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Balancing gas supply and demand with a sustainable gas supply chain – A study based on field data

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HIGHLIGHTS

- Regional gas demand was modeled using Fourier analysis.
- A flexible green gas supply chain was analyzed using three scenarios.
- Adding gas storage in a farm-scale green gas supply chain is expensive.
- Flexible biogas production seems to be promising from a cost price point of view.

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ABSTRACT

The possibilities of balancing gas supply and demand with a green gas supply chain were analyzed. The considered supply chain is based on co-digestion of cow manure and maize, the produced biogas is upgraded to (Dutch) natural gas standards. The applicability of modeling yearly gas demand data in a geographical region by Fourier analysis was investigated. For a sine shape gas demand, three scenarios were further investigated: varying biogas production in time, adding gas storage to a supply chain, and adding a second digester to the supply chain which is assumed to be switched off during the summer months. A regional gas demand modeled by a sine function is reasonable for household type of users as well as for business areas, or a mixture of those. Of the considered scenarios, gas storage is by far the most expensive. When gas demand has to be met by a green gas supply chain, flexible biogas production is an interesting option. Further research in this direction might open interesting pathways to sustainable gas supply chains.

1. Introduction

The current share of renewable energy in the total energy consumption in The Netherlands increased from 3.8% in 2010 to 4.2% in 2011. This is caused by an increase in renewable energy consumption as well as a decrease of the total energy consumption. About 75% of this share in 2011 has a biomass origin [1]. The Dutch government aims at a renewable energy share of 14% in 2020. The current share of green gas in the Dutch gas consumption is estimated to be about 1%. Published ambitions envision a share of 8–12% of green gas in 2020 [2]. It is evident that green gas can play an important role in achieving the renewable energy goals. Therefore, several studies have been carried out to investigate the possibilities of injection of green gas into the gas grid [3–5]. The possibilities of 12% natural gas replacement in 2020 and 20% in 2030 were investigated [3]. In these studies a constant production of green gas in time is assumed. There seem to be good opportunities but:

- A continuous 12% replacement of natural gas by green gas during a year seems not to be possible without taking measures. A number of hours a year the minimum gas demand is lower than the (theoretically) constant production of digesters, which implies overproduction.
- In some regions, digesting all available manure could deliver more green gas than can be injected into the gas grid during a period a year (again, under the assumption of constant production). In general, the studies indicate that the biomass availability is high enough to achieve a higher natural gas replacement than is currently the case.

Thus, the target for injection of green gas is higher than current practice and the availability of biomass offers possibilities to increase the share of green gas in the total gas consumption.

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Nomenclature

DM	dry matter: the share (%) of biomass not being water
DSO	distribution system operator
End user	household or company that demands gas
Green gas	biogas upgraded to natural gas standards, in literature also referred to as bio-methane
GRS	gas receiving station: Installation where natural gas from the transport grid (40 bar) enters a distribution grid (⩽8 bar)
Nm^3	normal cubic meter (at standardized conditions p = 1.01325 bar, T = 273 K)
oDM	organic dry matter: the share (%) of dry matter which consists of organic material
VS	volatile solids

Usual analyses of biogas systems consider its production to be constant in time. Constant production, upgrading to natural gas quality and injection into the grid has a decreasing cost price per produced Nm^3 when scale is increased. This is caused by decreasing investment costs of digesting, upgrading and injection per Nm^3 green gas as the production rate increases.

However, gas demand (i.e. the gas consumption by end users) varies with time, not only on a daily basis but also on a seasonal basis. From a technical point of view a constant green gas production and injection should not exceed the minimum gas demand in the grid into which the gas is injected. The pressure in the grid would become too high. This minimum gas demand might for instance occur on a warm July night. The usually suggested solution for a higher gas production than gas demand is gas storage, connection of gas distribution grids or compression and injection into the gas transport grid. It is not always clear what storage technology should be used under which circumstances. Neither is it clear whether a development in a more flexible biogas production, i.e. a higher production rate in winter and a lower production rate in summer, would increase the annual gas production quantity such, that the cost price of green gas (€ct/Nm^3) decreases and more natural gas replacement is possible. As digestion of biomass is a biological process, the predominant opinion is that the process should be kept stable and changing operational parameters should be done carefully [6]. On the other hand, it is also known that farmers sometimes add glycerin to boost the production or re-enter digestate in the digester if production must be limited. Chances for operating one or more extra digesters to meet the gas demand only during some months a year when gas demand is high are not explored yet to the current knowledge of the authors. Exploring these options would enhance the understanding of the possibilities of green gas in our gas supply, both technical and economic.

These considerations raise the following research question: What would be the cost price of green gas as a function of scale, when the seasonal (fluctuation in the) gas demand should be met by a green gas supply chain?

The following sub questions are derived from this research question:

(1) How can a seasonal gas demand be modeled as a mathematical description which is sufficiently accurate?
(2) How can a green gas supply chain be designed to be flexible to meet the varying gas demand? At this point three scenarios for investigation are distinguished:
   - Varying the gas production of a digester such that the seasonal swing in gas demand is met. In this scenario no gas storage is taken into account.
   - Incorporating a gas storage facility into the supply chain with constant gas production, such that, in case of overproduction, excess gas can be stored.
   - A digester is added parallel to the digester already available at constant production, with the intention to 'switch on and off' the extra digester.
(3) Given a gas demand pattern in a geographical region, can verdicts be done about optimal locations for digesters, i.e. is location planning a tool to establish a better fit between supply and demand? Optimal in this respect should be interpreted as the lowest cost price within defined sustainability criteria.

In Section 2 we discuss our approach to answering these questions. In Section 3 the results of our simulations are presented and in Section 4 we discuss the results after which the conclusions are presented in Section 5.

2. Method and assumptions

2.1. Sub question 1 – Modeling gas demand

In general, annual gas demand in a defined geographical region can be characterized by a minimum and a maximum gas demand and the way it alters during a year. The total annual demand divided by 8760 h gives the average hourly gas demand.

Schouten et al. [7] addressed the uncertainty in gas demand with a linear function which relates gas consumption in The Netherlands to the outdoor temperature, corrected for wind speed. Gas demand remains constant when the outdoor temperature is above a limit value. This relation between outdoor temperature and gas demand holds for households. However, the demand of (large) companies is not necessarily directly related to outdoor temperature while they may be connected to the same gas receiving station (GRS). Bärnthaler et al. [8] used specific user data to define a gas demand pattern of households, specific types of companies (bakery, laundry) and a mixture of those. It is evident that the gas demand is greatly dependent on the type of gas consumer.

In our study, we used actual gas demand data from September 2009 to September 2010 of six gas receiving stations (GRSs) in the north of The Netherlands. This gave us the opportunity to get a more or less general insight in field data of gas demand of households and companies in an anonymous way. The data were supplied by Rendo, a Dutch gas distribution system operator (DSO). Similar information on gas demand can be found in Donders et al. [4] and Smits et al. [5]. Sixteen cases were extracted from the supplied data, see Table 1. A distinction between small-scale and large-scale users was derived from the data. A small-scale user is an end user with an annual gas demand smaller than 170,000 Nm^3. A large-scale user is an end user with a minimum annual gas demand of 170,000 Nm^3. Large-scale users were confirmed to be companies on business areas, whereas small-scale users are mainly households, possibly combined with small or medium-sized companies. For every GRS a concise description is given on the type of users, the total annual gas demand, and the measured minimum and maximum hourly demand. A GRS in 'island operation' means that the grid under consideration is not interconnected to another GRS, thus that the natural gas in this distribution grid only enters via the GRS. Especially cases 5 and 6a are