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Is it beneficial to use biogas in the Danish transport sector? – An environmental-economic analysis

Rong-Gang Cong*, Dario Caro, Marianne Thomsen*

Department of Environmental Science, Aarhus University, Roskilde, Denmark

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ABSTRACT

Denmark is ambitious in the green transition of its transport sector. The biogas has potentials to substitute diesel as the vehicle fuel. In this paper, we examine the whole chain of biogas utilisation (biomass supply, biogas production and distribution, and fuel substitution) from both environmental and economic perspectives. We find that with low/high biomass supply potentials, the saved greenhouse gas emissions range from 0.89 to 1.66 million tons/2.19 to 4.27 million tons CO_2e (carbon dioxide equivalent). The soil carbon stock could increase 52310/124770 tons with low/high biomass supply potentials (measured as remaining carbon in soil in 100 years after application of digestate into soil). The biogas plant owners can obtain a return of investment ranging from 10.78% to 13.62% depending on biomass supply potentials and biogas production technologies. The farmers can save up to 717.93 and 1382.1 million DKK (Danish krone) by substituting mineral P (phosphorus) and N (nitrogen) fertilisers with low biomass supply potential and 1.74 and 3.44 billion DKK with high biomass supply potential. Finally, the vehicle users have incentives to use biogas because of its cost advantage. However, there are also some potential barriers and uncertainties in achieving the green transition, e.g. initial investment for CO_2 conversion equipment and diesel-vehicle users' sunk costs, which could require suitable policy supports. We suggest that using biogas in heavy-duty vehicles could be an effective way to reduce carbon emissions in the transport sector.

1. Introduction

Nowadays we face two important challenges: energy or resource scarcity, and climate change (Clastres, 2011; Cong, 2013). Although new sources of fossil fuels are occasionally discovered worldwide, they will be still depleted in the future due to the non-renewable essence (Shafiee and Topal, 2009). The combustion of fossil fuel is one main source of greenhouse gas (GHG) emissions which are responsible for the global warming and climate change (Davis and Caldeira, 2010). In contrast, renewable energy, such as bioenergy, may be naturally replenished (Cong and Shen, 2014). Upon sustainable management of biomass resources, bioenergy production systems may perform with low or near-zero carbon emission from the full life-cycle perspective (Niero et al., 2014; Seghetta et al., 2016b; Thomsen et al., 2017). Therefore, bioenergy production may be both resource and climate compatible. Bioenergy can substitute fossil energy in many ways, one of which is as the motor fuels (Farrell et al., 2006). One promising type of biofuel is biogas, which can be produced from organic biowaste, e.g. manure, sludge, green biomass, industrial and household waste, based on the anaerobic digestion process using the second generation biofuel technologies (Lastella et al., 2002). Biogas produced from organic waste and plant residues does not necessarily conflict with agricultural land for food production like the first generation technologies (Sims et al., 2010).

To limit the rise in global average temperature to 2 °C and improve the portfolio of energy supply, the European Union has set a “20-20-20” target by 2020 for reducing GHG emissions by 20% from the 1990 levels; supply 20% of EU energy from renewables; and increasing energy efficiency by 20% (Böhringer et al., 2009). The EU Renewable Energy Directive set Denmark a goal of at least 10% of the transport energy consumption to be based on renewable energy by 2020 (Danish Energy Agency, 2015). In accordance, the Danish government set a plan for Green Growth in 2009 stating that up to 50% of livestock manure in Denmark must be used for

* Corresponding authors. Department of Environmental Science, Aarhus University, Roskilde DK-4000, Denmark.
E-mail addresses: rc@envs.au.dk, cascong@126.com (R.-G. Cong), mth@envs.au.dk (M. Thomsen).

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Nomenclature

As	Arsenic
AT	Articulated truck
BS	Biogas settings
Cd	Cadmium
CH_4	Methane
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
Cr	Chromium
Cu	Copper
DKK	Danish krone
DM	Dry matters
GHG	Greenhouse gas
H	High
HDV	Heavy duty vehicle
Hg	Mercury
ICCT	The international Council on Clean Transportation
kWh	Kilowatt-hour
L	Low
LNG	Liquefied natural gas
N	Nitrogen
Ni	Nickel
Nm^3	Normal cubic meter
P	Phosphorus
Pb	Lead
PJ	Petajoule
RS	Reference scenario
TS	Total solid
TT	Truck-trailer
VS	Volatile solid
WtW	Well-to-wheel
Zn	Zinc

energy production (mainly biogas) by 2020 (Foged, 2012; Thomsen et al., 2017). There is also a policy objective that the Danish transport sector needs to be 100% CO_2 neutral in 2050, yet this sector is currently far behind the target compared to other sectors (Mathiesen et al., 2015).

Currently the Danish transport sector is highly dependent on fossil fuels (which occupied 95% of total transport energy consumption in 2014) while vehicles powered by biofuel and electric grow slowly (Table A1) (Jørgensen, 2014). As a promising vehicle fuel, biogas can be upgraded and distributed using natural-gas networks. Denmark has great potentials for biogas production from different organic biomass sources. The current biogas production is around 4 Petajoule (PJ) whereas the estimated potential can reach 40 PJ and perhaps up to 85 PJ if including all available organic resources (Energistyrelsen, 2014). Road transport uses about 160 PJ, of which heavy duty vehicles (HDVs) consume approximately 90 PJ and cannot be easily substituted by, e.g., electric vehicles.

In sum, there are political, administrative and commercial interests for the development and use of biogas in the transport sector and therefore there is the need to investigate the environmental and economic effects of using the biogas from different stakeholders' perspectives. Numerous studies have been carried out on evaluation of biogas utilisation from technical, economic and environmental perspectives (Johansson, 1996; Murphy et al., 2004; Patterson et al., 2011). First, biogas utilisation in transportation is dependent on technical development, e.g. utilisation efficiency of biogas affects its competitiveness (Murphy and Power, 2009). Second, the utilisation process is affected by numerous economic factors, e.g. production cost of biogas and prices of fossil fuels can jointly affect the profitability of biogas utilisation (Murphy and McCarthy, 2005). Third, biogas utilisation is also motivated by its environmental benefits. As such, GHG emission reduction from biogas utilisation could be consistent with public interests and compensated by the government, which is an important factor to keep the biogas system competitive (Lantz et al., 2007). However, the studies about biogas utilisation in the transportation sector are still relatively rare (Patterson et al., 2011; Uusitalo et al., 2013). It is not clear whether (or in which way) the biogas utilisation in the transport sector is beneficial. Furthermore, the answer to this question will be dependent on the intertwined factors above and also the perspectives, i.e. from the perspective of private sectors or the whole society. The private sectors could care more about the profitability, while ignoring the potential environmental externalities. In contrast, for the whole society the economic and environmental effects are both important.

The aim of this study is to compare costs and benefits of biogas utilisation in the Danish transport sector with the current fossil fuel option from perspectives of private sectors (i.e. biogas plants), farmers, vehicle users and the whole society. There are some specific questions to be addressed: 1) how large is the potential for GHG reduction when using biogas as the vehicle fuel; 2) how does the profitability of biogas plants vary given different energy production technologies; 3) is biogas competitive in current Danish market compared with fossil fuel (diesel)?

The paper is structured as follows: In Section 2, we present input data and analysis methods along the whole value chain and future scenario settings. In section 3, we present results in terms of environmental and economic effects from different stakeholders' perspectives. In section 4 we discuss implications of biogas utilisation to Danish energy policy and potential uncertainties in promoting biogas utilisation and section 5 concludes.

2. Materials and methods

In this study, we perform the environmental-economic analysis (Cong and Termansen, 2016) along the entire value chain from production to utilisation of biogas in the transport sector (Biogas settings, BS), where the reference scenario (RS) uses diesel in the transport sector. In the BS, the value chain includes biomass supply, biogas production, upgrade and distribution, and biogas use for vehicles. The value chain analysis of RS includes the economic analysis of diesel use (market price) and its direct and indirect emissions. The research framework is visualized in Fig. 1.

The outcome of the assessment is dependent on the total amount and structure of biomass supply, the biogas production technologies, the inputs and outputs of biogas plants and substitution with diesel currently used in HDVs.