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Evaluation of biomethane technologies in Europe – Technical concepts under the scope of a Delphi-Survey embedded in a multi-criteria analysis

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ABSTRACT

Methane from biomass is a well suited renewable energy carrier with a wide range of applications. The main technologies for its production out of biomass are biochemical conversion from the upgrading of biogas and thermochemical conversion by gasification and methanation. Presently there exists no methodology to compare the process alternatives for methane production from biomass. This paper investigates a comprehensive evaluation method based on a multi-criteria analysis. Due to the comparable well developed biomethane market in Europe, compared to other regions in the world, the study area was restricted to Europe. The weighting of the different criteria is carried out in two rounds as a pair-to-pair comparison of the criteria by experts from different technology fields in a Delphi-Survey. As a result, the prioritisation can be used to classify the biomass conversion technologies to convert biomass to biomethane. According to the weightings given by experts, the two criteria *energy efficiency* and *production costs* are of great importance compared to the other criteria.

1. Introduction

On a global scale, the reduction of greenhouse gas (GHG) emissions is a top political priority and the replacement of fossil fuels with other fuels such as natural gas is one step to reaching this goal. In this respect, the bioeconomy with its various technologies, substrates and products is a promising development. Biomethane in particular, which is chemical identic to natural gas, can contribute considerably. Due to the same properties as natural gas it can reduce GHG emissions without restrictions in distribution and application (energetic and material). Further it is able to compensate fluctuations caused by unstable photovoltaic or wind power injections into the power grid [39].

Biomethane can be produced via two pathways based on biochemical and thermochemical principals, which differ in technology, substrates, scale and state of implementation. The fact that these technologies are also at different stages of maturity makes it even more difficult to compare them [25,34].

So far there have hardly been any technical comparisons between the two mentioned pathways. A major hurdle is caused by different process evaluation criteria and system boundaries, such as substrates (with particular focus on lignin content) and conversion technology (with particular focus on conversion effort and scale [4]) which can only be standardized by great effort [41].

The technology for biomethane production has so far only been rated by single criteria such as production costs and the two pathways (biochemical and thermochemical) have not been compared with each other (e.g. Refs. [4,19,29,44]). If a multi-criteria analysis was carried out, the prioritization or weighting of the criteria was set by the authors (e.g. Refs. [29,44]) and thus (in respect to the methodology applied here) not entirely subjective.

For an efficient development and support of these technologies, a comprehensible technology evaluation has to be applied. Therefore assessment approaches need to include both, the general comparability of technical concepts and different relevant evaluation criteria with a priority ranking. When considering more than one criteria, it is inevitable that one will have to prioritize the criteria. In light of this, a method was developed to guarantee high objectivity by involving many experts from the different biomethane provision and consumption fields. This means, that even if the single prioritization of one external expert is subjective, the

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sum of all experts still remains objective [43].

The development of such a coherent technology evaluation for biomethane production is dealt with in this paper. Therefore a short overview on the technical principles and concepts is given.

The methodology is designed to compare different technologies using various criteria. The general approach is described in within the methodology, with a deeper insight into the Delphi-Survey.

The prioritization of the criteria was carried out by a pair-to-pair comparison with feasible values. Furthermore, the experts involved had the opportunity to provide feedback and comments and to mention other important criteria that had not been considered. The method described and applied here is quite novel and can be regarded as innovative, because it extends the methodologies applied so far, which a) only focused on one technology or pathway, b) only include one or limited criteria and c) do not involve external experts.

At the end of this paper, the prioritization results as well as the interpretation of the results of the Delphi-Survey are examined. They are analyzed between the survey rounds as well as between the different expert groups. Further, additional criteria (suggested by the experts) as well as remarks are discussed. Finally, the general approach and the results obtained are discussed with respect to the elaborated priorities for further technical development. Additional, the applicability of Delphi-Surveys for technology evaluation and development potential is analyzed. Thus, one aim of the paper is to increase the level of awareness of the Delphi-Survey, so that it can be applied more often in energy research.

2. Technology overview of renewable methane from biomass

Methane produced via the biological pathway is often referred to as biomethane, whereas methane produced via the thermochemical pathway is often referred to as bio-SNG. Due to the same composition, properties and usage and in terms of better understanding, it is hereinafter named biomethane for both pathways.

Biomethane can be used as an extensive substitute for natural gas and can therefore be used in the same fields, e.g. in heating, power and transport sectors. Furthermore, it can make use of the same infrastructure, e.g. the natural gas grid, tank trucks, vessels and storages. Due to the fact however that biomethane is relatively highly concentrated methane (typically 95–99% CH_4) whereas natural gas is a gas mixture, mostly comprising of methane, slight differences can occur between the calorific values. If these differences exceed certain thresholds, the biomethane has to be adapted.

To produce methane from biomass, two main technologies need to be differentiated between. These are (i) the biological pathway [18] and (ii) the thermochemical pathway [17,38]. Fig. 1 gives an overview of the two main conversion technologies for methane from biomass.

Biomethane via the biological pathway is well applied with more than 200 plants already in operation in Europe [42].

Production via the thermochemical pathway on the other hand is still under development. The first commercial plant went into operation in Gothenburg at the end of 2014 (Göteborg [14,16]. Additionally there are also various other demonstration or pilot plants in operation [25].

There is also a third possibility, the Power-to-Gas option with methanation. However, this technology is just starting to be developed and has great potential for converting exhaust power, where it is available, to hydrogen [8,21]. As this is not the main topic of research in this paper, it is not further evaluated here.

2.1. Biochemical conversion

Biomethane via the biochemical pathway is produced by upgrading biogas. The biogas, which is also used for direct heat or power contains on average 50–85% methane whereas the remaining gas is mostly CO_2 as well as some other minor components. The substrates are mostly energy crops (in combination with manure) or organic waste. By separating the CO_2 from the methane (a process referred to as biogas upgrading), biomethane with a purity of 95–99.9% is produced. The following upgrading technologies are applied [5,15,42]:

- Water scrubber
- Pressure swing adsorption (PSA)
- Chemical scrubber (amine scrubber)
- Organic physical scrubber
- Membrane separation

After the CO_2 is separated, the biomethane is usually conditioned to meet the necessary requirements before being injected into the gas grid or used as a fuel.

2.2. Thermochemical conversion

When biomethane is produced via the thermochemical pathway usually lignin-rich substrates such as wood or straw are applied. The main stages of the conversion pathway are: (i) pretreatment, (ii) gasification, (iii) raw syngas treatment, (iv) methanation and (v) synthetic natural gas (SNG) upgrading. Thus, much more effort is required compared to the biological pathway. The most important steps during this conversion are gasification and methanation. During gasification, the substrate is converted to raw syngas, which mainly consists of CO, CO_2, H_2, CH_4 and H_2O in the form of vapor. During methanation the syngas components are converted to methane. Because of the high amount of CO_2 and other trace components that still remain, a final SNG upgrading is necessary. For SNG upgrading, the same technologies as the biogas upgrading via the biochemical pathway can be applied [2,12,22].

3. Methodology

This paper focuses on the development of a comprehensive evaluation method of biomethane production processes using different conversion technologies to convert biomass to biomethane. Therefore the developed and applied methodology must be able to overcome the main hurdles that arise when comparing the technologies. This mainly includes the problem of the various substrates which are used, the type of the applied technologies and the consideration of more than one criterion for comparison.

To consider more than one criterion, a so called multi-criteria analysis can be applied [1,11]. To make use of these, the selected criteria have to be weighed in an objective manner. This can be achieved by involving independent experts from different research fields, e.g. by a Delphi-Survey. On the one hand, the applied multi-criteria analysis has to be complex enough to achieve all set targets and on the other hand it still has to be manageable for the participating experts [3]. Fig. 2 shows the applied overall methodology.

Due to the already well applied technology of biogas upgrading in Europe [42], Europe was chosen as study area.

3.1. Multi-criteria analysis

The evaluation method is based on a multi-criteria decision matrix. Whenever more than one criterion for decision making is important, a multi-criteria analysis can be applied. These analyses can be applied for political issues, design and construction or to rank different technologies with a focus on e.g. economical,