Energy Policy 63 (2013) 123–129

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

A microeconomic analysis of decentralized small scale biomass based CHP plants—The case of Germany

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HIGHLIGHTS

- A formal microeconomic model is used to analyse a decentralized biomass CHP plant.
- Model setup is used to generate numerical results based on real life scenarios.
- Nested CES production function is a new approach to model economics of biomass CHP.
- Analysis presents insight into microeconomics and cost drivers of biomass CHP.
- Evaluation of energy policy design with respect to environmental policy goals.

ARTICLE INFO

Article history:
Received 16 May 2013
Accepted 21 May 2013
Available online 28 June 2013

Keywords:
Biomass
Renewable energy
CES production function

ABSTRACT

Alternative energy sources, such as biomass CHP plants, have recently gained significantly in importance and action is due both on the large scale corporate level and on the small scale. Hence, making the scope and economic outline of such projects easily intelligible without losing relevant details seems a key factor to further promote the necessary developments. The model setup presented in this paper may therefore serve as a starting point for generating numerical results based on real life cases or scenarios. Its focus lies on the economic analysis of decentralized biomass CHP plants. It presents a new approach to analyzing the economic aspects of biomass CHP plants implementing a formal microeconomic approach. As Germany claims a leading role in the market for renewable energy production, the paper also takes a closer look on the effects of German energy policy with respect to biomass CHP plants.

1. Introduction

All over the world, the will to bring about a change in conventional energy production has been witnessed in both the social and political spheres, as manifested in documents or international events such as the Kyoto Protocol or Rio+20. To achieve the ambitious goals concerning CO_2 reduction, several measures are taken all over the world to significantly enlarge the scope of renewable energy production, both on a large scale and centralized or small scale and decentralized level. Aside from large projects such as North Sea wind parks or extensive solar parks, biomass has been considered a crucial and promising input factor to renewable energy generation (Hall, 1991). Even from early on, the potential of small-scale CHP plants has been analyzed (Evans, 1993; Durfait et al., 1993). Due to the EU's ambitious goals set to fight and mitigate climate change both the political and the scientific importance of the renewable energy potential of biomass and CHP plants has increased even further (Berndes and Hansson, 2007).

Scientific research on biogas based CHP plants is vast and substantial. Different aspects like the comparison of CHP systems with other technical concepts such as heat-only production (Wickart and Madlener, 2007), the trade-off between the use of biogas to CHP or as a transport fuel (Goulding and Power, 2013), the technological choice given a certain input factor scenario (Di Corato and Moretto, 2011), the assessment of the optimal sight (Rentizelas and Tatsiopoulos, 2010) or optimal size (Walla and Schneeberger, 2008) for a biogas based CHP plant or the analysis of the link between biogas plant performance factors on total substrate costs (Stürmer et al., 2011) have been reviewed. Despite this broad research on biogas based CHP plants, microeconomic analyses are sparse. Consequently our approach fills a research gap in this field. Furthermore, it is of significant practical importance as the scope and economic outline of a project are easy to grasp

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http://dx.doi.org/10.1016/j.enpol.2013.05.069

while still containing relevant details. In addition, it also creates a starting point for generating numerical results based on real life cases or scenarios.

With respect to the potential of small-scale CHP plants, however, the political and economic landscape of several EU nations has also been studied in detail. Evans (1993) as well as Toke and Fragaki (2008) have taken a look at the UK while Alboyaci et al. (2009) have focused on Turkey. Nonetheless, among EU nations, Germany is known for being one of the main actors in the shift towards renewable energy systems. [2] Various significant political and economic measures were taken during the last decade, which have been further accelerated since the disastrous events which occurred in Fokushima in 2011. An extensive study and resulting publication by König (2011) dealing with the German energy system shows that biomass CHP plants (B-CHP) may serve as promising measure to achieve both emission reduction as well as energy generation targets.

While this important study deals with comparing different types of biomass usage for energy production, we chose a different starting point for our analysis. In our paper, a formal microeconomic analysis and a numerical simulation of decentralized energy production based on B-CHP is conducted. We apply a nested constant elasticity of substitution (CES) production function approach to minimize the input costs of B-CHP. This approach has, to our knowledge, not been applied to B-CHP before.

Moreover, as it is the case that B-CHP are eligible for certain types of subsidies and benefits under the German FIT system – depending on the scale of the plant and the input factors used – the effects of and changes in this significant energy policy instrument are also incorporated into the analysis.

The paper is structured as follows: Section two provides a short overview of the general framework by describing recent developments in the German energy sector and touching upon the technical characteristics of a CHP plant and the distribution of CHP plants in Germany. Then, a brief summary of the theoretical background and related work in the field as well as the formal model setup is presented and analyzed. Section four illustrates the applicability of the model by a numerical example. Finally, section five is comprised of concluding remarks..

2. General framework

2.1. Status-quo of renewable energy in Germany

The contemporary political and legal environment of the German energy sector is primarily determined by the strategic decision of the German government towards an intensified usage of renewable energies in 2010 (Bundesministerium für Wirtschaft und Technologie (BMWi) and Bundesministerium für Umwelt, Naturschutz and Reaktorsicherheit (BMU), 2010). In 2011, this strategic focus was complemented by the decision for a nuclear power phase-out by the end of the year 2022 (Bundesgesetzblatt (BGBl), 2011). Also, various other ambitious goals were set, such as the reduction of greenhouse gas emissions by over 80% (compared to 1990) by 2050, or a decrease of primary energy consumption by over 50% in 2050 (compared to 2008). Eventually, the share of renewable energy is supposed to amount to at least 80% of gross final electricity consumption in 2050.

Following these decisions, Germany's already remarkable efforts on developing renewable energy technologies and realizing renewable energy infrastructures increased significantly. In 2011, the share of renewable sources with respect to total end-users' energy consumption (electricity, heat, fuels) amounted to 12.5% out of which approximately 67% came from bioenergy. Regarding electricity production, 20.3% (17.1 in 2010) of gross end-users' electricity consumption was provided by renewable energy sources out of which approximately 10% were generated by solid or liquid biogenic combustibles and 14% by biogas. Concerning heat production, renewable energy accounted for about 11% of gross end-users' heat production in 2011. Regarding the latter, biogenic resources play a particularly significant role, since approximately 91% of aggregate renewable heat production stems from biogenic resources (Bundesministerium für Umwelt, Naturschutz and Reaktorsicherheit (BMU), 2012).

Even though these empirical findings show quite a significant expansion of renewable energy systems over the past years, there are several obstacles in the way of achieving the respective targets. Among those, the expansion of the electricity grid currently has the highest priority on the political agenda, while the financing of the energy transition in general proves to be the main challenge. According to the results of several different studies, cumulative investment of approximately 235–335 billion euros (for detailed information see Erdmann, 2011; Bräuninger and Schulze, 2012) will be required for a successful transition. However, attaining funding from outside investors is proving to be difficult as investments in renewable energy are still classified as innovative and therefore as high risk. Consequently, a large part of the investments comes from private individuals who are mainly involved in local, decentralized projects. Overall, private financiers account for 40% of installed capacity in the entire renewable energy sector. Additional capital for local projects is also provided by farmers, who account for around 11% of aggregate investments in renewable energy systems (Kemfert and Schäfer, 2012).

2.2. Biogas based CHP systems in Germany

CHP systems play an important role in climate change mitigation as they provide the prospect of efficient utilization of primary energy resources and a reduction of CO_2 emissions. The key characteristic of a CHP system is its inherent capability to simultaneously produce heat and electric power. Compared to single output systems (e.g. the separate generation of heat in boilers or the generation of power in condensing plants), co-generation achieves higher energy efficiency levels of up to 90%. Consequently, fuel savings between 10 and 40% (depending on the technology used and the system replaced) can be attained. In principle various technological approaches are possible. The most widespread technical approaches involve steam turbines, steam piston engines, combined-cycle power plants and gas turbines (Madlener and Schmid, 2003).

It has proven quite difficult to assess the number of biogas based CHP systems installed. Studies focusing on CHP systems in Germany analyse either CHP in general and therefore provide cumulative data on biogas and natural gas CHP systems or they offer studies on biogas based energy infrastructures in general without differentiating between electricity – or heat – only systems or co-generation units. This paper focuses primarily on data from the German biomass research centre (Deutsches Biomasseforschungszentrum—DBFZ) which, according to its own statements, covers 90% of all registered biogas plants in Germany. Therefore, it provides a solid data base for assessing the aggregate number of biogas CHP systems installed in Germany. According to the DBFZ, 7055 biogas based plants were in operation in Germany in 2011, of which the majority (about 85%) have a maximum installed electric capacity of equal to or less than 500 kW. In general, these plants are spread out evenly across the country aside from clustering in Bavaria, Lower Saxony and sparsely

[2] http://www.bmu.de/en/topics/climate-energy/renewable-energy/general-information/.