Resources, Conservation and Recycling 122 (2017) 388–404

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Full length article

Assessment of feedstocks for biogas production, part II—Results for strategic decision making

Jonas Ammenberg, Roozbeh Feiz*

Division of Environmental Technology and Management, Department of Management and Engineering, Linköping University, Sweden

ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form 2 December 2016
Accepted 29 January 2017
Available online 23 February 2017

Keywords:
Multi-criteria analysis
Biogas
Ley crops
Straw
Blue mussel
Food waste

ABSTRACT

Biogas is a biofuel that can contribute to more renewable and local energy systems. From a feedstock perspective there is a great biogas potential in Sweden, but many biogas producers face challenges and are struggling with profitability. Among the many influencing factors, the choice of feedstocks (biomass) for producing biogas and biofertilizer is of strategic importance. Within the Biogas Research Center (BRC) research project has been ongoing for four years, involving researchers, biogas and biofertilizer producers, agricultural organizations and others. The main aim has been to develop a method to assess the suitability of feedstock for biogas and biofertilizer production, and to apply this method on a few selected feedstocks of different character. This project is presented in two companion articles, of which this is the second. While the first article is focused on the developed multi-criteria method, this article present assessment results for ley crops, straw, farmed blue mussels and food waste. These results clarify how the method can be applied and highlight barriers, drivers and opportunities for each feedstock. Comparisons are also made. The results indicate that biogas production from food waste and ley crops is the most straightforward, and for straw and farmed blue mussels there are more obstacles to overcome. For all of them, the dynamic and very uncertain policy landscape is a barrier. In the final section, some conclusions about the method and its application are drawn, combining the information form both articles (part I & II).

1. Introduction

Biogas is a biofuel that can contribute to a more renewable and local energy system and improved nutrient management[1] (Börjesson and Mattiasson, 2008; Lantz et al., 2007). In comparison with other biofuels, biogas is more flexible and can be produced from many different types of feedstock, including biomass containing various shares of carbohydrates, lipids and proteins (Angelidaki et al., 2011), both from primary and secondary raw materials (e.g. Weiland, 2003). However, a significantly expanded biogas production is dependent on good business conditions, in turn related to societal acceptance and support (Dahlgren et al., 2013). The Swedish “biogas sector” can be seen as relatively young and immature, in comparison with traditional alternatives within the ‘energy and transportation sphere’ (Fallde and Eklund, 2015). It is complex due to many involved actors within different sectors, including for example waste management, agriculture, forestry, and aquatics; and its links to several socio-technical systems such as those for waste, energy and transportation. There are also several technological options, both regarding production and use of the products (e.g. Poeschl et al., 2012; Weiland, 2010), an ongoing development regarding technology and feedstock (e.g. Ersson et al., 2015; Lantz, 2013a), and institutional conditions, that influence its development (Dahlgren et al., 2013; Lantz et al., 2007; cf. Patterson et al., 2011).

The literature (Dahlgren et al., 2013; Energimyndigheten, 2010; Lantz, 2013a) as well as experiences from interaction with biogas producers and other knowledgeable actors (Ammenberg et al., 2015) show that Swedish biogas producers commonly face diverse and serious challenges — with many struggling to reach or maintain profitability. The situation appears to be similar in several other countries (e.g. Budzianowski, 2012; Herrmann, 2013; Patterson et al., 2011; cf. Surendra et al., 2014).

Many of the challenges are linked to the choice of feedstock, as described in the companion paper: Part I (Feiz and Ammenberg, 2016). Thus, it is highly relevant for biogas producers, policymakers and other involved actors to be able to assess potential biogas feedstock from multiple perspectives, to learn more about their suitability. For that purpose, a multi-criteria assessment method

* Corresponding author.
E-mail addresses: jonas.ammenberg@liu.se (J. Ammenberg), roozbeh.feiz@liu.se (R. Feiz).

[1] Biogas production also involves production of digestate, often seen as a by-product that is commonly used as a biofertilizer. For simplicity, the terms *biogas production* and *biogas producer* are used, but they include biofertilizer production as well if nothing else is stated.

http://dx.doi.org/10.1016/j.resconrec.2017.01.020
0921-3449/

has been developed within a project that involved researchers, representatives from the biogas and biofertilizer industry and representatives from two national agricultural interest and business organizations. The intention was to develop a method for strategic, broad and systematic assessment of biogas feedstock, covering areas related to resource efficiency, feasibility for implementation and potential for growth. The results should provide an overview of important issues and facilitate informed decision-making. The aim of this paper is to:

- Apply the multi-criteria method to assess four types of feedstock, namely blue mussels (farmed), ley crops (which is simply referred to as ley), straw and household food waste.
- Analyze the results for each feedstock, and compare the different types of feedstock.
- Critically reflect upon the application and usefulness of the method.

2. Methodology

In line with the aim, the feedstock assessments have mainly been carried out by applying the multi-criteria method established within the research project. As this part of the methodology is thoroughly described and motivated in part I, this section complements it by providing information about the selection of feedstocks and a description of each feedstock category. It also deals with the collection and management of information.

2.1. Feedstock

The feedstocks were selected considering the interests of the involved organizations, a wish to include both well-known and "new feedstock", and to encompass generic assessments (i.e., from a Swedish, national perspective) as well as case-specific assessments (e.g., considering a certain biogas plant). Thus, the selection was made both for a broad test of the method and considering business interests.

The first feedstock is ley (ley crops), which is an agricultural product suggested by the Federation of Swedish Farmers. Ley was studied for a case, a selected farm, and from a generic perspective. The generic results are included in this paper. Ley refers to several species, typically divided into legumes (such as red and white clover and lucerne/alfaalfa) and grasses (such as timothy, tall fescue and English rye grass) (Engström, 2004). Ley is commonly used as fodder and can be important in farmers' crop sequences, for example in addition to grains, oil plants and peas. Ley crops are often stored by ensilaging (ley silage), and the result is advantageous for use as feedstock for biogas production. The dry matter of ley silage contains about 28% sugar and starch, 25% cellulose and hemicellulose, 18% lignin, 17% protein and 2% fat (Carlsson et al., 2013). The dry matter content of ley is typically from 20 to 25% (Wrange, 2014), but it can range from 13.5–35.5% (Gabrielson, 2014). The type of ley, harvesting time, weather and storing conditions influence the TS content (Nizami and Murphy, 2010). The volatile content of ley is typically between 87 and 93% (VS of TS) (Gabrielson, 2014).

The second feedstock is straw, also an agricultural (by-)product. It was suggested by Lantmännen, an agricultural cooperative that is one of the largest groups within food, energy and agriculture in the Nordic region. Straw was studied for a case involving a cluster of many farms, but also from a generic perspective; the latter is included in this article. Straw is a by-product (residue) of cereal and oilseed production, where wheat, rye, barley, triticale and oil plants are the main sources of straw in Sweden. It is mainly a lignocellulosic type of biomass. From a dry matter perspective, wheat straw has about 30–40% cellulose, 26–50% hemicellulose, and 8–21% lignin. Obviously, the dry matter content of straw can vary depending on its type and also due to exposure to rain or moisture, but it is typically between 70 and 78%. The volatile content of straw is normally around 90–91%, but can vary between 79 and 91% (Carlsson and Uldal, 2009; Chandra et al., 2012).

As a third type, farmed blue mussels (Mytilus edulis) were included, seen as a rather "new feedstock" for which we have only found a few studies dealing with biogas production. Mussels also meant that the MCA methodology was tested within the aquatic sector. Blue mussels are among the most common macroorganisms in the Baltic Sea, but the focus is on mussel farming. Mussels can live in both brackish and saline waters. In the Baltic Sea they typically grow at a depth of 30 m, and their body is composed of flesh and shell. The weight of the shell of a living mussel is about 33–66% of its total weight. The shell is relatively non-degradable and does not significantly contribute to biogas production. The dry matter content of mussels is about 40% including the shell, and 10% without it (Nkemka, 2012).

Lastly, this article deals with the source-sorted organic fraction of municipal solid waste, i.e. food waste from households. It was suggested by NSR Produktion (NSR), a municipal energy and waste company having biogas production. The food waste was mainly studied as a case encompassing the waste from the six municipalities (in Southwest Sweden) that own NSR and the company's biogas plant, but this article also includes generic information about food waste to be able to make relevant comparisons with the other feedstocks. The municipal waste is sorted in different fractions, of which organic food waste is one. There was no case-specific data on the NSR food waste composition, but similar food waste has been investigated by Carlsson et al. (2013) and consists of 4% lignin, 22% sugar/starch, 18% fat, 12% protein and 23% cellulose/hemicellulose. Untreated food waste, in contrast, has 33% TS, 85% VS of TS, and 461 m^3 CH_4/t VS (Carlsson and Uldal, 2009). Before the anaerobic digestion, NSR has a pretreatment step to remove large particles and impurities, and to make the waste pumpable. The waste is shredded, mixed with water and treated in a screw press that separates the waste into slurry and a dry fraction. The dry fraction is incinerated and the slurry is anaerobically digested. After pretreatment at the NSR plant the composition of the slurry has been found to be 19% fat and 19% protein, while 61% (per VS) consisted of other carbohydrates (Bohn et al., 2010). The slurry from the pretreatment plant had a dry matter content of 11%, of which 82% was volatile solids (Bohn et al., 2010).

2.2. Information management and assessments

To a large extent the assessments are based on literature studies, where researchers and students (in masters' thesis projects or project courses) have used and referred to the literature. The literature of relevance has been searched for and entered into a database, considering the four types of feedstock and the areas, questions and indicators of the MCA method. The collected scientific and gray literature has been classified and prioritized, with the ambition to focus on the most relevant sources. The information found most essential has been selected, documented and summarized. Experts, mainly from the participating organizations, have been involved, conducting or contributing to the assessments. Thus, the selected and summarized information to some extent includes expert opinions as well.

Finally, the information was used to carry out the assessment for each indicator, using the scales presented in Part I. For each indicator, short texts were written to clarify each assessment result, including its variability and certainty. Complementary comments were made in some cases when we found information of relevance for a key question or area that was not well-covered by the specific indicators and scales, or that for some reason was seen as espe-