BIOMASS AND BIOENERGY 35 (2011) 1572–1581

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Biomass from agriculture in small-scale combined heat and power plants – A comparative life cycle assessment

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ARTICLE INFO

Article history:
Received 7 October 2009
Received in revised form
29 November 2010
Accepted 21 December 2010
Available online 22 January 2011

Keywords:
Biogas
Gasification
Willows
Green manure
CHP
LCA

ABSTRACT

Biomass produced on farm land is a renewable fuel that can prove suitable for small-scale combined heat and power (CHP) plants in rural areas. However, it can still be questioned if biomass-based energy generation is a good environmental choice with regards to the impact on greenhouse gas emissions, and if there are negative consequences of using of agricultural land for other purposes than food production.

In this study, a simplified life cycle assessment (LCA) was conducted over four scenarios for supply of the entire demand of power and heat of a rural village. Three of the scenarios are based on utilization of biomass in 100 kW (e) combined heat and power (CHP) systems and the fourth is based on fossil fuel in a large-scale plant. The biomass systems analyzed were based on 1) biogas production with ley as substrate and the biogas combusted in a microturbine, 2) gasification of willow chips and the product gas combusted in an IC-engine and 3) combustion of willow chips for a Stirling engine. The two first scenarios also require a straw boiler.

The results show that the biomass-based scenarios reduce greenhouse gas emissions considerably compared to the scenario based on fossil fuel, but have higher acidifying emissions. Scenario 1 has by far the best performance with respect to global warming potential and the advantage of utilizing a byproduct and thus not occupying extra land. Scenario 2 and 3 require less primary energy and less fossil energy input than 1, but set-aside land for willow production must be available. The low electric efficiency of scenario 3 makes it an unsuitable option.

1. Introduction

The need for new systems for renewable energy generation is increasing, as ambitious energy policies such as the EU target of 20% renewable energy by 2020 [1] are taken into effect. Biomass for energy is one such source, with in particular biomass of agricultural origin being a large but so far not extensively utilized resource for energy generation [2].

Biomass from agriculture could in particular prove to be interesting for energy generation to rural areas where end-users are located close to the farm producing the biomass. This would avoid problems with transport of biomass, which in general has low bulk and energy density in its non-compacted form. The development of new technologies for the utilization of biomass in small-scale (≤100 kW(e)) combined heat and power (CHP) systems has progressed fast over the

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0961-9534/$ – see front matter
doi:10.1016/j.biombioe.2010.12.027

last few years, and there are now several technical systems available [3]. Some have been in commercial production for quite some time, like biogas production systems, that have been installed in thousands in Germany after the introduction of the German Renewable Energy Act in 2001, which guaranteed producers a certain price for the produced energy [4]. Other technologies, as the fuel-flexible small-scale Stirling engines are currently being commercialized by several companies [5] whereas small-scale gasification plants for biomass so far exist as demonstration plants.[6].

Agricultural land is however a limited resource and extensive energy crop production will displace food production and eventually result in that natural or semi-natural land is taken into agricultural production [7], for which there are adverse environmental impacts from the transformation of such lands to plantations for biomass or bioliquids production [8]. Moreover, the increasing production of energy crops has triggered a debate over moral aspects of using fertile land for other purposes than food production. A way of going around these problems is to focus on the use of agricultural byproducts for energy generation, or production of biomass on set-aside or marginal land not in use for food production. This could also be strategic from the economic perspective.

Byproducts available are for example straw from grain production. The realistic potential for use of straw for energy generation in Sweden has been estimated to about 7 TWh, of which about 0.5 TWh is used today [9]. Manure from animal farms and ley used as green manure in organic farming can be used as substrate for biogas production. A nitrogen-fixing ley crop is included in the crop rotation to be plowed back into the soil, which increases the concentration of nitrogen and organic matter. If the ley is digested and the digestion residues returned to the soils, the fertilization effect is probably better than from the undigested ley, according to some studies [10]. The number of organic farms is growing [11] as a response to increasing public interest for environmental issues which means that the potential for such biogas production could become significant.

Furthermore, the Swedish Board of Agriculture has quantified the amount of Swedish arable land that was set-aside or for other reasons not cultivated in 2008 to 1 50 000 ha [12]. Although it is likely that this land has been chosen to be set-aside due to a lower soil quality or an inconvenient location or shape of the field, this might not be an obstacle to growing energy crops on this land, for example willows (Salix). In particular, this is true if there are sufficient economic incentives for producing energy crops.

Reliable methods for measuring the environmental impact of the use of the biomass as primary energy source are crucial in order for policymakers and decision makers to make informed choices on suitable energy supply system. One such method that is gaining attention and fields of application is the life cycle assessment (LCA) methodology, in which the emissions from all processes along the production chain are quantified and summarized in different impact categories, as for example Global Warming Potential (GWP) and Acidification Potential (AP) [13]. The LCA methodology is standardized in ISO 14040 [14] and has been applied extensively to biofuels in the literature (Börjesson 2006 [15], Cherubini et al., 2009 [16], Ahlgren et al. (2008) [17] etc.) and also for policymaking, as for example in the sustainability criteria for biofuels under the Renewable Energy Directive [1].

This study investigates three different CHP production systems with organically produced biomass, from the consequential LCA perspective. The CHP plants were dimensioned to supply a nearby village with the entire annual heat and electricity demand, and fueled with byproducts from agricultural production or biomass that were produced on set-aside land. The systems were compared to a fourth system based on large-scale production of power based on fossil fuels. The purpose was to draw conclusions on which system that is preferable with respect to fossil energy requirement (FER), primary energy requirement (PER), land use (LU), global warming potential (GWP) and acidification potential (AP). While LCA studies today often focus on the production of a single type of biofuel, the systems here have been developed specifically to apply to a feasible situation in Sweden where a new group of houses are built on a certain distance from a city, making the use of existing district heating systems unrealistic from a technical and/or economic perspective. Previous LCA studies of biofuels often also exclude the impacts on the agricultural land of changes in cultivation methods, not least the soil carbon balance, whereas this study takes every consequence of the CHP system into account, including the carbon sequestration potential in arable soils.

2. Methodology

2.1. General system description and system boundaries

The study is a consequential LCA comparing four different scenarios for supply of heat and electricity to a village of 150 houses located in the county of Västra Götaland in South-western Sweden. In a consequential LCA, the differences in environmental impact (from a given set of impact categories) stemming from changes made to a reference system are quantified [18]. In this case, the reference system is production of cash crops according to a defined crop rotation at the farm, and the impacts on the reference system of the respective energy supply scenarios are quantified. The houses are assumed to be built within the coming five years with today's energy efficiency standards [19]. Three of the scenarios utilize biomass produced at a nearby farm for conversion to heat and power in small-scale CHP plants and are referred to as Bio1, Bio2 and Bio3. The production and processes required at the farm for each scenario are schematically described Fig. 1. In the fourth scenario, heat and hot water are produced by electricity-driven heat pumps, and all electricity is assumed to be produced in a natural gas-fired large-scale power plant. Natural gas (NG) is the most common fuel for thermal power plant currently planned or under construction in Europe [20] and is therefore assumed here to be the marginal electricity production technology on a long-term basis. This scenario is referred to as NG. The four scenarios are compared to a reference system where only food crops are produced at the farm.

It was assumed that the farm studied applies organic production methods according to the criteria stipulated in Council Regulation (EC) No 834/2007. Chemical pesticides or commercial fertilizers are therefore not applied. However,