The scale of transition: An integrated study of the performance of CHP biomass plants in the Netherlands*

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Abstract

Combined heat and power plants using biomass are considered important as to substantially increase the share of renewables in the total energy supply and meet ambitious climate targets. The analysis focuses on the links between the size of bio-fuelled CHP plants and their techno-economic and environmental performance, as well as social acceptance. In an exploratory way, this paper compares the performance of six bioenergy plants in the Netherlands in these three key areas, thereby focusing on the link between the size of biomass plants and overall performance in an integrated multi-dimensional manner. The findings show that economic and environmental performance does not necessarily improve with scale and, in effect, several large-scale biomass plants score low in several environmental indicators. In addition, we find that there is often limited data availability on economic, environmental and social characteristics of biomass plants in the Netherlands, despite the fact that their operations are largely supported by public funds.

Keywords: Biomass, environmental performance, cost-efficiency, social acceptance, scale.

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1. Introduction

Our understanding of the deployment of energy production technologies to minimise negative local impacts, while maximizing energy benefits, is usually incomplete and inconsistent (Howard et al. 2013). Due to commercial reasons (e.g. related to property rights protection) the available technical operational data are often limited (Dong et al. 2009, Howard et al. 2013). Hence, policies designed for supporting renewable energy options are only to a certain extent based on knowledge and experience of options´ effectiveness. In large part, policies underlie assumptions that are not so much related to (scientific) evidence but to a dominant discourse that shapes and (co)produces policy and research agendas.

Bioenergy is a proven technology that holds significant potential for the future, but the current value chain is immature and investments are not taking place at the expected pace (European Climate Foundation et al. 2010). Expected economic performance is a key factor behind decisions to invest in biomass energy plants (Amigun & Blottnitz 2010). The literature provides an ambiguous picture on the relationship between the size and economic performance of biomass power plants. Many studies into the economics of biomass energy (e.g. Caputo et al. 2005; Dornburg & Faaij 2001, Wood & Rowley 2011) focus on systems analysis and modeling and very few studies are based on empirical data (e.g. Evald & Witt 2006). Dornburg & Faaij (2001) find that the specific investment cost (i.e. set-up infrastructure cost) per kilowatt-thermal (kWth) decreases as the scale of production grows, although there is a threshold point above which the relationship becomes flat. However, authors not only associate this finding to economies of scale but also to the lower-grade fuel type typically used in smaller plants, which drives up the cost per megawatt (MW) of energy generated (ARUP 2011). Other findings (Amigun & Blottnitz 2010) suggest the presence of diseconomies of scale for biogas systems - the larger the scale, the higher the transportation and heat distribution costs and, furthermore, the harder it becomes to achieve high heat utilisation rates. Kumar et al. (2003) find a rather constant relationship between costs per unit of energy produced and plant capacity, given that any reductions in specific investment costs per unit of energy capacity are offset by the cost of additional fuel transportation.

Apart from the economic dimension, the performance of biomass energy plants is often assessed against a range of environmental indicators (e.g. airborne emissions, CO_2 emission savings), as well as its acceptance among people living in its vicinity. Large plants may result in higher primary energy savings per unit of biomass energy used (Dornburg & Faaij 2001). Furthermore, operating at industrial sites, they may face less public opposition as compared to small-scale biomass installations that are often in close vicinity to residential areas and may provoke a so-called Not-In-My-BackYard (NIMBY) response. However, scientific literature does not provide convincing evidence in support of these claims.

Any adherence to assumptions related to benefits of a particular scale may hinder the transition to economically, environmentally and socially sustainable energy systems and therefore need to be empirically addressed (e.g. Hisschemöller et al. 2006; Hisschemöller and Bode 2011; Kemp et al. 1998). Studies usually focus on either the techno-economic performance of bio-fuelled plants (Dornburg & Faaij 2001; Rodrigues, Faaij & Walter 2003), the environmental impacts of bioenergy (Bird et al. 2011) or the opposition to biomass projects (Upretti 2004; Upretti & Horst 2004; Upham & Shackley 2006). This literature is rather fragmented in how performance is assessed. Instead, the aim of this paper is to explore the relationship between size of bio-fuelled CHP plants and overall performance in an integrated multi-dimensional manner by looking both at techno-economic, environmental performance, as well as social acceptance. To what extent does scale affect the techno-economic, environmental and social aspects of a bio-CHP plant and to what degree can scale provide an explanation to the difference in performance on these three pillars of sustainability for bio-fuelled CHP plants? With the use of 6 case studies, this research provides a comparative assessment of biomass-fuelled CHP plants in the Netherlands.

The exploratory nature of our study justifies the selection of cases featuring different technologies and ownership structures.[1] This enables us to take into consideration a multitude of variables, yet we are aware that it makes it more difficult to generalise our results. Nonetheless, generalisation from a case study should not be expected to lead to statistical but rather to analytic generalisation (Yin 2012).

Section 2 provides background information and discusses the selection of the cases. Section 3 discusses methodological aspects. Section 4 presents the study results with respect to the techno-economic, environmental performance and public acceptance of biomass power plants of different scale. Section 5 discusses the significance of the results and Section 6 concludes.

2. Case study selection

Six biomass CHP plants were selected for comparative analysis (see Table 1).

- Figure 1 -

First, we selected six biomass power plants of different scale. With scale being defined as the electrical capacity of a plant, the installations selected varied in capacity between 340 and 120,000 kWe. Second, the study aimed at including cases that jointly cover a wide range of biomass sources and related technologies. Our sample includes clean biomass combustion plants as well as a waste-to-energy (WtE) installation and a digestion unit for manure. According to US EPA “clean biomass is

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[1] We are indebted to Pauline Westendorp, an expert in decentralized renewable energy initiatives in the Netherlands, for assisting us in the selection of biomass energy projects.

biomass that does not contain contaminants at concentrations not normally associated with virgin biomass materials" (US EPA 2014). Third, the study aimed at including case studies of different ownership structures, since the literature suggests this being a key factor for public acceptance (Musall & Kuik, 2011). Our sample consists of privately owned projects with the exception of the publicly owned AEB (Afval Energie Bedrijf) plant in Amsterdam. Unfortunately, at the time of research, there was no case of a community-owned installation available in the Netherlands. The main characteristics of the 6 identified biomass power plants are summarised below.

- Table 1 -

(1) Lelystad – Incineration plant

The Lelystad biomass-fuelled CHP plant, commissioned in 2000, was the first dedicated biomass installation by energy company Nuon. The company wanted to gain experience in the use of biomass for electricity and heat production – the Lelystad incineration plant replaced initial plans for an expansion of an existing gas fired installation. Wood chips obtained from the Flevoland forests and from pruning activities in local municipalities are incinerated for the production of energy. The size of the plant matches well the heat demand of the nearby city districts; it supplies heat to the district-heating system, that serves 6,000 customers, and the electricity produced is fed into the grid.

(2) Sittard

This plant was initiated as a private venture named Biomassa Energiecentrale Sittard (BES). The plant, in operation since 2005, uses green waste that includes resources from landscape maintenance provided by the Sittard municipality, the local park department, as well as other raw materials supplied by the locals and residues from composting units. The installation provides electricity to the grid equal to the needs of 3,000 households and makes use of Organic Rankine Cycle (ORC) technology. The major part of the heat produced is distributed via the energy company Essent to the local district-heating network of Hoogveld (approximately 1,100 dwellings, a school, an elderly care center and a business complex). At the moment of the research, a significant amount of heat was wasted due to lack of demand. However, the company aims at a broader network called "Green Net" (a public-private partnership across municipalities for the implementation of district heating), which would use all the heat produced. In May 2007 the biomass plant in Sittard was significantly damaged due to an explosion and the fire that followed during its operation.

(3) Cuijk

The plant started its operation in 1999 and was the first large-scale stand-alone biomass plant of energy company Essent. In 2009, the plant ceased its operation, since the termination of government subsidy made it unprofitable. During its operation the electricity produced was sufficient for the needs of 60,000 households but heat distribution to surrounding businesses was not considered economically feasible. The feedstock consisted of industrial and forest wood-chips, pruning from forests and from municipal public gardens, waste from the wood industry, as well as residue materials from a neighbour company. A multiple fuel strategy was chosen in order to avoid dependence on the annual variation of supply. Recently it received a new government grant and restarted its heat and power production.

(4) Lelystad – fermentation plant

Built in 1996, the plant was the first digester of its kind in the Netherlands among the first in the world. A group of municipalities in Flevoland, envisioning a sustainable treatment of waste, decided in 1992 to put the processing of their organic waste on a competitive tender. Orgaworld won the tender. It offered ‘biocel fermentation’ of organic residues and conversion into biogas, heat and compost by means of micro-organisms in an anaerobic environment. Orgaworld uses organic waste from households, restaurants and supermarkets in the area, as well as industrial waste and municipal wastewater, for the production of both energy and agricultural inputs. The produced heat is used for process heating and the amount of electricity that is fed into the grid rises to 660,000 kWh (about 200,000 households). Under the prevailing regulations, waste transport was allowed only within the barriers of the province and each region had to manage its own waste. Therefore, the scale of the plant was constrained to the demand of the municipalities of the province of Flevoland.

(5) Zeewolde

In 2002, Zeewolde municipality started developing a new residential area with a district-heating network. The project proposed by Essent Local Energy Solutions (a subsidiary of Essent) won the tender offering cogeneration of heat and power from biogas from the manure of a local dairy farm. A digester and two CHP units were built (one on the farm and one in the residential area) as well as a 5.6 km pipeline transferring the biogas. The CHP units are currently owned by the farmer, who sells the electricity to the market and the heat to Essent. Essent owns the district-heating network, which currently caters for approximately 1,000 households.

(6) Amsterdam

Waste to Energy Amsterdam (AEB) generates electricity and heat by the incineration of municipal solid waste (MSW). The publicly owned company has grown out of the former Amsterdam City Sanitation Division; its first WtE plant began its operation in 1919, with a capacity of 150.000 tonnes per year. Currently AEB operates one of the world´s largest WtE plants. Amsterdam’s MSW is biomass-based and, hence, biodegradable at a percentage of 51%. The electricity produced is equivalent to the needs of 285,000 households − the heat generated during the incineration provides over 200,000 households with heating and hot water. Currently, around 15,000 units, including houses, industrial installations and offices in Western Amsterdam have been connected to the network. Additionally, heat and electricity is produced by biogas from the municipal waste water treatment plant. Between the two plants a synergy exists: the WtE plant provides electricity and heat to the water sewage plant and, in return, the sewage plant digests sewage sludge and provides biogas back to the WtE plant for the production of additional electricity and heat.

3. Methodology

To address the main research question, we make use of a case study methodology combining a qualitative and a quantitative approach. First, data obtained from the literature as well as from in-depth interviews with plant managers were used to produce figures with respect to the economic viability of the projects and their environmental impacts. During the interviews the managers were asked to substantiate their arguments providing any publically available archival records. These data in large part constitute the input for the quantitative analysis, which focused on calculating the corresponding monetary costs, benefits and environmental impacts of the plants. Second, the interviews with the plant managers aimed to shed light on the current discourse on the enabling environment for CHP-related biomass projects in the Netherlands. In this respect, we asked about the managers´ motivation for the plant construction. Part of the interviews dealt with public acceptance. Furthermore, we included a round of explorative interviews with end-users of one of the plants (in Sittard). We purposively conducted interviews for that particular plant, given the large number of expressed complaints by end-users about the site (as confirmed by the Sittard plant manager).

To allow for a meaningful comparison we divided the sample into two groups based on the type of biomass used. The first group (C1, C2 and C3) consists of Dutch biomass installations that make use of clean biomass where the technology used is comparable. The second group (C4, C5 and C6) utilises a range of different energy inputs (i.e. organic waste, manure and MSW), which differ significantly in calorific value and technology required for energy generation. The feedstock variability may influence the economic, environmental, or social performance of a plant. Within each of the subgroups we rank installations according to size. This allows us to ‘isolate’ more accurately the effect of scale on performance, particularly when we concentrate attention to the more homogenous group of the first three installations (for which feedstock and technology variability is smaller).

3.1. Techno-economic performance

Techno-economic performance has been assessed with multiple indicators focusing on the *investment set-up cost* of the plant, its overall *cost-effectiveness, payback period* and *return on investment* (ROI).

Regarding the specific investment (set-up infrastructure) cost of plants built in different time periods; we adjusted all past monetary costs to present values for the sake of comparison. Naturally the present value calculations are sensitive to the interest rate chosen. In order to avoid overinflating the magnitude of investment costs of the earlier-built power plans, we opted for a more modest rate of investment (3%) compared to the one suggested by the U.S. Office of Management and Budget (7%) for private investments (although using a 7% interest rate does not alter the relative ranking).

With respect to the cost-effectiveness of the plants, managers were asked about the production cost per kWh generated and the payback period of their investment (based on average annual cashflows). Plant managers were also asked about the energy efficiency (and the associated power to heat ratio), which relates to the economic and environmental performance of their installations. The energy efficiency corresponds to the ratio of the generator's electricity supply to the enthalpy input of the feedstock in use.

3.2 Environmental performance

Bioenergy provides multiple environmental benefits, with the most fundamental being the *reduction in greenhouse gas* (GHG) emissions in comparison with the reference fossil fuel based energy system. Environmental performance is likely to depend not only on scale but also on the type of feedstock used for power generation (this is discussed in more detail in Section 4). The study looks into (a) the level of the *lifecycle* CO_2 *reduction*, as well as other *airborne emissions* generated from the combustion of biomass, namely the levels of (b) nitrogen oxides (NO_x), (c) sulfur dioxide (SO_2), (d) carbon monoxide (CO), and (e) particular matter.

The managers were asked to substantiate their answers providing supporting documentation (although the majority of managers only provided information verbally)[2]. Results need to be interpreted with caution. First, companies adopt different ways of calculating the CO_2 emission savings that their plants generate. This mainly relates to the transport emissions. Therefore, emission measurements have been complemented with data on the number of trucks of feedstock per day (as a proxy for transport-related emissions)[3].

Where data on the plants were missing, especially with respect to airborne emissions, data from literature sources were used in so far available. For Cuijk (C3) the emission savings were calculated based on data from Weisser (2006) and Zhang et al. (2010)[4]. For Zeewolde (C5) data from literature sources was used for the non-CO_2 airborne emissions (Borjesson & Berglund 2006).

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[2] An independent observer from Nature and Environment Federation was consulted to confirm the validity of the information provided by managers with respect to the environmental and social aspects of their plants.

[3] We realise that also the proxy needs to be interpreted with caution given that the average distance travelled per truck also matters and might vary across the six biomass plants.

[4] Based on Lifecycle assessment, net carbon emissions savings per unit of electricity for bioenergy rise to about ¾ of the emissions from gas-fired power plant.

3.3. Social acceptance

Both plant managers and end-users were approached to comment on issues related to the social acceptance of the installations. The managers were asked about how they perceive the *public acceptance* of their plants, about the *involvement* of the end-users and their perceptions of environmental impacts. These questions were guided by two considerations. First, public involvement is often limited in energy projects in the Netherlands and biomass projects are sometimes confronted with public opposition because of negative externalities (pollution, noise, and smell) associated with the plant –it should be noted that the issue of noise and smell is discussed in this section, precisely because it is often one of the primary reasons behind public opposition to power plants. Second, the success of energy projects is often determined by a good relationship between the project and its social environment, especially when benefits from the project become visible to people living in its vicinity (Musall & Kuik 2011). Explorative interviews were carried out with 21 end-users living in the vicinity of the Sittard plant (C2), given the numerous complaints that had been raised for this particular site. These interviews do not allow for general conclusions. Yet, they are relevant in that they show contrasting opinions at the two ends of the supply chain.

4. Study findings

4.1. Techno-economic performance

Energy efficiency

The key results for the energy efficiency indicators are summarised in Table 1 (section 2). Of all plants, Lelystad Incineration (C1) was found to have the highest energy efficiency. Amongst the clean biomass plants, Cuijk (C3) has the lowest efficiency, which during its former operation had only been used for power generation. With the exception of Cuijk (C3) –where there was zero heat utilisation– and Amsterdam (C6) –where relatively small amount of the heat was used– the overall amount of heat provided is larger than the amount of electricity.

Economic performance

The economic performance of the 6 biomass projects is summarised in Table 2.

- Table 2 -

Zeewolde (C5) was found to have the lowest investment (set-up) cost. Because of missing data, its most recent expansion with a second CHP unit and digester was not included in the analysis. Lack of data for Amsterdam (C6) also constrained us to only take into consideration the last set-up investment (2007).

For a meaningful comparison Table 3 presents data on the specific investment cost per kW produced for those plants that use the same type of technology and feedstock (incineration of clean biomass). Specific Investment Cost per kW is given by the ratio between the investment cost and the total capacity of the projects (see Table 2).

- Table 3 -

Based on the fact that the *Specific Investment Cost* depends on the total capacity of a plant and that Cuijk (C3) did not make use of its thermal capacity since it exclusively operated as a power plant (25,000 kWe), the Cuijk installation has a rather high specific investment cost per kW. If Cuijk made full use of its capacity (100,000 kW), the specific investment cost would have dropped to 730 euros per kW (Cuijk*).

The collected empirical data do not necessarily support the existence of economies of scale, since along with an increase of scale the specific investment cost does not always decrease. For example, for Sittard (C2), the specific investment cost, including the additional repair cost after the accident, appears lower than the specific investment cost of the smaller scale incineration plant in Lelystad (C1) (see Table 2). Yet, given that the plant in Sittard (C2) was built five years later, this can be possibly attributed to the learning curve effect, and not to scaling effects.

For the majority of the plants, the interviewees estimated the payback period for the investment to be 10 years (Table 2). Only for Lelystad incineration (C1) and Amsterdam (C6) the estimated payback period was longer (12 and 25 years respectively). However, the plant in Sittard (C2) currently exhibits a negative ROI, which might suggest a longer payback period as compared to the interviewee´s estimation.

Regarding production costs, there is some evidence of economies of scale. Across the whole sample, Amsterdam (C6) is characterised by both the lowest production cost (between 5 and 6.5 eurocents per kWh), as well as the largest scale of energy production (Table 2). Cuijk (C3) scores also well in terms of cost-efficiency despite the high transportation costs which account for 30% of overall production costs; its production cost is between 8 and 9 eurocents per kWh. Results largely depend on the type of technology and biomass inputs used. Production cost of the incineration plants is found higher than that of the fermentation plants. Across the first category, Sittard (C2), with a marginally higher capacity than Lelystad Incineration (C1), seems to be less cost-effective with a production cost of 25 eurocents per kWh (against 22 eurocents per kWh). This may relate to the plant’s (C2) lower energy efficiency. Concerning the second category, again the bigger plant in Zeewolde (C5) has relatively lower production costs than the small Fermentation plant in Lelystad (C3).

The managers of the two small biomass plants in Lelystad (C1 & C4), although they have higher production costs per kWh compared to larger plants (C3 & C5), reported the highest ROI rates (above 10%). This is likely to be attributed to the high energy efficiency of their installations associated with higher heat utilisation (Table 1). For Case 1, high efficiency can be credited to its high heat utilisation for district-heating purposes. For Case 4 this comes as a result of the large utilisation of heat for internal processes, as well as the sales of by-products (compost). The data, though, need to be interpreted with caution given that these plants do not necessarily have the shortest payback periods in accordance with their higher ROI. This might be due to the fact that ROI reported data (with the exception of Cuijk (C3)) refer to 2012 rather than to the whole period for which the plants are operational.

For Amsterdam (C6) ROI is technically almost zero, despite the fact that its production cost is the lowest. According to the interviewee, the specific pricing policy of the company is not focused on achieving and/or calculating ROI. The plant is owned by the municipality of Amsterdam, which is formally not allowed to make a profit on waste management activity (VNG 2008; Lishchenko 2013).

4.2. Environmental performance

As shown in table 4, the plants use a variety of feedstock types. For the plants in the first group the managers mentioned that the feedstock either derives from local green biomass sources (municipal parks, forests, local green waste) or, as in the case of the plant in Cuijk (C3), the feedstock imported was certified as sustainable biomass. The plants in the second category use waste sources as feedstock, varying from organic green waste to manure or MSW.

Surprisingly, there has been limited access to information on airborne emissions. Most transparent were the small-scale incineration plant in Lelystad (C1), the WtE plant in Amsterdam (C6) followed by the large-scale plant in Cuijk (C3).

- Table 4 -

Overall, the bigger plants provide greater carbon emissions savings. However, when carbon emissions are expressed per MWh produced the picture becomes less clear, with size and type of feedstock co-determining environmental performance. Emission savings per MWh are typically higher for those that rely on MSW, manure or green-waste. Amsterdam (C6) marks the highest ratio of carbon emission reduction per MWh and this can be attributed to its energy efficiency. It should be noted that the information provided does not account for the whole lifecycle emissions in all examined cases, with the exception of Cuijk (C3) and Amsterdam (C6).

Measurements on CO_2 emissions have been complemented with data on the number of trucks of waste per day as a proxy for the extent of transport-related pollution. With the exception of Lelystad fermentation (C4), which receives about 5 to 6 trucks per day, small-scale plants receive on average 3 trucks per day. Feedstock is transferred from near-by surrounding areas, with an estimated radius of 60 to 70 km. For WtE plants, the radius of transport is significantly wider, with plants receiving waste even from abroad (UK).

The relationship between other airborne emissions and scale is rather complex and depends on the type of feedstock used. Focusing on clean biomass plants dust and the nitrogen oxides emissions are negatively correlated with the scale of production, while the opposite holds for sulfur dioxide emissions. Amsterdam (C6) performs better in all specific emission levels. This is likely to be attributed to its recent construction and state-of-the-art technology adopted. Small-scale plants are allowed by legislation to emit more pollutants at production, given that they have lower levels of transport-related pollutants.

4.3. Social acceptance

Public engagement is known to contribute to the local acceptance of a project (Devine-Wright 2005) and building human capital can lead to the creation of an "enabling environment" (Horst 2008) that is required for the energy transition. Nevertheless for the majority of the biomass-based projects examined, there has been hardly any public participation in the early stages of their development. Generally, local communities do not become involved prior to the final stages of the projects, when electricity and heat is actually distributed. In all cases public involvement has been rather passive and the communication from energy companies has been largely top-down.

The attention given to public engagement has been particularly limited. For instance, the owner of Zeewolde (C5) did not show any interest in involving the local end-users. The same holds for Amsterdam (C6). Lelystad fermentation (C4) organises an annual social event, where it distributes fertilisers for free, but it is not interested in informing the public about energy production and the entire operation of the plant. As an exception, Sittard (C2) organises open-days, when the public is invited to visit the facilities and learn about the plant's operations; yet attendance is often low.

The short interviews with 21 end-users in Sittard (C2) revealed that they felt excluded from the overall process. Yet, this does not necessarily signify support or disapproval of the project in their vicinity. Since they are receiving "renewable heat" from the plant, end-users are quite aware of the plant´s existence in their vicinity. Nonetheless, they have limited knowledge on specific issues related to energy production and environmental side effects, a statement, which is confirmed by the plant managers. They largely acknowledge that biomass-based energy production entails environmental benefits but their conflicting opinions on how scale matters (beneficial vs. negative effect) for the latter reveals that they are still poorly informed about the environmental and technical characteristics of energy plants. These findings are in line with previous findings (Hoogen 2007); scholars frequently refer to the multiple benefits accruing from bioenergy such as reduced environmental impacts, fossil fuel savings and financial gains. (Upreti & Horst 2004; Upham & Shackley 2006) the majority of individuals were found to be primarily concerned with issues that affect them directly, such as noise and smell: scale only becomes a matter of concern when it is linked to these problems. Safety concerns were also raised.

The reasons behind limited public involvement might be both energy-firm and end-user related. End-users, despite their interest into being involved in the plant’s activities, may not be truly willing to invest time in it. From the companies’ perspective, public involvement requires time, effort and additional funds, which the companies may be reluctant to invest. For the managers, social acceptance is strongly associated with the location of the plant rather than the scale of production. Scale nevertheless, can indirectly affect people’s attitude, since small-scale plants are usually located closer to residential areas.

In case of actual public involvement, plant managers anticipate opposition rather than support. In the case of Sittard (C2) the manager used the term “NIMBY”. The NIMBY logic refers to a social dilemma, i.e. a discrepancy between the public and private interests (Hisschemöller et al. 2001; Hisschemöller et al. 2009; Devine-Wright 2007). Local end-users acknowledge that renewable energy production is a public good deserving general support; they however oppose the deployment of a project in their immediate proximity. Local resistance cannot primarily be attributed to selfish motives, as is sometimes incorrectly assumed (e.g. Wolsink 2000), but to an inequitable distribution of costs and benefits. In a typical NIMBY case, the benefits are divided over a very large group, whereas the burdens go to the locals. The fact that local opposition is often successful is explained by the distribution of costs and benefits. There is ample evidence that local involvement, especially local co-ownership decreases negative perceptions and dramatically increases public acceptance rises (Musall & Kuik 2011).

5. Analysis and discussion

From the findings three issues appear that deserve further consideration. First, we will address this paper´s main question, i.e. the extent at which the scale of biomass CHP plants affects their techno-economic, environmental and social performance. Second, we will probe into an issue that we encountered during the study, i.e. the limited data availability and how we dealt with this during the study. Plant managers provided very limited documentation in the form of internal reports or external studies that substantiate the information they presented during the interviews. Third, we will discuss the implications of this for public support of such projects.

Techno-economic performance

Is scale relevant to the techno-economic performance of a CHP biomass plant? To answer this question we interpret the economic data submitted by the managers, although we do this with some caution, as they reveal some contradictions. The collected empirical data do not clearly support evidence of economies of scale with regards to the specific investment cost. Some evidence was found that scaling up has an impact on the production cost of the plants, but this is not depicted in the plants’ ROI or payback period. The data suggest that energy efficiency plays a more important role than production cost in a plant’s ROI, and as a matter of fact, Lelystad (C1) with production cost higher than Cuijk (C3) (22 against 8-9 eurocents per kWh) marks higher ROI (11-15 against 8%). However, what may be even more interesting to note is the discrepancy between the managers' estimations on the payback period and the rest of the economic data provided.

It should be mentioned that for the WtE plant in Amsterdam (C6), data on ROI were not available. The interviewee explained this by the fact that the plant is owned by the municipality of Amsterdam, and thus, is formally not allowed to profit on its waste management activity (VNG 2008). Nevertheless, the "no more than usual" principle dictates heat companies (monopolists) to charge a price for district heating that equals the costs of heating through natural gas (competition between energy companies); gas prices over the past years have doubled and are anticipated to further increase over the coming decades. This might suggest that an ROI would still exist which is also suggested by AEB in its public communication "Part of the profit is reinvested to enable waste to be processed even more sustainably and efficiently with the highest possible yield" (City of Amsterdam 2011).

Environmental performance

Is scale relevant to the environmental performance of a CHP biomass plant? Large-scale plants were found to perform better in terms of CO_2 emissions savings. Yet, with regards to CO_2 emission savings per MWh, the plants that perform better are the large-scale plant in Amsterdam (C6), followed by the small fermentation plant in Lelystad (C4) and the large-scale plant in Cuijk (C3). Therefore, results are not only dependent on scale but also on the efficiency of a plant. This suggests that the relationship between airborne emissions and scale is rather complex and context specific.

Results on the environmental aspects should be interpreted with caution. First of all, although environmental data are supposed to be publicly available, some interviewees either did not submit or only partially submitted the requested information. For the NO_x and CO emissions from Sittard (C2), the only information provided was that they fell within the legal limits. The managers of the biogas plant in Zeewolde (C5) provided information only on the CO_2 emissions savings; data from literature sources have been used and the measurements on the other airborne emissions were assessed according to the data presented by Borjesson and Berglund (2006). For Cuijk (C3) the emission savings were calculated based on data from Weisser (2006) and Zhang et al. (2010). The information provided for the airborne emissions of Lelystad fermentation (C4) was poor and the missing data could not be proxied with readily available estimates from the literature (our pursued literature search did not provide any sufficiently suitable data). Data availability was high for the incineration plants of Lelystad (C1) and Amsterdam (C6), owned by two large energy companies (Nuon and AEB respectively). Yet, the interviewees did not provide supporting background evidence of the information provided.

Another important issue is that companies adopt different ways of calculating the CO_2 emission savings that their plants generate. The companies calculate the emission savings simply via a comparison with the reference system, except for Cuijk (C3) and Amsterdam (C6) where the transport emissions are considered. As a proxy for transport-related pollution emissions, measurements have been complemented with data on the number of trucks of feedstock per day.

Social acceptance

Last, is scale relevant to the social acceptance of a CHP biomass plant? As regards social performance, we find limited public engagement. Although plants organise information days for the general public and communicate to the media, their expectations as regards the public attitude are low. Some even mention (to expect) public resistance rather than support. Our findings from exploratory interviews with a random group of end-users in Sittard (C2) show lack of public involvement; a number of them mentioned that they felt excluded from the entire process. This must neither be interpreted as lack of interest or lack of public support. It has been shown that public engagement can contribute to the local acceptance of a project (Devine-Wright 2005). Yet, it could also be argued that the absence of people's involvement could reflect indifference or even support for the project. The interviews showed that the end-users were not significantly environmentally aware and that scale could become an issue of concern to them when it directly affects them as a result of noise and smell. Interestingly, models for coproduction and co-ownership as currently widely applied with onshore wind have as yet not been considered for CHP biomass plants in the Netherlands.

Our paper is a case study analysis for the Netherlands. The small sample allowed a more in-depth comparative analysis. Our propositions with regards to the relevance of scale to the techno-economic, environmental and social performance of a CHP biomass plant could generalise to other situations on the basis of analytic claims (Yin 2012).

The lack of data availability and publicly available documentation on the techno-economic and environmental performance of biomass installations is certainly a point of concern, especially because government grants and subsidies have been indispensable for their implementation. It is very well possible that such data are available but confidential, in which case plant managers would have been reluctant to share it with us. However, such information must be publicly available in order to enable a thorough evaluation of the pros and cons of biomass installations of different size and technologies and facilitate decisions on how to utilise scarce public resources in a legitimate way.

6. Conclusion

This paper explores the relationship between scale and biomass plant performance in an integrated multi-dimensional manner, probing into techno-economic, environmental and social aspects of biomass-based CHP units in the Netherlands. This paper suggests that scaling up of biomass energy units does not necessarily lead to better economic and environmental performance. Smaller scale biomass plants exhibit benefits in the domain of both environmental and economic performance. Both scale and technologies matter in terms of energy efficiency and environmental externalities. Whereas the public is generally interested in renewable energy issues, their current limited involvement in local biomass projects must not be interpreted as a signal that peoples' attitudes are negative with respect to small-scale plants. Our findings suggest that location is a critical factor behind the attitude of people towards biomass plants, which is of high importance for both small and large-scale plants. People's attitude is indirectly affected by scale as small-scale plants are usually located closer to residential areas. When the plant is not at the immediate proximity of the local community, then, as no direct effect takes place, people seem to be indifferent of scale.

The study's policy relevance relates to the increasing interest in the transition towards a sustainable energy system. In this context, the limited data availability on the technical, economic and environmental characteristics of the Dutch biomass plants can be considered troublesome. Managers did not provide all relevant documentation to substantiate the information they disclosed. Given that biomass-based energy units are supported by public subsidies, we would suggest relevant information to be easily accessible to the public.

Further empirical research in an integrated interdisciplinary manner is needed for a consolidated understanding of biomass energy systems and their implications. To that extent, the inclusion of models for coproduction and co-ownership in the study would be desirable.

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