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Costs of Producing Biogas at Dairy Farms in The Netherlands

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ABSTRACT

By 2020, Dutch dairy chains envisage to be self-sufficient with regard to energy used by dairy farms and dairy processors. This would require dairy farms to produce 25 PJ per year, possibly by a combination of wind, solar and biogas. This paper focuses on biogas. To evaluate the project's viability we estimated the expected technical and financial performance of 4 types of business models, i.e. "CHP-farm", "CHP-large", "green gas" and "central upgrading of green gas". Data stem from among others 23 biogas plants in the Netherlands. Anticipating that CHP-models and green gas models occur with a likelihood of 40% and 60% respectively, the total number of biogas plants would amount to 232 (1% of dairy farms), including a total of 5 million tons of manure per year (14% of all cattle manure in the Netherlands) and annual government subsidies of Euro 295 million. Aggregated annual profits are expected to be positive, but over the project's total life time there is an expected deficit of Euro 262. For this to change costs of feedstocks or digestate disposal costs would for instance have to go down. Also fully switching to green gas models dampens the deficit. Results are used in current stakeholders debates on the organization of an "energy neutral dairy chain" in the Netherlands. Further analyses incorporating uncertainty around key technical and economic parameters including financial impacts of CO_2-reductions are underway.

Keywords: *green electricity, green gas, empirical data, technical performance, financial performance*

1 Introduction

Anaerobic digestion of organic wastes and by-products from agriculture and the food industry is a process known for many years and is widely used for waste stabilization, pollution control, improvement of manure quality and biogas production (Weiland, 2006). Biogas production from manure contributes to climate protection by reducing emissions of CO_2 via substitution of fossil fuels and by reducing CH4 emissions from the manure during storage (Moller et al., 2007). It is expected that biogas production will be instrumental in reaching European goals in the field of renewable energy. Due to the simultaneous advantages of avoiding greenhouse gas emissions and producing energy (Sommer et al., 2004) as well as reducing odor emissions (Hansen et al., 2006), there has been a rapid development in the use of biogas in recent years (Weiland, 2006).

In the EU, where only about 5% of the gross consumption is made up of renewables, which is lower than observed in other parts of the world, the share of renewables is expected to double by 2010, and the share of biogas, as part of it, is expected to rise to 12% (Nielsen, Al Seadi, 2006). The Dutch government, in its white paper on energy calls for a simultaneous approach of continuous energy savings, a 30% improvement of efficiency by 2020 and a 20% share of renewable energy in 2020 (Kwant, 2003). In the Netherlands, the potential of energy production from biogas has been estimated to be 49 PJ in 2020 (Nielsen, Al Seadi, 2006).

As part of the “clean and efficient” program, the Dutch dairy chain is aiming to achieve an energy-neutral production. This new initiative, hereafter called as the energy-neutral milk initiative, aims at bringing the whole chain, i.e. from the dairy farm to the factory, ultimately to be self sufficient in energy in 2020. This is envisaged to be achieved by building fermentation units to convert manure and food waste into biogas, which can then be used (directly or indirectly) by local dairy factories. The energy consumption in the dairy chain for milk production and processing is estimated to be 25 PJ per annum excluding energy consumed for feed and artificial fertilizers. Our analyses aim to estimate the aggregated costs of producing this amount of energy at farm level. We herewith consider various business models varying in size and output.

In analyzing the feasibility of biogas plants, a mix of variables is relevant as economic efficiency of anaerobic digestion depends on among others investment costs, the costs of operating the biogas plant and the optimum methane production (Chynoweth, 2004; Walla, Schneeberger, 2005). A maximum methane yield is especially important with the digestion of energy crops as these (in contrast to animal manures or organic wastes) have production costs that have to be covered by the methane production (Walla, Schneeberger, 2009). So far, feasibility studies of biogas plants generally use only a limited amount of practical data, see for instance Georgakakis et al. (2003), Singh and Sooch (2003), Svensson et al. (2005) and Svensson et al. (2006). In our study we use cross-sectional data of 23 farm level biogas plants located in the Netherlands.

2 Review of literature

Biogas produced in anaerobic digestion (AD) plants is primarily composed of methane (CH_4) and carbon dioxide ($C0_2$) with smaller amounts of hydrogen sulphide (H_2S), ammonia (NH_3) and other particles (Persson et al., 2006). A lot of fermentation plants have been built, particularly in Denmark, Germany and Sweden, with capacities varying from 10,000 tons of biomass/year to around 150,000 tons/year. In the Netherlands these plants tend to be capable of processing 2000-4000 tons/year (for a single farm) up to around 36,000 tons/year (Wempe, Dumont, 2008)[1]. Existing plants vary greatly in size and design. The large-scale processing of residual products, for example from the food industry and agricultural sector, also allows biogas to be produced on an industrial scale. Table 1 depicts technical and financial data of farm and large-scale operating biogas plants equipped with combined heat and power (CHP) units from different sources.

Table 1.
Literature review on technical and financial data of CHP units

	Unit	Kool et al. (2005)	Kool et al. (2005)	Koskamp et al. (2000)	Hjort-Gregersen (2006)[6]	Wiese and Kujawski (2008)
Scale	F/L[2]	Farm	Farm	Farm	Large	Farm
Temperature	M/T[3]	M	M	M	M	M
HRT[1]	Days	60-90	60-90	60-90	12-25	>60
Biogas yield	m^3/ton	30[4]	43[5]	15-19[4]	29[7]	120[8]
Methane content	%	63	63	-	60	50
Engine efficiency	%	20	20	-	37	42
Electricity	kwh/m^3 biogas	1.2	1.2	1.2	2.4	2.08[9]
Financial data:						
Investment	Euro/kwh	1.39	-	-	0.65	0.83
Production cost	Euro/kwh	0.023	-	-	0.89	-
Interest	%	5	-	-	5	-
Depreciation	Year	10	-	-	15-20	-

[1]HRT=hydraulic retention time, [2]Farm scale $\leq$ 1MW, large scale = $\geq$ 2MW per year, [3]M = Mesophilic, T= Thermophilic, [4]Manure only, [5]Manure and maize, [6]Equipped with reversed osmosis separation system, [7]Manure to organic waste: 70:30, [8]Manure to energy crops:35:65, [9]Benchmark values 1.4-2.4 (Hesse, 2006).

To date, almost all of the biogas produced worldwide is used for electricity and heat production (Borjesson, Mattiasson, 2008). Of the heat produced, around 35% is used to heat the plant itself. The remainder cannot always be used locally and is often released into the air, thus resulting in the energetic return (efficiency) falling from 90% to 65% (Vries, Burgel, 2005). The alternative route with much higher energy utilization efficiency would be converting the biogas into natural gas by means of a suitable biogas

[1] For large plants, i.e. > 36,000 tons/year, environmental impact assessments are required.

upgrading process and to feed the upgraded biogas into the natural gas grid. When the gas is fed to the grid, it has to meet energy standards which usually require 97% methane (Persson et al., 2006). In this paper, this upgraded biogas will be referred to as “green gas”. There are various technologies that can be used for upgrading of biogas into green gas; the most common technologies being the water scrubber technology and the pressure swing adsorption (PSA) technology (Jonsson, 2004). The main step in the upgrading process is the separation of carbon dioxide from the methane gas in order to reach the required Wobbe index or heating value of the gas (Persson et al., 2006). Table 2 shows an overview of technical and financial data of upgrading biogas at varying scales. Data are from feasibility studies; except the study by Dirkse (2007) which reports data from an operating plant in Tilburg, the Netherlands.

Table 2.
Literature review on technical and financial data of upgrading biogas

	Unit	Dirkse (2007)	Hullu et al. (2008)	Stroomer (2008)	De Veth (2008)	Wempe and Dumont (2008)
Scale	F/L[1]	L	F	L	L	L
Technical data:						
Biogas conversion efficiency	%	70	80	62	67	80
Financial data:	Euro/m^3	0.60[2]	0.22[4]	0.38[4]	0.24[4]	0.20[4]
Investment upgrading	Euro/m^3	n.r.	n.r.	0.34	-	n.r.
Investment gas pipe	Euro/m^3	0.14[3]	0.13[3]	0.04[5]	-	0.27[3]
Production cost	Year	15	10	10[6]	12	-
Depreciation						

[1]Farm scale = 1million m^3/year, large scale = 4-5 million m^3/year, [2]Digestion and upgrading plant, [3]Utilities such as electrical power, water, chemicals, excluding cost of feedstock, [4]Upgrading plant only, [5]Electricity cost and maintenance, [6]10 years for upgrading plant and 20 years for gas pipe, n.r. = not reported

3 Materials and methods

3.1 Data collection

Data on selected parameters were gathered from 23 operating biogas plants in the Netherlands. All plants are CHP unit plants. Consolidated results from data acquisition and analysis are shown in Table 3. The amount of substrate processed varies between less than 5,000 ton/year in the smallest installation up to 63,000 ton/year in large plants. Most of the plants (more than 70%) are farm-scale plants with a biomass digestion capacity of up to 36,000 ton/year. Biogas yields range from 70 to 182 m^3/ton. The majority of the digestion is carried out at mesophicilic temperatures with two plants having temperatures greater than 50^{o}C. The lowest electrical efficiency is 31%, while one plant achieves an efficiency of over 40%.

Table 3.
Sample data of biogas plants with CHP units (n = 23)[1]

	Small scale <10,000 ton (n= 4)	Farm scale 10,000-36,000 ton (n=17)	Large scale >36,000 (n=2)
HRT (days)[1]	56	39	41
Biogas yield (m^3/ton)	150	118	98
Methane content of biogas (%)	57	58	57
Electrical efficiency (%)	36	35	36
Investment per kwh (Euro/kwh)	0.49	0.44	0.40
Start-up cost (% of investment)	2	1.6	1.8
Feed to grid (Euro/kwh)	0.00197	0.00150	0.00131
Price of corn (Euro/ton)	27	30	31
Price of grass silage (Euro/ton)	20	23	-
Price of other co-product (Euro/ton)	22.30	19.80	24.95

[1]Median

The majority of the plants uses cattle manure as the main feedstock with a share of 50% of the incoming materials. Three plants operate with fermentation of pig manure and other co-digestion materials. Energy maize and grass silage are the dominant feedstocks used for co-fermentation. Other co-digestion materials include weed, potatoes, vegetables mix, glycerin, solid fraction digestate and expired products from supermarkets. Besides cattle manure some plants also use horse and chicken manure. Investment costs refer to the total of the whole installation inclusive of silos, digester, CHP unit and civil works. All the plants are under the MEP[2] subsidy and the majority started operation in 2006/2007. Data refer to 2008.

3.2 Business models

To produce the 25 PJ energy required by the dairy chain from AD of biomass, possible business models including their likelihood of occurrence were determined in consultation with stakeholders. Stakeholders were from sector and research organizations, industry, financial institutions and government. Key considerations were heat utilization, feedstocks digested and size of plants. Heat produced by biogas plants should be properly utilized to get permits and subsidy. Proper heat utilization is described as avoiding excessive flaring of heat to the air. Table 4 shows the four business models that are deemed to be possible in the future. For each business model, production capacity, required investments and inputs and outputs are outlined. Business models are categorized according to size (farm-scale versus large scale) and output type (electricity versus green gas).

Table 4.
Description of business models[1]

	CHP-farm scale	CHP-large scale	Green gas	Central upgrading
Annual production	≤ 2 MW	2-5 MW	4-5 million m^3	5-6 million m^3
Organization	Existing dairy farm	Stand-alone plant	Stand-alone plant	Two farm-scale biogas and central upgrading
Investments	Digester CHP unit Digestate separation	Digester CHP unit RO separator Dryer	Digester Gas improver Digestate separation	Digester Gas improver Digestate separation
Input	50% manure 50% other (With dairy waste)	50% manure 50% other	50% manure 50% other	50% manure 50% other
Output	Electricity Heat, 40% own use Digestate	Electricity Heat, 40% own use FF RO	Green gas Digestate	Green gas Digestate

[1]CHP = combined heat and power unit; ; FF = fixed fraction ; RO = reverse osmosis.

Farm-scale CHP plants have a production capacity of up to 2 MW of electricity built on an existing dairy farm. The substrate mixture comprises of 50% dairy manure and 50% other co-substrates in all models. The farm-scale CHP model uses dairy processing waste as an input. Large-scale CHP-models have a production capacity of 2-5 MW of electricity. Investments depend on the final output; electricity and heat (CHP unit) or green gas (upgrading). The large-scale CHP model is equipped with a reverse osmosis (RO) separator and dryer to ensure that heat produced by the plant is properly utilized within the plant, i.e. to heat the digester and dry the digestate. In the central upgrading model, two farm-scale digestion plants will deliver biogas to a central upgrading unit which will then upgrade the gas and feed it to the gas grid.

3.3 Financial model and assumptions

Key project variables in the biogas model are investment costs, price of feedstocks, biogas yields, subsidy levels of electricity and green gas and disposal costs of digestate. Table 5 lists the variables along with their unit of measurement and source. Variables for which sample data could not be used are modeled based on literature and expert opinion. This is for instance the case for investment costs of green gas upgrading equipments. Historical energy maize prices were obtained from LEI (2008). For grass silage and other products, data from the operating biogas plants are used to define relevant values. With regard to energy prices, the new SDE[3] level for electricity and green gas of Euro 15.2 ct/kwh and Euro 58.30 ct/m3

[2] 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.
[3] SDE is a follow-up to the former MEP scheme which subsidizes the exploitation of new sustainable energy projects, i.e. production of renewable gas and electricity for a maximum of 12 years.

respectively are assumed. SDE amounts include the base price of Euro 4.4 ct/kwh and Euro 14.7 ct/m3 for electricity and green gas respectively (VROM, 2009). RO concentrate (CHP-large) is considered as animal manure with a disposal cost of Euro 8/ton while the dried fraction (80% dry matter) is disposed of at no cost.

Table 5.
Parameterization of business models

	Unit	Source[1]	Parameterization per business model			
			CHP-farm	CHP-Large	Green gas	Central upgrading
Biogas yield	m^3/ton	Data	118	118	118	118
Biogas to electricity conversion	kwh/m^3	Data	2.05	2.05	-	-
Biogas to heat conversion	kwh/m^3	Data	2.28	2.28	-	-
Upgrading efficiency	%	(a,b)			0.70	0.70
Digestate unprocessed (% of incoming feedstocks)	%	Data	80	80	80	80
Wet fraction (% digestate)	%	Data; (b)	85	65	85	85
Thick fraction 30% dry matter (% digestate)	%	(b)	15	15	15	15
Dried fraction 80% dry matter (% of thick fraction)	%	(b)	37	37	-	-
Reverse osmosis (% digestate)	%	(c)	-	20	-	-
Investment CHP unit (digester, CHP, separator)	Euro/kwh	Data	0.45	0.40		
Investment green gas (digester, upgrading, separator)	Euro/m^3 green gas	(a,b,d)	-	-	0.60	-
Investment biogas plant (digester and separator only)	Euro/m^3 biogas	(a,b)	-	-	-	0.42
Investment central upgrading (upgrading only)	Euro/m^3 green gas	(a,b,d)	-	-	-	0.22
RO separator and dryer	Euro million	(c)	-	1.5	-	-
Start-up	% investment	Data	1.6	1.8	1.8	1.8
Energy maize price	Euro/ton	(e)	28	28	28	28
Grass silage	Euro/ton	Data	20	20	20	20
Other co-products	Euro/ton	Data	25	25	25	25
Gas upgrading running cost	Euro/m^3	(a,d)	-	-	0.14	0.14
Wet fraction disposal cost	Euro/ton	(b)	10	10	10	10
Thick fraction disposal cost	Euro/ton	(b)	17.50	17.50	17.50	17.50
Dried fraction disposal cost	Euro/ton	(b, c)	0	0	0	0
RO disposal cost	Euro/ton	(c)	-	8	-	-
Electricity price	Euro/kwh	(f)	0.152	0.152	-	-
Green gas price	Euro/m^3	(f)	-	-	0.583	0.583
Gate fee dairy waste	Euroton	(g)	38	-	-	-

[1]"Data" as outlined in Table 3. Other sources: (a) = Dirkse, 2007; (b) = De Veth, 2008; (c) = Gebrezgabher et al., 2009; (d) = Hullu et al., 2008; (e) = LEI, 2008; (f) = VROM, 2009; (g) = personal communication dairy processing company.

When modeling the technical and financial performance of the various business models, a number of assumptions was made. The plants operate with fermentation of cattle manure, energy maize, grass silage and other co-digestion materials (including dairy waste in the case of CHP farm-scale) with a share of 50%, 15%, 10% and 25% of the total incoming materials respectively. This substrate composition is comparable to the 23 operating biogas plants. With fermentation taking place at mesophilic temperatures average biogas yields are estimated to be 118 m^3/ton of feedstock. Digestate is partly (50%) applied on own land in the farm-scale model and the rest is delivered to other farms. Furthermore, we assume that 40% of the heat is used within the plant to heat the digester and dry the digestate; the rest is lost to the air. In addition, it is assumed that plants will be able to use the existing public net (so deliver indirectly to dairy processors). Of the total electricity and green gas produced, 10% is used within the plant while the rest is fed to the grid.

3.4 Scenarios for upgrading to 25 PJ per year

In the *default scenario* all parameters are as described in the previous section. Also, it is assumed that, to produce the 25 PJ of energy required by the dairy chain, a large portion (60%) is produced by green gas models and the remaining 40% by CHP models with CHP-farm and CHP-large each having a share of 30% and 10% respectively. This assumption is deemed to be plausible as the prospects of an upgrading plant are better compared to a CHP unit, because of its potential to avoid excessive loss of heat to air and the new relatively high subsidies for green gas. The *RO as green fertilizer scenario* assumes that in the CHP-large model the RO is treated as green fertilizer replacing artificial fertilizers and a market price of Euro 5/ton excluding costs of transport. In the *higher subsidy scenario* it is assumed that prices of green electricity increase to Euro 17.7 ct/kwh while for green gas rates stay the same. Higher prices for electricity are possible in case of a better utilization of the heat. The *green gas only scenario* assumes that all the energy will be produced from green gas only as the prospects of green gas are promising in terms of energy efficiency and relatively higher subsidies. The likelihood of the business models in this scenario is 50% for the green gas model and 50% for the central upgrading model.

4 Results

4.1 Technical results

Technical results (Table 6) are presented in terms of the estimated total tons of feedstocks digested, electricity, heat, green gas and digestate produced. Given the estimated average biogas yield and conversion efficiencies as outlined in Table 5, the CHP farm-scale model requires 36,000 tons of feedstock while the large-scale models require about 64,000 tons of feedstock to produce the required amount of energy. The mixture of substrates will yield 8.70 million kwh (around 1.12 MW assuming 7800 operating hours per year) in the farm-scale model and 15.26 million kwh (around 2 MW) in the large-scale CHP. In the green gas models, yields are 4.5 million m^3 and 5.35 million m^3 of green gas.

Table 6.
Technical results per business model

	CHP-farm	CHP-Large	Green gas	Central upgrading
Total feedstock (ton/year)	36,000	64,489	54,479	64,800
Electricity (million kwh /year)	8.70	15.60	-	
Green gas (million m3/year)	-	-	4.50	5.35
Heat (million kwh/year)	9.69	17.35	0	0
Digestate-unprocessed (1000 ton/year)	28.8	51.60	43.60	51.84
Wet fraction (1000 ton/year)	24.48	33.50	37.05	44.06
Thick fraction (1000 ton/year)	4.32	7.74	6.54	7.78
Dried fraction (1000 ton/year)	1.60	2.86		
RO (1000 ton/year)		10.32		

4.2 Financial results

The financial results of each business model are summarized in Table 7. Investment figures show that investments are estimated to be highest for the CHP-large plant (Euro 7.7 million) and lowest for the green gas plant (Euro 2.7 million). Estimated revenues and costs are highest in case of the central upgrading: Euro 3.1 million and Euro 2.85 million respectively. Expected operating profits are positive for 2 business models, i.e. green gas and central upgrading. For the CHP plants, expected revenues are not sufficient to recover expected costs. When calculating the net present value with time horizons between 15 and 20 years, values for both CHP-models become negative. Clearly, the higher efficiency of green gas models (no heat loss) and the—related—relatively high levels of subsidy for the amount of green gas produced make these models more attractive.

Table 7.
Financial results per business model (Euro 1000)

	CHP-farm	CHP-large	Green gas	Central upgrading
Investment				
Digester, CHP unit &digestate separation	3,920	6,240	-	-
Large scale upgrading[1]	-	-	2,700	-
Biogas plant[2]	-	-	-	2,250
Central upgrading	-	-	-	1,200
RO separator and dryer	-	1,500	-	
Total investment	**3,920**	**7,740**	**2,700**	**3,450**
Revenues				
Electricity	1,191	2,134	-	-
Green gas	-	-	2,623	3,120
Heat	-	-	-	-
Gate fees	137	-	-	-
Total revenues	**1,328**	**2,134**	**2,623**	**3,120**
Costs				
Start up	63	112	49	61
Energy maize	208	372	312	377
Grass silage	76	136	114	138
Other co-products	143	425	356	431
Labor	78	140	140	140
Operating & maintenance CHP	131	234	-	-
Operating & maintenance upgrading	-	-	180	214
Gas upgrading running cost	-	-	630	749
Feed to grid	13	23	11	12
Wet fraction disposal	130	-	190	230
Thick fraction disposal	88	-	114	136
Dried fraction (80% dry matter)	-	0	-	-
RO disposal	-	82	-	-
Water disposal	-	33	-	-
Depreciation	261	387	135	248
Interest	216	425	149	188
Total cost	**1,407**	**2,369**	**2,380**	**2,847**
Operating profit	-78	-235	243	273
NPV[3]	**-1,921**	**-5,085**	**807**	**721**

[1]Including digester and digestate separation, [2]Two farm scale biogas plants deliver raw biogas to central upgrading. Investment includes digester and digestate separation unit, [3]Discount rate of 10% discounted over 15 years for CHP-farm, 20 years for CHP-large and Green gas. For Central upgrading, 15 years for the biogas plants and 20 years for the upgrading plant.

4.3 Aggregated results for upgrading to 25 PJ

As the ultimate “energy goal” of the dairy chain is to produce 25 PJ per year, we also estimated the total number of business models that needs to be in operation to achieve this, including the expected annual profitability and the economic viability over the plants’ life time (Table 8). In the default scenario, in which we assume, based on the stakeholder opinions, that the CHP-farm, CHP-large, green gas and central upgrading models occur with probabilities of 30%, 10%, 35% and 25% respectively, a total of 216 models would be needed to produce the energy required. In terms of number of plants this would be 232, as central upgrading models consist of 2 farm-level biogas plants. This amounts to about 1% of dairy farms in the Netherlands. Considering 50% of feedstocks to be cattle manure, the total amount of manure needed sums up to 5 million tons, which is about 14% of the total amount of cattle manure produced in the Netherlands.

Total SDE subsidies involved would be Euro 295 million per year (number of business models x energy produced x subsidy per kwh and m^3). Yet, despite a positive profitability on an annual basis (Euro 7 million at the aggregate level) we expect a deficit of Euro 262 million over the project’s total lifetime. So, more subsidy would be needed, or, alternatively, input costs or digestate disposal costs would for instance have to decrease. Getting RO accepted as green fertilizer in the CHP-large model (accounting for 10% in the total share) does not contribute much—in terms of the financial viability of the aggregate picture. However, if subsidies in the CHP-models, i.e. subsidies for green electricity, would increase to the upper level indicated in the policy paper, the whole picture is expected to change, i.e. into positive figures both for profitability (Euro 44 million per year) and net present value (Euro 7 million). In practice however this would require higher heat usage which would likely also involve additional investments. If the 25 PJ would be produced by green gas models only, the number of business models is reduced to 135 (with the number of plants reducing to 166) due to the higher efficiency of green gas plants. Also, the financial viability would further improve.

Table 8.
Number of business models and aggregated financial results for default and alternative scenarios when upscaling to 25 PJ per year

	Number of business models to produce 25 PJ/year[1,2]	Aggregated operating profit (million euro)	Aggregated NPV (million euro)[3]
Default	216 (232)	7	-262
RO accepted as green fertilizer[4]	216 (232)	8	-256
Higher subsidy for electricity[5]	216 (232)	44	7
Green gas only	135 (166)	35	104

[1]Likelihood of business models is 30%, 10%, 35% and 25% for CHP-farm, CHP-large, green gas and central upgrading respectively under default, RO as green fertilizer and higher subsidy for electricity scenarios. Under the green gas only scenario, the likelihood of business models is 50:50 for the green gas and central upgrading models, [2]Number of plants is between brackets (numbers deviate from number of business models because the model of central upgrading consists of 2 biogas plants), [3]Discount rate of 10% discounted over 15 years for CHP-farm, 20 years for CHP-large and Green gas. For Central upgrading, 15 years for the biogas plants and 20 years for the upgrading plant, [4]RO is treated as green fertilizer with market price of Euro 5/ton, excluding transport. [5]Subsidy for electricity increases from Euro 15.12 ct/kwh to Euro 17.7 ct/kwh.

5 Conclusions and discussion

This paper presents a profitability analysis of the energy-neutral milk initiative by the dairy sector in the Netherlands. In order to produce the aggregated amount of 25 PJ of energy per year, relevant input/output coefficients, investment costs and operational revenues and costs were determined for 4 business models. From the findings, the following conclusions can be drawn:

1) In the default scenario the production of 25 PJ of energy resulted in an expected operating profit of Euro 7 million and an expected NPV of minus Euro 262 million. Although the project resulted in a mean positive operating profit, the profits were not high enough to cover the investment cost (negative NPV). The high operating profit (Euro 35 million) and NPV (Euro 104 million) under the "green gas only scenario" are attributed to the high efficiency of upgrading gas as compared to CHP units and the current relatively high subsidy levels per m3 of green gas.

2) Key issues for determining the economic viability of the project can be looked at from an input, process and output perspective. From an input and process side, investment costs, biogas yield and price of co-digestion materials are important determinants of economic success. Higher biogas yields are particularly essential as the costs of co-digestion materials (production cost) have to be covered by these yields. Subsidy levels and the price of digestates (including RO) are important output related factors contributing to financial viability.

Analyses also bring forward a number of discussion points:

1) Various data sources were utilized to estimate the input and output coefficients. Technical and economic data from 23 operating biogas plants were used to estimate biogas yields, engine efficiencies and the required investments related to CHP units. However, since the majority of these plants are in a starting-up phase, we only used data of one year (cross-sectional) to estimate our parameters. Parameters related to upgrading gas mostly came from literature and expert opinions. If more data become available the model can be updated.

2) The current study is set up in a deterministic way. Empirical data however indicate that substantial variation exists on a number of parameters, such as with respect to start-up costs and biogas yields per ton of input. To account for this variation, further analyses are underway to incorporate risk in order to provide dairy chain decision makers not only with expected values but also with the more optimistic and pessimistic situations.

3) Economic results of the CHP-large model suggest that the model is not economically viable. However, a previous case study of Biogreen (Gebrezgabher et al., 2009) found a positive NPV for a large CHP unit equipped with an RO installation when RO is treated as green fertilizer. The positive result obtained in the case study as opposed to the current study is due to higher gate fees for pig manure, flower bulbs and poultry manure, received by the plant. In the current study it is assumed that no gate fees are received for dairy manure or other co-products. This suggests that analyses of biogas plants are relatively case-specific, which is a further plea to incorporate risk in evaluating the viability of large-scale projects such as envisaged by Dutch dairy chains.

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