.500

Source: [15–17,25,26].

2.5. Description of scenarios

Two groups of scenarios, management and policy scenarios, were investigated in addition to default scenario. Default scenario is a model of the given situation; proportion and price of feedstocks digested and labor costs are as shown in Table 1. The plant receives an MEP subsidy for electricity production up to 2 MW while heat is used within the plant. RO is considered as an animal manure, with a disposal cost of €20 ton^{-1}, and FF is exported to other EU countries. Water, which accounts for about 50% by volume of the total by-product, is expelled to sewage.

Management scenarios analyzed impact of a change in proportion and price per ton of feedstock, mainly energy maize, on methane yield and overall profitability. The objective of investigating these scenarios was to identify feedstock that will result in a better economic performance. Quantity of pig manure digested remained constant under all scenarios (as shown in Table 1), but percentage of energy maize digested was increased to 15%, by reducing poultry manure to 5% (less poultry manure scenario) or food waste to 1% (less food waste scenario). Moreover, an analysis with lower energy maize prices was conducted to examine impact on profitability of the plant (lower maize price scenario).

Policy scenarios were two-fold, focusing on both RO selling options and MEP subsidy. In RO scenario, we analyzed outcomes, in terms of RO allocation and profitability, if RO is considered as a "green fertilizer". Given the knowledge of each region's nutrient uptake capacity taken from Netherlands central bureau of statistics (CBS), we assumed that 5%, 20% and 15% of the total hectares allocated to arable and grassland in Salland, Veenkolonien and Ijsselmuiden, respectively, will buy RO. We assumed that all farms, arable and grassland, are potential buyers when RO is treated as a green fertilizer but only arable farms are potential buyers when RO is treated as animal manure (default scenario). Artificial fertilizers are used by both arable and grassland, but most dairy farmers with land will tend to apply their own manure, hence we excluded them from potential buyers under default scenario. A scenario with no MEP subsidy was also investigated to assess the plant's performance in the absence of a subsidy.

3. Results

3.1. Technical results of scenarios

Table 3 presents technical results of default and alternative scenarios, showing electricity yield, production cost per unit

Table 3
Technical results of Green power for default and alternative scenarios.

	Default	Management scenarios			Policy scenario	
		Less poultry manure	Less food waste	Lower maize price	RO as green fertilizer	No subsidy
Electricity yield (kwh ton^{-1})	222.30	224.00	227.00	222.30	222.30	222.30
Electricity (million kwh year^{-1})	15.00	15.12	15.32	15.00	15.00	15.00
Digestate FF (ton year^{-1})	8,000	8,000	8,000	8000	8,000	8,000
Digestate UF (ton year^{-1})	14,000	14,000	14,000	14,000	14,000	14,000
Digestate RO (ton year^{-1})	10,327	10,327	10,327	10,327	10,327	10,327
Water (m^3 year^{-1})	34,000	34,000	34,000	34,000	34,000	34,000
Unit cost of input (€ ton^{-1})	−3.48	−1.40	−3.56	−4.58	−3.48	−3.48
Transportation RO (tons):						
Salland	1,913	1,913	1,913	1,913	10,327	1,913
Veenkolonien	7,739	7,739	7,739	7,739	0	7,739
IJsselmuiden	675	675	675	675	0	675
Export FF (tons)	8,000	8,000	8,000	8,000	8,000	8,000
Expel water (m^3)	34,000	34,000	34,000	34,000	34,000	34,000
Shadow prices (€):						
Pig manure	36.54	36.54	36.54	36.54	36.54	21.07
Poultry manure	75.80	75.80	75.80	75.80	75.80	37.62
Energy maize	30.58	30.58	30.58	40.58	30.58	−11.79
Food waste	10.24	10.24	10.24	10.24	10.24	−20.80
Flower bulbs	50.24	50.24	50.24	50.24	50.24	19.20
Capacity	38.38	36.57	39.19	39.48	38.38	16.81

of input, transportation of concentrates, and shadow prices of inputs and capacity. Default scenario produces electricity yield of 222.30 kwh ton^{-1} of feedstock digested. Less poultry manure and less food waste scenarios result in slightly higher yields of 224 kwh ton^{-1} and 227 m^3 ton^{-1}, respectively than default scenario. Less poultry manure scenario has a higher yield than default but results in a higher production cost per unit of input due to a higher energy maize cost. Less food waste scenario has a higher yield and lower production cost per unit of input as compared to other scenarios. This is because energy maize and poultry manure have high dry matter content, and cost of food waste is higher than cost of poultry manure, for which a fee of €14 ton^{-1} is received by the plant. Hence less food waste scenario optimizes energy production as compared to default and less poultry manure scenarios.

Cost of feedstock is the next most important economic factor; a change in energy maize price results in a change in production cost of between €−3.48 and €−4.58 ton^{-1} for default and lower maize price scenarios, respectively.

Under default and management scenarios, where RO is considered as an animal manure that will be competing with other animal manures, regulation on N in the form of animal manure will apply. Total tons of RO transported to Salland, Veenkolonien and IJsselmuiden are 1913, 7739 and 675 tons, respectively. Most of RO is transported to Veenkolonien, as it comprises mostly of arable land. Regional data of Veenkolonien reveals that it has a shortage of nutrients. Approximately 80% of fertilizable land already uses nutrients, while the remaining 20% can be regarded as a potential application area, which makes the region more attractive for transporting RO as compared to other regions that have limited nutrient uptake capacities.

RO as green fertilizer scenario results in transporting all the concentrate to Salland. Apart from the relatively lower transportation cost to the region, deciding factor for transporting all concentrate to Salland is that both arable and grassland are considered as potential buyers.

Shadow prices of all inputs remain the same under all scenarios except under no subsidy scenario. Under default and alternative scenarios, poultry manure has the highest shadow price of €75.80 and €37.62 with and without subsidy, respectively, followed by flower bulbs and pig manure. This is attributed to the fact that these feedstocks have either high gate fees or are acquired at zero cost. When there is no subsidy, energy maize and food waste have lower and negative shadow prices, implying that increasing these feedstocks is not economical. Though energy maize and food waste both have high methane yields, their high costs result in low shadow prices. Therefore, increasing poultry manure in total feedstocks would bring a better result under all scenarios as compared to increasing other feedstocks. Shadow prices of energy maize and capacity are sensitive to price of energy maize. A one unit (ton) increase in capacity will result in an increase in gross margin of €38.38 under default scenario, but the increase is larger (€39.48), with a lower energy maize price. Shadow prices are important decision parameters, as they allow model users to determine whether certain potential changes in the given situation might actually increase profitability.

3.2. *Economic results of scenarios*

Table 4 shows gross revenues, costs, profit before taxes, net present value, and internal rate of return for all of the scenarios investigated. The economic results follow from technical results. Higher NPV values represent greater economic benefits The plant is in a good economic situation under default scenario, earning a profit before tax of €1 million and showing a positive NPV of €4 million and an IRR of 21%. In the presence of a subsidy, less poultry manure scenario resulted in the least profit before tax and NPV due to higher total feedstock costs. RO as green fertilizer scenario resulted in the highest profit before tax (€6.3 million) and an NPV (€1.4 million) as a result of increased revenues from selling RO as a green fertilizer. In no subsidy situation, the plant operates under a loss and a substantial decline in NPV and IRR (showing a negative value) is observed, implying that subsidy plays a great role in the profitability of the plant.

4. Discussion and conclusions

This paper aimed to analyze the economic performance of AD of a given biogas plant. A scenario analysis was carried out based on a linear programming model to identify feedstocks that optimize electricity production and to determine optimal application of digestate. The economic analysis was also based on the concepts of NPV and IRR to assess cost-effectiveness of the biogas system.

Default scenario produces electricity yield of 222.30 kwh ton^{-1} of feedstock digested. A higher yield is realized under less food

Table 4
Economic results (× € 1000) of Green power for default and alternative scenarios.

	Default	Management scenarios			Policy scenarios	
		Less poultry manure	Less food waste	Lower maize price	RO as green fertilizer	No subsidy
Revenues						
Sales of electricity	900	907	919	900	900	900
Sales of RO	−206	−206	−206	−206	52	−206
Sales of FF	0	0	0	0	0	0
MEP subsidy	1455	1467	1486	1455	1455	0
Total revenues	2148	2167	2199	2148	2407	694
Costs						
Pig manure	−566	−566	−566	−566	−566	−566
Poultry manure	−85	−47	−85	−85	−85	−85
Energy maize	282	384	384	208	282	282
Food waste	135	135	27	135	135	135
Flower bulbs	0	0	0	0	0	0
Total biomass cost	−234	−94	−240	−309	−234	−234
Total labour cost	166	166	166	166	166	166
RO transportation	39	39	39	39	31	39
Water disposal	35	35	35	35	35	35
O & M[a] cost	220	220	220	220	220	220
Interest & banking	255	255	255	255	255	255
Depreciation	337	337	337	337	337	337
Overhead[b]	175	175	175	175	175	175
Total costs[c]	993	1134	988	919	985	993
Profit before tax	1155	1034	1211	1229	1406	−300
NPV[d]	4195	3233	4592	4770	6267	−5499
IRR (%)	21	19	22	22	25	0

[a] Operating and maintenance costs include maintenance of digester, CHP unit and decanter.
[b] Overhead cost includes indirect costs such as salary of management, insurance cost and accountancy.
[c] Total labour cost, RO transportation cost, O & M and overhead costs are subjected to an average annual increase of 2%.
[d] Assuming a discount rate of 10%, over 20 years.

waste scenario, which produced 2% more yield than default and 1% more than less poultry manure scenario, and thus less food waste scenario optimizes energy production. Another important economic factor is cost of feedstock; less poultry manure scenario resulted in a higher production cost, whereas low energy maize price scenario resulted in a lower production cost per unit of input.

Our findings show that number of tons of RO transported to regions and distance transported are different under default and RO as green fertilizer scenarios. The concentrate will stay closer to the plant when it is treated as green fertilizer, thus resulting in lower transportation costs and less environmental impact. Therefore, treating RO as a green fertilizer is not only lucrative for the plant but also lessens the environmental burden of long distance transportation of concentrates. Moreover, it results in saving energy consumption for the production of chemical fertilizers.

A synthesized economic evaluation of all scenarios except no subsidy scenario shows a positive NPV. The highest NPV and IRR values are observed under RO as green fertilizer scenario due to increased revenues from selling RO as a green fertilizer and reduced transportation cost of concentrates. No subsidy scenario results in a negative NPV, implying that subsidy plays a great role in profitability of the biogas plant.

Economic analysis done in this study was based on a number of assumptions. Estimated methane yield of feedstocks was generated from literature as the plant is in its starting up phase, and a reliable estimate of technical performance could not be obtained. To insure that technical performance is not overestimated, values for yield were corrected by 80% due to the plant's short retention time. The investment costs accounted for include land value, which, in the given situation, is treated as agricultural land as opposed to an industrial segment. The average price for an industrial segment is more than six times the average price for agricultural land [23]. The lower price of land overestimates the economic performance relative to when the land is treated as an industrial segment. Because there is not much long-term experience using digesters in Netherlands, the project life is uncertain. However given its size and design, it is assumed that a well-designed and maintained digester will have a project life of 20 years.

The implementation of this environmentally friendly technique depends widely on a political framework that creates and provides an economically attractive incentive for running AD plants. Dutch renewables policy has been widely criticized for having been too unstable to provide sufficient incentives for investments in renewable energy technologies [24]. The uncertainty in receiving subsidies makes a highly cost-efficient system important. Our recommendations for biogas plants to be profitable without a subsidy is to look for alternative revenues, for instance, from digestate and heat or savings in feedstock costs by making a contract with arable farms to supply them with RO concentrate in return for less expensive energy crops. At the moment, however, we can conclude that, given the uncertainty of RO treatment regulations and the currently low values of digestate and heat, high investment and operating costs limit the feasibility of AD of wastes of farm origin and other co-substrates unless subsidies are provided.

Analysis based on an LP model yields useful insights into the relative performance of a biogas plant and demonstrates the implications of two distinct selling options in relation to RO concentrate. However, our study can further be extended to incorporate and address uncertainties associated with estimating methane yields, subsidies, and price of digestates.

Acknowledgement

This study was funded by the Agricultural Economics Research Institute (LEI).*Role of funding source:* The agricultural economics research institute (LEI) had an involvement in the study by setting the objectives of the study but did not take part in data collection and writing of the report. LEI was involved in the decision to submit the paper for publication.

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