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How to decarbonize the natural gas sector: A dynamic simulation approach for the market development estimation of renewable gas in Germany

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HIGHLIGHTS

- A dynamic market simulation model for biomethane is presented.
- Enables the estimation of effects from legislative changes.
- A functioning emission trading scheme is crucial for further market development.

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ABSTRACT

The dedicated emission reduction and renewable implementation goals of several countries within the European Union led to the implementation of different support schemes and consequently to market development for biomethane. As the development and market penetration of biomethane as a renewable energy source is in most cases dependent on governmental support (in the form of incentive schemes or support programs) it is highly beneficial to be able to estimate the effects of planned actions. The current framework for biomethane encompasses high uncertainties within the market due to changing legislative conditions. Consequently this research presents a dynamic market model developed that is able to determine the effects of different policies and regulations to producing biomethane capacity, substitution pathways, land use and greenhouse gas emission reduction. It is the first model that encompasses the three sectors power, heat and transport in a dynamic model for biogenic energy carriers exploring the effects of new Government policies. Results indicate that a large proportion of the biomethane used today can no longer be produced economically when the financial support ends after a period of 20 years. Those plants, receiving a comparably high financial support, can only keep on producing and selling biomethane if there are other market opportunities than the CHP market. New instruments like blending could increase the biomethane sale in the direct heating market above the level shown in our results besides other measures like the prohibition of fossil fuels. The transport market would be able to compensate large proportions of the losses from the CHP market under a strong stepwise increment of the price for emission allowances.

1. Introduction

Among renewable energy sources gaseous energy carriers play an important role replacing fossil energy carriers in already existing infrastructure. Biomethane is one such energy carrier that has attracted large interest in the European Union and in Germany in particular and can be used for heat, power and transport fuel provision. Biomethane is a biogenic and gaseous energy carrier whose composition and energy content is very close to natural gas, depending on upgrading technology, feedstock and fermentation process [1]. It can be produced either by the production of biogas from anaerobic digestion of organic matter such as manure, sewage, organic waste, energy crops, etc. or by thermochemical conversion of lignin-rich biomass and an associated gas upgrading. While the production of biomethane from digestion dominates the market, the production of biomethane via gasification (bio-SNG) is a promising option for the mid-term future [2]. As this study is not about the production of biomethane it should be noted that more information on the different biomethane production pathways is

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available [3–5]). Like natural gas, biomethane can be fed into the gas grid, can be used for the combined production of heat and power (CHP), direct heat provision by natural gas burners, as fuel in compressed natural gas vehicles, being liquefied into liquefied natural gas (LNG), or as raw material in the chemical industry. Depending on the scope of application and the utilization pathway significant greenhouse gas emission reduction can be achieved substituting natural gas with biomethane [6,7]. The dedicated emission reduction and renewable implementation goals as well as the gas grid decarbonisation strategies of Germany and other European countries like the UK, France, Italy, Denmark or Switzerland led to the installation of different support schemes and consequently to market development [8].

The development and market penetration of biomethane as a kind of renewable energy is in most cases dependent on governmental support in the form of incentive schemes, support programs or similar [9]. However, governmental support for renewable energy is subject to ongoing adaptions. Long lasting support schemes or tax reliefs can end or be adapted, new support schemes can be designed to support the market transformation from an incentive – driven market to a market – oriented market. It is then important to be able to estimate the market reaction to changes of the legal framework. At the same time governmental support in form of policies and strategies has to be thought out because a higher share of renewable energy, and bioenergy in particular, is often associated with sustainability and climate change issues [10–13]. Modeling and evaluating renewable energy policies (ex-post or ex-ante) can be a helpful tool to estimate or determine the success of renewable energy policies [14].

In the past decade many studies were published about biomethane facility configurations [15–18], biomethane production potentials [19–24] and biomethane production and utilization pathways [25–29]. The implementation and realization of new facility configurations, potentials pathways and utilization pathways is in most cases dependent on incentive schemes, as the production of biomethane and its use is usually costlier than the counterpart natural gas. It is therefore of high interest to estimate the market's reaction to a change of the legal framework in addition to the ecological effects.

The approach presented here is the first of its kind that simulates the market reaction to a change of the market boundary conditions for a biogenic energy carrier. In addition it is the first market modeling approach considering the three end user markets for biogenic energy carriers (heat, transport and power). It is highly important to consider both the market reaction to a change of its boundary conditions and the effects to the three end user markets. The simulation model presented in this study is able to address both issues. Furthermore the simulation model is able to determine the behavior between the different sectors in terms of biomethane utilization. In doing so the presented model can determine the amounts of biomethane used in the different sectors and a switch of capacity between the sectors.

A literature analysis highlighted three research gaps: (i) a model considering the sectors power, heat and transport for policy effect modeling of a biogenic energy carrier, (ii) the absence of a dynamic simulation model for biogenic energy carriers determining the market reaction rather than using predefined trajectories and (iii) the absence of a (market) simulation model which is able to determine substitution pathways for natural gas [9,30–35]. It is therefore crucial to combine studies about new feedstock types; modified or newly developed technologies for biomethane provision; or innovative utilization pathways. This assessment provides a realistic estimation of market uptake of these issues as well as their chances of market uptake within a revised legislative framework. The approach presented here can be adjusted and modified using a system dynamics methodology which is implemented in the software package VENSIM [36].

Due to the framework conditions of biomethane described above and the aforementioned research gaps a dynamic market model has been developed. The model is able to determine the effects of revised policies and regulations in relation to production capacity, substitution pathways, land use and greenhouse gas emission reduction. The methodology used is system dynamics. To our knowledge, it is the first model that encompasses the three sectors power, heat and transport in a dynamic model for biogenic energy carriers. We decided to use Germany as a case study since it is the largest biomethane market worldwide. The proposed model enables decision-makers to benefit from estimating the possible effects of different decisions. Furthermore the approach enables an assessment of the implementation of newly developed production pathways and technologies and is therefore of high interest for other scientists developing them. In this way it is possible to estimate the market penetration of new biomethane production pathways in combination with incentive schemes.

1.1. Background information

1.1.1. The German case study

With 190 biomethane producing facilities by the end of 2016, Germany is the leading market for the production of biomethane throughout the world [37]. Biomethane in Germany is overwhelmingly used in CHP plants (87%), as fuel (4%) and for direct heat provision and export (9%) [38]. Besides production potential, technological and economic issues it is also important to consider competition with natural gas which is crucial for investment decisions influencing the market development [39]. The most important support scheme, the Renewable Energy Sources Act (EEG), was adapted in 2004 and first introduced incentives for biomass energy [6]. The first biomethane plant was connected to the grid in 2006. After an initial phase of information and material delay, continuous development of the biomethane sector has been realized. However, due to the most recent adaption of the EEG there is an almost encompassing stop to the construction of new biomethane production facilities.

1.1.2. Previous work

Since bioenergy is the most used renewable energy in the world, in Europe and in Germany it is an integral part of many studies dealing with the impact of new policies using dynamic modelling approaches [40–42]. For example, system dynamics has been used multiple times to estimate future effects of changing boundary conditions in renewable energy contexts [43–47]. Barisa et al. developed a system dynamics model to explore various policy schemes on increasing the proportion of bio-based fuels in the Latvian transport sector [44]. Romagnoli et al. tried to find the most suitable policy mix for the promotion of wood fuel in the Latvian district heating sector using a system dynamics model. They tested four different policies on their long-term effects on the substitution of natural gas with local biomass. Their results indicate that a mix of the four different policies will be the most promising option for the promotion of bioenergy in the Latvian district heating market [48]. Another approach using dynamic modeling for biofuel systems was performed by Shafiei et al.. They examine the capacity expansion strategies of biofuels and the market development potential of biofuel vehicles in Iceland [49]. Eker and van Daalen developed a system dynamics model of the biomethane production in the Netherlands under deep uncertainty [30]. Although there are some similarities to our study like considering both anaerobic and thermochemical biomethane and avoided greenhouse gas emissions there are some major differences between both studies. Whilst this study explores the capacity development under varying boundary conditions, Eker and van Daalen give a capacity goal in their approach. Furthermore both markets work in a totally different way and Eker and van Daalen do not consider the transport sector. However, their work shows the attention to renewable gas in other European countries.

1.1.3. Environmental and sustainability dimension

Sustainability of biomethane is a key issue for Government policy to support its development. In the EU the primary policy mechanism that has promoted biomethane implementation is the Renewable Energy