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Systematic approach for recognizing limiting factors for growth of biomethane use in transportation sector – A case study in Finland

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ABSTRACT

In this paper, limiting factors for increased use of biomethane as a transportation fuel are studied. The aim of this research is to recognize and estimate the limiting factors for biomethane utilization in the transportation sector. The limiting factors are studied by using calculation models from Life cycle perspective and literature reviews. According to the results, the main limiting factors can be classified into the following categories: production potential, technology, economy or policy. For biomethane utilization in Finland, the main limiting factors seem to be the lack of distribution infrastructure in northern parts of the country and the uncertain economical feasibility for agricultural biomass producers and for vehicle owners. From the political perspective, the external costs for petrol operated vehicles are higher than for biomethane operated vehicles. Reductions from the external costs could be used by political decisions as a base to support the growth of biomethane in the transportation sector which could lead to GHG emission reductions. A similar systematic approach can also be used to study limiting factors for other transportation energy systems.

1. Introduction

Due to increased greenhouse gas (GHG) emissions, in 2020, 10% of transportation energy consumption in the European Union should be based on renewable energy, such as electricity and hydrogen and on biofuels [1–3]. In the transportation use one of the potential biofuels which is expected to lead into significant GHG emission reductions is biomethane [4]. Biomethane can be produced by upgrading biogas which is produced from organic raw materials by anaerobic digestion. Biomethane has approximately similar quality as natural gas (NG), and it can be distributed using the existing NG grids, gas refuelling stations and utilized in gas-operated vehicles [1].

Despite the competitive or even lower consumer price compared to other fuels and the environmental benefits, the development of gas-operated vehicle amount has been slow in Finland and also in many other countries [5–7]. Biomethane production is local and based on domestic feedstock and could therefore improve the employment and increase the self-sufficiency regionally [8,9]. Domestic production can also be more easily overseen and environmental effects are easier to point out than for the imported biofuels.

A considerable amount of research has been carried out related to GHG emissions of the production and distribution of biomethane. In transportation use, biomethane can be used to replace fossil petrol, diesel or NG which leads to GHG emission reductions [10–14]. It seems that GHG reductions are also obvious if biogas is used for energy production by substituting NG [15]. Biogas upgrading, vehicle use and utilization via an NG grid could be the most promising technologies that could support the rapid growth of biogas utilization [16].

In addition to GHG emission reductions and potentials, Uusitalo et al., 2012 and Patterson et al., 2011 have concluded in their studies that directing biogas to the transportation sector is economically competitive against the electricity and heat production from biogas [17,18]. In addition, Patterson et al., 2011 found out that producing biogas is cheaper than producing liquid fuels [18]. On the other hand according to the results of Tricase & Lombardi (2009), in Italy biogas production is limited by the higher price compared to the price of fossil fuels [19].

Biogas potentials vary depending on geographical location and may put limitations for biomethane production. Smyth 2010 has studied the biomethane potential of cultivated grass and agricultural wastes and residues in Ireland. According to her studies, by using 10% grass produced in Ireland for biomethane production, 55% of private vehicles could be fuelled by biomethane [20]. In Finland, biomethane production is currently based mainly on organic waste materials such as biowaste. Therefore the potential of feedstock might be inadequate

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for increased biomethane production or the biomethane feedstock may be geographically located in different places than biomethane consumers and distribution network.

In addition, there may be some technological limiting factors which can be related to the distribution network or gas-vehicle technology. For example, there are countries with a very low amount of refuelling stations (for example in Denmark one and in Estonia 2) and gas-operated vehicles [5]. According to EIA 2012, the absence of widespread public refuelling infrastructure may impose a serious constraint on NG vehicle purchases [21].

The limiting factors may also be related to economy. According to Patterson et al., 2011, one of the limiting factors may be the higher purchase and maintaining costs of gas-operated vehicles [18]. According to their estimates, in the UK, support in this area could lead to the rapid expansion of biomethane transportation infrastructure. According to Poeschl et al., 2010, the Renewable Energy Act and energy tax reliefs provide bases for the support of expanded biomethane utilization in Germany [16]. Bomb et al., 2007 have compared the biofuel use in the UK and Germany from socio-political points of views. Their conclusions are that the consumers buy the cheapest fuel and the fuel emissions do not have a significant effect on the decisions. Excise duty exemptions and reductions are the key instruments to ensure the price competitive production of biofuels [22]. Åhman 2010 studied the biomethane potential and economics in Europe [6]. According to his results, biomethane should be considered as a large-scale future contender. Lantz et al. (2007) found out that economic aspects have a high influence in the profitability of biogas systems, but they did not carry out feasibility calculations for different operators along the life cycle of biomethane [23]. To study the biomethane chain from different operators' perspective would be important in recognizing the economic bottlenecks. As a conclusion, it seems that the limiting factors can be related to production potential, technology, economy or policy.

There is still a lack in knowledge about factors which are affecting the biomethane utilization in the transportation sector. Creating a systematic approach to study the limiting factors for biomethane utilization in the transportation sector can help to develop and expand the utilization in different local and national cases. Based on literature, the main attention is paid to study the following factors and to answer the following questions: Does biomethane production potential limit the amount of gas-operated vehicles? Are there technological limitations related to distribution infrastructure or vehicles? Are there economical limitations for some of the operators in biomethane production, distribution and utilization chain? Are political actions needed to increase biomethane use and if they are where the support is needed? All of the research questions will be studied from the life cycle of biomethane perspective and using literature and calculation models. This study is carried out by using Finnish operational environment as an example for approach. Based on the biomethane case, a systematic approach to recognize and estimate limiting factors for biomethane and other transportation systems is created.

2. Materials and methods

In this study, the research is carried out by using the life cycle perspective for biomethane chain from feedstock to transportation fuel. The life cycle is studied from technological, from economical and from policy perspective. Technological aspects are related to the potential to produce biomethane, to the distribution infrastructure and to vehicle technology. Economical aspects are related to different operators in biomethane production, distribution and utilization chain. Political aspects are related to the targets to increase renewable energy in the transportation sector, and they can be affected by different economical support mechanisms. This study is carried out by going through literature related to the research questions and by creating calculation models to give information about biomethane potentials, economics and external costs. Literature review is mainly used to evaluate the state of technology.

2.1. Modelling biomethane production potential

Evaluating feedstock amounts and biomethane production potential are the first steps in the life cycle of biomethane. This study was carried out by calculating theoretical biomethane potentials for different regions in Finland.

In this paper a basic assumption is that biogas is not used to produce energy needed in the biogas production process. Therefore, all biogas can be upgraded to biomethane. The energy needed in the processes has to be produced by other energy. The results are compared to renewable transportation fuel targets of the European Union. In addition, the effects on Finland's transportation fuel self sufficiency are also studied. The data for masses was available from the Centre of Economic Development, Transport and the Environment [24]. The population is concentrated on Southern Finland while Northern and Eastern Finland are more sparsely populated. Due to the population distribution, also the highest fuel need is in Southern Finland. Appendix I presents the population, area and amount of passenger cars in each region. In Finland, biomethane is mainly produced from biowaste, waste water treatment plant (WWTP) sludge and agricultural biomasses, such as manure, potato waste and grass [9]. Theoretical biomethane energy potential (TB_{pot}) in MJ for certain region and feedstock can be calculated:

$$TB_{pot} = \sum_{i=1}^{n} m_i \cdot TS_i \cdot Y_{bg,i} \cdot LHV_{CH4} \cdot \rho_{CH4} \tag{1}$$

where m_i is the mass in feedstock I (t), TS is the share of total solids in feedstock i, Y_{bg} is the methane yield from TS of feedstock i ($m^3\ t_{TS}^{-1}$), LHV_{CH4} is the lower heating value of methane (50 MJ kg^{-1}) and ρ_{CH4} is density of methane (0.7 kg m^{-3}) [25]. The number of feedstock is n. Initial data and assumption related theoretical biomethane potential evaluation is presented in Table 1.

The average driving distance of passenger cars in Finland is approximately 16 800 km a^{-1} [35]. The average consumption of gas operated passenger cars depends on the car type. For this study, the consumption of Volkswagen Passat 0.6 kWh km^{-1} is chosen [36].

2.2. Evaluating infrastructure and gas-operated vehicle technology

The second and the third step in the life cycle of biomethane are the distribution and the use in gas-operated vehicles. The lack of gas-refuelling stations or distribution options could be a limiting factor from the infrastructure perspective as was previously pointed out by Lantz et al. (2007).

The development of refuelling station network in Finland is estimated by comparing the refuelling station and gas-operated car amounts to other European countries. In addition, different ways for distribution are also estimated. There are approximately 1200 gas-operated vehicles in Finland and 18 refuelling stations for gaseous fuel [37,7]. The total number of gas-operated vehicles in Europe is approximately 1 700 000 [37]. Data about gas-operated vehicles, car amounts and refuelling stations are collected from the statistics of the World Natural Gas Vehicle association and the World Bank [37,5,38]. In addition, potential technological limitations for gas-operated vehicles compared to traditional vehicles are studied from the literature.

2.3. Modelling economical limiting factors

For economical modelling, the biomethane production, distribution and utilization chain is divided into four main operators