BIOMASS AND BIOENERGY 70 (2014) 287–301

Available online at www.sciencedirect.com

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Time-dependent climate impact of heat production from Swedish willow and poplar pellets – In a life cycle perspective

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ARTICLE INFO

Article history:
Received 8 December 2013
Received in revised form
26 August 2014
Accepted 12 September 2014
Available online 5 October 2014

Keywords:
Pellets
Poplar
Willow
LCA
Climate impact
Global mean surface temperature change

ABSTRACT

Sweden has the potential to increase fuel pellet production from alternative raw materials, such as willow and poplar, and also to use former agricultural land for energy crop production. This study used a life cycle perspective to investigate district heat production from pellets produced from willow or poplar cultivated on fallow land in Sweden. The energy efficiency and global warming potential of the systems was evaluated, additionally was the climate impact, expressed in global mean surface temperature change, evaluated from annual greenhouse gas data, including the most relevant fossil and biogenic sources and sinks. The systems were also compared with a fossil fuel alternative in which coal was assumed to be used for heat production. The results showed that the systems investigated had a cooling effect on both global mean surface temperature and global warming potential within the 100-year study period owing mainly to an increase in live biomass and a more long-term increase in soil organic carbon (C), which shows the importance of land use. At the same time, the systems produced renewable energy. The poplar system contributed to a larger cooling effect than the willow system due to more C being sequestered in live biomass and soil in the longer growth periods between harvests and to higher yield. The energy efficiency of the willow and poplar systems used for pellet fuel production was about 11 times the energy input.

1. Introduction

Upgrading biomass to pellets with low moisture content, high energy density and homogeneous shape makes the product more suitable for transport and storage compared with the unrefined material. It is also relatively easy to replace fossil fuels with pellets in existing power or heat plants [1,2]. The interest in wood pellets has increased sharply during the past decade, with an increase in global production from 1.7 Mt to 15.7 Mt between 2000 and 2010 [3]. Many market actors predict a continuing major increase in global pellet production in the future [4,5]. The EU is the largest pellet market today and, as a consequence of the EU 20-20-20 targets, large-scale power producers in Europe are now planning on converting from coal to biomass fuels. New large-scale pellet plants are emerging, especially in North America and Russia, with the main aim of exporting to large-scale heat and power plants in Europe [5].

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http://dx.doi.org/10.1016/j.biombioe.2014.09.004

Sweden has a large bioenergy sector, providing 22% of total domestic energy input in 2011 [6]. However, despite relatively high production of pellets, 1.3 Mt in 2011, about 35% of the pellets used in Sweden are imported [7]. Residues from the sawmilling industry, *e.g.* sawdust, chips or shavings, have traditionally been the main materials used as raw materials in pellet production. In Sweden, however, these traditional resources are generally fully utilised and the pellet industry is now competing for raw materials with other industries, *e.g.* the pulp industry [8].

Life cycle assessment (LCA) is a commonly used method for evaluating the potential environmental impact of a product or a system, taking into account the entire life cycle and thus reducing the risk of problem-shifting from one phase to another [9]. Within LCA, climate impact is the most commonly used impact category. It is usually described as global warming potential (GWP) [10], which is expressed in CO_2-eq. by weighting the cumulative radiative forcing (CRF) of the different greenhouse gases (GHG) to the CRF of CO_2 over a defined time horizon [11]. The choice of time horizon determines the relative importance of long-term and short-term climate forces, with the importance of the latter decreasing with longer time horizons [12].

Bioenergy from crop products is usually considered carbon neutral within LCA with the assumption of zero net flux of biogenic CO_2, *i.e.* the same amount of carbon released during combustion of biomass is captured during regrowth of new plants [13]. However, this assumption has been criticised for not including temporal changes in C within the system [13,14]. In LCA, all emissions from the system are usually summed to a single pulse, irrespective of when in time they occur. Characterisation factors are then used to convert the net emissions to CO_2-eq. when assessing the climate impact [15]. This makes it impossible to capture the effect of time of emissions and the temporal fluxes of GHG inherent in a biomass-based system [13,14].

Ericsson et al. [16] propose use of the time-dependent metric global mean surface temperature change (ΔT_S), which encompasses the fluxes of GHG in the system over time. Presenting the climate impact as a function of time avoids the need to choose a defined time horizon. To calculate ΔT_S, a time-distributed life cycle inventory is needed, which could include annual carbon flows, both fossil and biogenic. A number of other climate impact assessment methods for including the temporary changes in bioenergy systems have also been proposed (*e.g.* [13, 17–21]).

Within Sweden, the potential exists to use former agricultural land for energy crop production. Since 1990, 275,000 ha of agricultural land have been abandoned and about 100,000 ha of this could be used for cultivation of energy crops [22].

Fast-growing and high-yielding broad-leaved tree species, such as willow and poplar, can become important renewable energy sources in Sweden [23]. Cultivation of willow and poplar can also have positive effects on *e.g.* farm diversification and the stands can be used as a vegetation filter for contaminated water [24]. Besides renewable energy production, establishment of willow or poplar on agricultural land can also function as a carbon sink, with an increased live biomass stock [16] and soil organic carbon (SOC) pool [10,25]. To date, there are few commercial poplar plantations in Sweden [26], but commercial willow plantations expanded in the 1990s, partly as a consequence of subsidies for establishing willow [27]. Today there are about 12,000 ha of willow plantations, primarily used for district heat production [28], but the competitive raw material costs and acceptable fuel quality mean that willow is also suitable for pellet production [29]. The higher ash content makes it not possible to produce high quality pellets, A1 according to European standard EN 14961-2, from solely willow or poplar. Larger-scale users are, however, often better equipped to handle low quality pellets [2].

With alternative raw materials, Sweden could increase pellet production so as to supply the Swedish market but potentially also to meet the increasing demand from the European market. Much indicates that pellets could be produced from alternative raw materials in Sweden with an acceptable environmental impact and environmental benefits relative to the energy source replaced. However, there is no well-documented knowledge about the environmental benefits from these systems.

The overall aim of this study was to examine the environmental effects of increased production of pellets from new domestic raw materials in Sweden. The specific objective was to assess the climate impact and energy efficiency in a life cycle perspective of heat production from pellets produced from willow or poplar cultivated on fallow land in Sweden. A conventional LCA was performed to evaluate energy efficiency and global warming potential of the system. In addition, the time-dependent effect on global warming, expressed in global mean surface temperature change, was calculated. This was done by recording GHG in a time-dynamic life cycle inventory (LCI) that included sources and sinks on an annual basis. The systems were also compared with a fossil fuel alternative in which coal was assumed to be used for heat production.

2. Method

2.1. System boundaries and functional unit

Two pellet systems were investigated using two different raw materials: willow and poplar. The willow and poplar were assumed to be cultivated in the Mälardalen region (59°N 16°W) in Sweden and then used for heat production in a district heating (DH) plant in the same region.

The system boundaries included raw material production, biomass transport to the pellet plant, pelleting, transport of pellets to a DH plant and combustion at the DH plant. All activities included are referred to here as the willow or poplar system. It was assumed that no technical improvement or increase in yield had occurred due to breeding or changes in management methods and short-lived climate forces (SLCF) and albedo effects were excluded. The yearly fluxes of the three major GHG gases contributing to global warming, CO_2, CH_4 and N_2O, were recorded in a dynamic LCI.

The functional unit was 1 GJ heat produced at a regional DH plant using willow or poplar pellets. However, the time-distributed LCI and time-dependent climate impact were