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A model-based analysis of biomethane production in the Netherlands and the effectiveness of the subsidization policy under uncertainty

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HIGHLIGHTS

- We developed a system dynamics model of the biomethane production in the Netherlands.
- Future states of biomethane production, subsidization costs and emission reduction show a wide variety.
- Long duration and relatively low subsidy prices are found to be robust values of the policy levers.
- The subsidization policy is most vulnerable to the investment behavior of biogas producers.

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ABSTRACT

Biomethane is a renewable alternative to natural gas. It has the potential to increase the sustainability of the energy system and to help deal with supply problems. However, several factors make the future of biomethane production complex and uncertain, such as resource availability, demand, capacity installation, profitability and the competition between the biomethane and electricity sectors for sharing the available biogas and biomass resources. In this research, we study the dynamics of the Dutch biomethane production and analyze the effects of subsidization policy with a system dynamics model. The policy is tested under uncertainty with respect to three conflicting objectives, namely maximizing production and emission reduction, and minimizing costs. According to the results, the subsidization is crucial to develop biomethane production, and the performance of the policy is enhanced in terms of robustness and of meeting all three objectives satisfactorily when the policy is implemented for a long time, with relatively low subsidy prices. Besides, the subsidization policy is found to be most vulnerable to the producers' uncertain investment response to profitability. In future research, different policy options such as subsidizing other biomass-based renewable energy options and policies affecting the biomethane demand can be tested.

1. Introduction

Renewable gas production has received much attention in many countries in recent years. Renewable gas can contribute to decreasing CO_2 emissions, it can be a local substitute for the depleting natural gas resources or imported gas, and it can extend the use of natural gas infrastructure constructed by very large investments. The term “biomethane” refers to renewable gas of which the methane content is adjusted to the natural gas quality standards so that it can be injected into the grid. The current resources of biomethane production are biomass and excess electricity. The technology of producing biomethane from excess electricity is called ‘power-to-gas’ which firstly transforms electricity into hydrogen, and then adds CO_2 to obtain methane. Both hydrogen and methane can be used to feed the grid, but the power-to-gas technology is not mature yet (Patel, 2012). Biomass is currently the main source for biomethane, and there are two production technologies: digestion and gasification. At present, biogas produced via digestion dominates the market. However, gasification of biomass has a higher yield, and its product named “synthetic” or “substitute natural gas” is a promising alternative (Foreest, 2012).

In a commodity market framework, biomethane production from biomass is influenced by several factors such as demand, resource availability and installed production capacity, which interactively determine the investment decisions, profitability, and the production volume of biomethane. Due to the complexity raised by these interactions, and the uncertainties regarding the

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technological and economical characteristics, the future dynamics of biomethane production cannot be investigated easily. Existing studies on biomethane production deal with two main subjects: practical production issues at the micro level (Ryckebosch et al., 2011; Angelidaki et al., 2009), or biomass availability at the macro-level (Hoogwijk et al., 2003; Faaij et al., 1997; Hedegaard et al., 2008). The process of biomethane production is analyzed at an operational level production chain framework in only a few studies. Yet, these studies mostly have a financial approach, and either analyze the net present value of the production and injection projects (Gebrezgabher et al., 2012; Balussou et al., 2012) or use static calculation models (Bekkering et al., 2010; Butenko et al., 2012). A study on the long-term dynamics created by the operational level interactions is still missing, as well as an analysis of policy effects on these dynamics.

In the Netherlands, biomethane has arisen as a promising alternative to the depleting natural gas resources and as a contributor to reducing CO_2 emissions. To increase the role of biomethane in the gas supply, several support schemes are applied by the Dutch government. However, due to the complexity of the biomethane production chain and the associated uncertainties, it is not known whether this goal can be reached. Therefore, this study investigates the long-term dynamics of biomethane production in the Netherlands, and analyzes the effectiveness of subsidization policy under uncertainty. For this purpose, a system dynamics simulation model has been built and used for generating a large ensemble of scenarios and exploring the effects of uncertainties. The subsidization policy is assessed and analyzed with respect to this ensemble of scenarios.

In the remainder of this paper, first the problem formulation using the policy analysis framework is presented in Section 1.1, and the modeling and analysis methodology adopted are explained in Section 2. Section 3 describes the scope and key components of the model. In Section 4, the results of the base run and uncertainty analyses are presented and discussed, and the paper is ending with conclusions in Section 5.

1.1. Problem formulation

In the context of model-based policy analysis, Walker et al. (2013) describe five components of the formulation of a policy problem, as seen in Fig. 1. These components are (1) *Value systems* (*W*) of the stakeholders and policymakers which include objectives and preferences, (2) *Outcome indicators* (*O*) that are determined based on the objectives of stakeholders and help assessing the performance of policies, (3) *Policy variables* (*P*) that are used to intervene the system and improve the outcomes, (4) *External factors/Uncertainties* (*X*) that affect the system and (5) the *System model* (*R*) representing the real system within certain boundaries.

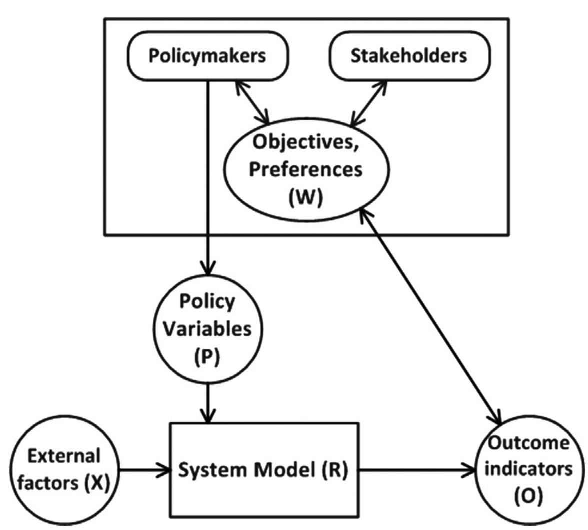

Fig. 1. Model-based policy analysis framework. Adapted from Walker et al. (2013).

The objectives aimed for by the subsidization policy are maximizing production and emission reduction, and minimizing costs. However, these objectives are conflicting since subsidization in principle increases production and emission reductions, but raises the costs. The complexity of the problem arises from the difficulty of finding the values of policy variables which are satisfactory for these conflicting objectives.

The Dutch subsidization policy is implemented in the model with three important policy levers. The first one is the duration of the policy, which indicates how long the subsidization is provided, starting from 2008. The other two policy variables are the subsidy prices paid to the producers, as a percentage of the unit production cost, for the two types of production (digestion and gasification). It must be noted that the model takes the budget constraints into account for the total amount paid.

Considering the biomethane production problem in this framework, the policy variables (*P*) of the subsidization policy and the outcome indicators (*O*) are summarized in Table 1. The system model (*R*) developed for this problem is based on the causal relations between resource availability, capacity construction, production, demand and prices, and it is described in Section 4. The uncertainties (*X*) affecting this system are mainly about the technology characteristics, costs, investment behavior of the producers, and future natural gas and electricity prices; and they are listed in detail in Appendix B.

In brief, this paper analyzes the subsidization policy, which is defined by three variables (P_{dig}, P_{gas}, P_{dur}), by evaluating its effects on the three outcome indicators (O_{prod}, O_{cost}, O_{CO2}) in plausible future scenarios generated by propagating the effects of uncertainties through the system model.

2. Methods

To investigate the future dynamics of biomethane production under uncertainty, the research methodology adopted in this study is Exploratory Modeling and Analysis (EMA). The EMA approach is based on Bankes (1993) who states that under deep uncertainty, a ‘best estimate’ future cannot be reached with comprehensive models or stochastic methods. In such cases, exploration of the future by systematically taking uncertainties into account is a better strategy than estimation. Besides, generating a huge set of scenarios and analyzing the outcomes of these scenarios facilitate robust decision making (Lempert et al., 2003). The extensive use of EMA was first investigated and demonstrated by Agusdinata (2008) and it has been used in several domains, for robust decision making (Lempert and Groves, 2010; Lempert et al., 2006), adaptive policy making (Hamarat et al., 2013, 2014), and future-oriented technology analysis (Kwakkel and Pruyt, 2013a).

System Dynamics (SD) is a modeling methodology used to analyze and understand the behavior of dynamic complex systems based on causal relations and feedback loops (Forrester, 1961; Sterman, 2000). The structure of an SD model is based on differential equations, and solving these equations numerically generates the model behavior. For the purpose of understanding and capturing the complexity of policy problems, SD has been successfully used in several studies on energy systems in general (Naill, 1992; Dyner, 2000; Davidsen et al., 1990), on the analysis of renewable energy systems and policies (Hsu, 2012; Rendon-Sagardi et al., 2014; Jeon and Shin, 2014) and biomass use