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Will implementation of green gas into the gas supply be feasible in the future?

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HIGHLIGHTS

- The relation between energy efficiency, greenhouse gas reduction and cost price of a green gas supply chain was analyzed.
- Opportunities for improving a green gas supply chain were evaluated.
- Fossil and renewable energy resources are made explicit in energy efficiency definition.
- Switching to green electricity is the major contributor to improving the energy efficiency and greenhouse gas reduction.

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ABSTRACT

The energy efficiency, greenhouse gas reduction and cost price of a green gas supply chain were evaluated. The considered supply chain is based on co-digestion of dairy cattle manure and maize, biogas upgrading and injection into a distribution gas grid. A reference scenario was defined which reflects the current state of practice, assuming that input energy is from fossil origin. Possible improvements of this reference scenario were investigated. For this analysis two new definitions for energy input–output ratio were introduced; one based on input of primary energy from all origin, and one related to energy from fossil origin only. The influence of the improvements on greenhouse gas reduction and cost price was assessed too. Results show that electricity (from fossil origin) is the major contributor to energy input in the reference scenario. Switching to green electricity significantly improves the energy efficiency (both definitions) and greenhouse gas reduction. Preventing methane leakage during digestion and upgrading, and re-using heat within the supply chain also show improvements on these parameters as well as on cost price, although their influence is smaller. Decreasing the share of energy crops in the substrate mix shows a negative effect. It is shown that greenhouse gas reduction of more than 80% is possible with current technology. To meet this high sustainability level, multiple improvement options will have to be implemented in the green gas supply chain. Doing so will result in a modest decrease of the green gas cost price.

1. Introduction

Decarbonization of, and increasing the share of renewable energy in the energy supply are important topics nowadays. The EU has set goals in this respect, which meet the vision that people's well-being, industrial competitiveness and the overall functioning of society are dependent on safe, secure, sustainable and affordable energy [1]. Dutch ambitions on the future energy system are an example of goals on a national level, and are laid down in the Dutch Energy Covenant [2]. The stimulation of decentralized renewable energy production by co-operations is one of the pillars of this covenant: The Netherlands aims for 14% renewable energy production in 2020 (currently 4%) and 16% in 2023. Other pillars in this covenant are saving energy as a means to improve energy efficiency, and greenhouse gas (GHG) reduction (80–95% reduction in 2050).

Biogas and green gas are considered to become part of the future energy system (e.g., [3,4]), not only as an energy carrier, but also as a means to balance supply and demand of energy. At present, in The Netherlands green gas initiatives are often not profitable without subsidies [5–7], but it cannot be concluded plainly that green gas is too expensive. The long term perspectives of

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Nomenclature

FM	fresh matter
FPE	fossil primary energy
FPEIO	fossil primary energy input–output ratio
GHG	greenhouse gas
Green gas	biogas upgraded to natural gas quality, in literature also referred to as biomethane
HHV	higher heating value/(MJ/Nm^3)
LCA	life cycle analysis
Nm^3	normal cubic meter (at standardized conditions p = 1.01325 bar, T = 273.15 K)
PE	primary energy, i.e., energy as found in nature before having undergone any conversion
PEIO	primary energy input–output ratio

biogas will be strongly determined by possible geopolitical developments and by national and international legislation (e.g., in terms of levels of subsidies, desired energy mix, taxes and sustainability criteria [7]). It is likely that pollution by current fossil energy systems (e.g., coal-fired power plants) will be included more and more in future energy production costs. The existing EU's and Dutch energy systems need high levels of investment in the future, even in the absence of ambitious decarbonization efforts [1], which may cause uncertainty on future energy prices. Also a possible paradigm shift should be considered. In the current paradigm, gas is a commodity, available from (large) fossil reservoirs. One pays for the amount of gas needed. Within this paradigm, supply flexibility, i.e., the ability to meet energy demand at all seasons and hours, is not a real issue. In a future paradigm with multiple renewable energy resources, balancing supply and demand will be a predominant issue, and flexibility will have to be paid for. Possibilities and costs of flexibility of a green gas supply chain were investigated before [8,9]. Costs will be an important criterion in the future, but questions can be raised on the comparability of the current vs. future, or centralized vs. decentralized energy costs. Given the fact that green gas is considered to be part of the future energy mix, an increasing attractiveness of green gas is clearly not only determined by decreasing costs.

Thus, the question arises how the share of green gas in the energy system can grow. This growth will be stimulated by aiming for the EU and Dutch energy saving and GHG reduction goals from a supply chain design engineering point of view. This is also supported by literature (e.g., [10,11]) and fits within a wider institutional perspective on renewable energy developments [12]. The energy balances of different biogas chains were studied and compared before [13–15], but energy optimizations within each chain were not investigated. Also the needed primary energy PE within supply chains was considered to be from fossil origin, which is not necessarily the case. To the authors' knowledge, no distinction was made in scientific literature on biogas so far between primary energy from fossil or renewable resources. Considering both, i.e., without making the distinction, is an indicator of engineering energy efficiency. Improving energy efficiency is a sound engineering objective. Only considering the fossil resources is a more direct indicator related to sustainability. Replacement of fossil energy by renewable energy may reduce GHG emissions which is also a sound objective, but it not necessarily improves the energy efficiency as such. Only increasing energy efficiency of supply chains not necessarily leads to reduced energy consumption of end-users. Other policies such as taxation or regulation are required [16]. This must be considered as well, but is outside the scope of our study.

The relation between energy balance, GHG reduction and cost price of a green gas supply chain is analyzed in this study. Three sub questions are defined:

1. Based on definitions of fossil and/or renewable primary energy use, what are the contributors to energy efficiency and GHG reduction of a green gas supply chain?
2. What is the influence of selected modifications of the considered green gas supply chain on reduction of (fossil) energy use and GHG emissions?
3. What are the consequences of these modifications to the cost price of green gas?

This study aims to add knowledge on further improving the energy efficiency and GHG reduction of a green gas supply chain, in relation to costs. The used model, a reference scenario, a consideration and definitions of energy efficiency and GHG reduction, and opportunities to improve these aspects are described in the following section, after which the results are presented and discussed. The study ends with conclusions and recommendations for future research.

2. Method

The considered green gas supply chain was modeled as consecutive transformation blocks, shown schematically in Fig. 1.

This supply chain model has a generic character, based on farm-scale co-digestion of manure and co-substrates. Manure is considered to be a waste stream from milk or meat production. Co-substrates are considered to be (energy) crops. Seeds, (artificial) fertilizers and pesticides are inputs needed for this. The biomass is co-digested in a single stage tank reactor and upgraded to green gas in a water wash upgrading installation. The green gas is thought to be injected into a distribution gas grid (8 bar). Part of the digestate from the digester is used again on the land as a fertilizer for the energy crops, partly replacing artificial fertilizer according to limitations set by Dutch law. The other part is considered waste. Transport comprises transport of manure and co-substrates to the farm, transport of digestate as fertilizer and transport of excess digestate as waste.

CO_2 emissions from the upgrading process are not considered because release of CO_2 is part of the short cycle. CO_2 capture by growing maize is also not taken into account. In the used model GHG emissions of manure are not taken into consideration, because manure is considered a waste stream. From this point of view, GHG emissions from manure could be accounted for in the process of milk production. By expanding milk (or meat) production to include a biogas supply chain, the total system includes avoided emissions of GHG. Other approaches are reported in literature as well (e.g., [18]).

In our study a reference scenario was chosen, based on co-digestion of dairy cattle manure and maize with mass fractions of 50% each. Data of a previous study were used [17]. The functional unit chosen is 300 Nm^3/h green gas injection into the gas grid. Cost price calculations are based on net present value of a 12-year project. Used data for this reference scenario are presented in Table 1.

The energy inputs of each transformation block were identified, the needed energy was converted to primary energy (PE). Two distinctions were made: