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The impact of CO_2-costs on biogas usage

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ABSTRACT

The Danish government has set a target of being fossil fuel independent by 2050 implying that a high degree of inflexible renewable energy will be included in the energy system; biogas can add flexibility and potentially has a negative CO_2-emission. In this paper, we investigate the socio-economic system costs of reaching a Danish biogas target of 3.8 PJ in the energy system, and how CO_2-costs affect the system costs and biogas usage.

We perform our analysis using the energy systems model, Balmorel, and expand the model with a common target for raw biogas and upgraded biogas (biomethane). Raw biogas can be used directly in heat and power production, while biomethane has the same properties as natural gas. Balmorel is altered such that natural gas and biomethane can be used in the same technologies.

Several CO_2-cost estimates are investigated; hereunder a high estimate for the expected CO_2-externality costs. We find that system costs increase with CO_2-costs in most cases, while the biogas target becomes socio-economically cheaper. In the case of a very high CO_2-cost, system costs decrease and biomethane becomes the primary fuel. Furthermore, biomethane functions as regulating power and the Danish fuel consumption increases due to a higher electricity export.

1. Introduction

The Danish climate strategy is shaped around a goal of being independent of fossil fuels in all energy consuming sectors by 2050, and one tool among many is biogas. First focus point have been the heat and power sector (from now on called the energy system) in which there has already been a large development in energy savings and implementation of renewable energy. Therefore, an energy system independent of fossil fuels by 2035 has been determined as a stepping stone towards the 2050 goal [1].

Biogas production have been developed in Denmark since the late 1970's with varying focus points [2]. Biogas is a renewable fuel that can be produced from a large variety of inputs such as manure, waste water and other wet substrates, which are expensive to use in other technologies. In Denmark, biogas is primarily based on manure of which there is an abundant supply from the large Danish agricultural industry. The degassed manure from the biogas process has an improved fertiliser value and can potentially improve the water environment as less nutrients are washed out from the fields. Furthermore emissions from the far more potent greenhouse gasses: methane (CH_4) and laughing gas (N_2O) are converted into CO_2-emissions—making biogas one of the few fuels that potentially can reduce greenhouse gas emission effects.

In Denmark, biogas has primarily been used in local, combined heat and power plants (CHPs). As biogas is produced constantly all over the year and it is expensive to store, it is also *used* constantly, i.e. producing a constant stream of heat and power. With an increase in volatile renewable power production, this is not necessarily the optimal usage of biogas. In 2014 new regulation was ratified, such that biogas is now also subsidised when it is upgraded to natural gas quality (biomethane). Biomethane can be transported in the natural gas grid, which allows it to be used *where* it is needed, *when* it is needed.

Biogas has been applied in other analyses on systems optimisation—in particular on the issue of waste as a fuel [3–5]. Biogas is often one fuel out of many and seldom turn out to be the preferred fuel as seen in e.g. Ref. [3] and the national biomass value chain model [6]. In our analysis, we turn our attention to biogas (hereunder biomethane) by including a separate target of biogas usage.

There is a variety of literature on energy systems optimisation using different optimisation models, e.g. Balmorel [7–9], MARKAL/TIMES [10–12], and EnergyPLAN [13–15]. An overview of existing energy systems models can be found in Ref. [16]. With the choice of

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model, it becomes necessary to assess whether the model can include varying properties of the two types of biogas and the target of biogas usage.

In this paper, we consider the year 2025 for which the Danish Energy Agency (DEA) has a prognosis of the biogas production [17], which seems to be aligned with the goal of being fossil fuel independent by 2035. We model biomethane as a substitute fuel for natural gas in an energy systems optimisation model and include a common goal on the use of biogas in the energy system. We allow the model to use biomethane as well as raw biogas and thereby we can compare the two options for the energy system. To our knowledge no other articles have included both raw biogas and biomethane in an energy systems optimisation model to evaluate their usage. The optimisation model is minimising the socio-economic cost of the energy system. From the model, the use of raw biogas and biomethane can be evaluated to find the socio-economic cost of a biogas target in the energy system both as a system cost and a marginal cost of the target. Furthermore, scenarios for different settings of the CO_2-cost is introduced to evaluate the effect on the system cost and the marginal cost of the target.

2. Biogas in Denmark

Biogas production has been developed in Denmark since the late 1970s [2], primarily based on manure and co-substrates from a large agricultural industry; and due to regulation biogas plants have primarily supplied heat and power locally.

As Denmark moves towards being fossil independent by 2050, it becomes necessary to find replacements for particularly coal and natural gas in the energy system. There is already by 2017 a massive development in Denmark where coal to a large extent has been replaced by biomass and wind power. However, the lack of flexibility and predictability among renewable energy sources such as wind and solar power [18] has become a repeated concern, when renewable energy is integrated into the energy system. One suggested benefit from biogas is the potential to add this needed flexibility. The traditionally, Danish biogas usage where biogas is sent directly through a dedicated pipeline to a nearby CHP-plant, can however not be expected to add much flexibility—in some cases it might even work against flexibility, since an effective production of raw biogas only can vary a little and due to high costs with local storing [19] it has to be used gradually while it is produced.

Raw biogas can also be upgraded to natural gas quality and sent as biomethane into the national gas grid. Raw biogas is made of approximately 65% methane and 35% CO_2, and the upgrading process consists essentially in removing this CO_2-surplus, converting the raw biogas into biomethane (98% methane and 2% CO_2). Alternatively, hydrogen from electrolysis could be added to raw biogas, converting the CO_2-surplus into additional methane [20]. This process would increase the biomethane production with roughly 70%. The biomethane can be transported in the gas grid, stored and used with the same flexibility as natural gas in the heat and power sector, in industry or in heavy transport.

2.1. Biogas targets

There is no particular target for Danish biogas usage in 2025. However, a target of using 50% of all manure for biogas production by 2020 was set in the Green Growth Agreement [21]. This is an extensive increase in the biogas production, as currently only 7–10% of the Danish manure is used for biogas production. If 50% of the manure were to be used for biogas production it would correspond to approximately 11 PJ.

The energy consumption prognosis from the Danish Energy Agency (DEA) [17], predicts a 7 PJ increase in total biogas consumption from 10 PJ in 2015 to 17 PJ in 2025. In Fig. 1 the latest and expected development in biogas consumption are depicted (left y-axis) and for comparison the natural gas consumption is also depicted (right y-axis). From this it is clear, that even with a high percentage increase in biogas consumption, it will still be far from the current natural gas consumption.

The latest calculations on future biogas potentials for Denmark corresponds to approximately 60–85 PJ [22,23]. But even with such high production it only corresponds to roughly 10% of the current total energy demand in Denmark, which is around 750 PJ. Furthermore, biogas is considered relatively expensive compared to other renewable technologies. The expected Danish energy consumption is depicted in Fig. 2 together with the energy consumption for the energy system for 2015 and a prognosis for 2025 from the Danish Energy Agency (DEA).

From the 2025 prognosis it becomes clear that an increased biogas production is not expected to be used in the heat and power sector. An increase in biogas consumption is most likely to happen in the transport and industrial sectors according to the Danish biogas task force analysis [24].

2.2. Regulation

As already mentioned, support for biogas was until recently only given indirectly to electricity produced on raw biogas in a local CHP. With the new regulation support is also given to upgraded biogas. The support for 2015 can be seen in Table 1 together with an approximation for the support in 2025. Since the support is dependent on both the natural gas price and the net price index, it is uncertain what the exact support will be in 2025.

With the current regulation, the support for raw and upgraded biogas is in many ways similar and since costs for upgrading are high, a private economic analysis could point to direct use as the preferred usage. According to [25], this is also the preferred choice as long as the plant is small. Following the inflexible production of biogas and the support design, when raw biogas is used in a local CHP, CHP is incentivised to produce constantly, independently of the electricity market. Support for biomethane is given before the biomethane is used and—except for a reduced CO_2-cost—biomethane is expected to have the same properties as natural gas and is taxed the same way. Therefore, the private economic competitiveness of biomethane can already be determined at the gate into the gas system: if the fuel costs including CO_2-costs are sufficiently low, biomethane could compete with natural gas, which may favour upgrading [26,27].

In conclusion, it is reasonable to expect that biogas will be used both raw and upgraded in the future energy system depending on the local conditions, e.g. the local district heating demand.

3. Biogas in the energy system

Based on the above, we find it reasonable to include both raw biogas and biomethane when we model biogas within a Danish energy system context. The raw biogas and biomethane should be included in the energy systems model with different properties, e.g. cost and efficiency, and the common target should be handled by the model.

3.1. Balmorel

We choose to use the energy system model, Balmorel [28], for analysing the use of raw biogas and biomethane. Balmorel is a bottom-up model in which the energy system can be optimised