Renewable and Sustainable Energy Reviews 29 (2014) 369–382

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Greenhouse gas emissions of forest bioenergy supply and utilization in Finland

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ARTICLE INFO

Article history:
Received 6 March 2013
Received in revised form
17 August 2013
Accepted 24 August 2013

Keywords:
Bioenergy
Life cycle assessment
Greenhouse gas emissions
Feedstock
Sustainability
Forest biomass
Supply chain

ABSTRACT

The paper assesses greenhouse gas (GHG) emissions of forest bioenergy supply and utilization in Finland. Each step in the supply chains of harvesting residues (HR), small-diameter energy wood (EW) and stumps (ST) is assessed separately, with geography-related differences between Northern and Southern Finland (NF and SF) taken into consideration. Furthermore, the GHG performance of five distinct bioenergy options—(1) combined heat and power production, (2) condensing power production, (3) torrefied pellets, (4) gasification, and (5) pyrolysis oil production—is assessed and compared with that of current reference systems in Finland and also the European Union (EU) sustainability criteria. If soil carbon stock (SCS) changes and possible storage emissions are omitted, the GHG emissions deriving from the supply chain of comminuted forest biomass to plants are 2.4, 3.0, and 2.6 $gCO_2eq\ MJ^{-1}$ for HR, EW, and ST in SF, respectively. In NF, the corresponding values are 2.9, 3.6, and 3.2 $gCO_2eq\ MJ^{-1}$, respectively. If SCS changes and possible emissions from storage are accounted for, the emissions for HR, EW, and ST are in the ranges 9.2–49.2, 24.4–64.4, and 33.1–73.1 $gCO_2eq\ MJ^{-1}$ in SF and 12.7–52.7, 29.4–69.4, and 39.5–79.5 $gCO_2eq\ MJ^{-1}$ in NF. Most supply-chain GHG emissions arise from SCS changes and possible emissions from storage of comminuted biomass, both of which may involve significant uncertainty factors. In comparison to local reference systems, significant GHG savings can be achieved through energy utilization of forest biomass, but if SCS changes and, in particular, storage emissions are taken into account, fulfillment of the EU sustainability criteria is not guaranteed.

Contents

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.08.101

1. Introduction

Energy produced by combustion of biomass-based fuels is considered carbon-neutral [1]. For biomass from forests, the presumption is that, as long as the harvested areas grow back as forests, the carbon dioxide (CO_2) emitted will be recaptured in the growing trees over time [2]. However, in addition to the assumed forest re-growth, which should in time neutralize the CO_2 emissions released in combustion, there are several other steps in the process that have to be taken into account and various aspects to be considered when one is assessing the greenhouse gas (GHG) performance of bioenergy systems.

Life-cycle assessment (LCA), as a methodology, involves evaluation of all relevant process steps and environmental burdens associated with a given system, producing results that may be used in development of the system itself but that also should facilitate objective comparison between systems. Life-cycle assessment is the method chosen by the European Union (EU) for bioenergy sustainability assessments [3,4]. However, the results of LCA depend on input parameter values, system boundaries, allocation procedures, and the fossil reference system, and many key parameters vary with the system and by location [5,6]. Forest biomass from natural forests represents a geographically distributed feedstock, and geographical location affects the results of forest bioenergy LCA in several ways. For example, raw material's availability, forest operations, transportation possibilities, biomass end use, fossil reference systems, and forest carbon balances are all to some extent dependent on geographical location.

In 2009, the EU Renewable Energy Directive (RED) [3] introduced binding sustainability criteria for liquid biofuels, which will likely also be applied for solid and gaseous biofuels [4]. These requirements include 35% GHG savings in comparison to fossil comparator values, and they will become stricter, reaching a requirement of 50% and 60% savings, respectively, in 2017 and 2018 for new installations. Even though default GHG performance figures for various bioenergy systems and fossil comparator values are presented [3] and [4], the actual savings achieved, if any, vary. Therefore, for determination of whether or not these criteria are met by a given bioenergy system, comprehensive life-cycle GHG performance assessments are needed and indeed have been called for by many researchers [7–10].

The objectives of this paper are (1) to assess and summarize the GHG emissions derived from forest biomass supply chains in Finland and (2) to assess the net reductions in GHG emissions achieved via various forest biomass energy utilization systems relative to both the current situation in Finland and the EU's sustainability criteria. In the emission calculations of this study, sources and data that the authors assessed as representing Finnish conditions as realistically as possible were used. Also, previous relevant studies addressing the three most significant sources of possible GHG emissions are reviewed: soil carbon stock changes, emissions due to decay of comminuted forest biomass during storage, and forest fuel supply chains (i.e., emissions related to machinery use in the supply chains).

The categories of forest biomass assessed in this study include harvesting residues from final fellings (HR), spruce (*Picea abies*) stumps from clear-cuts (ST), and small-diameter energy wood from early thinnings or first thinnings (EW).

The results and information presented in this paper can be used in decision-making and further research examining various possibilities for use of forest biomass for energy in Finland as means to reduce GHG emissions, both from a legislative point of view (i.e., in terms of possible GHG savings calculated in line with the EU RED methodology) and from the perspective of the actual GHG savings possible under current conditions in Finland.

2. Materials and methods

When this was possible, emissions dependent on geographical location were assessed separately for Southern Finland (SF) and Northern Finland (NF) [11] (Fig. 1). The boundaries applied in the study are presented in (Fig. 2) and the feedstock properties in (Table 1).

2.1. Time horizon

In this study, the emissions were assessed in terms of global warming potential (GWP) on a 100-year time horizon (TH). The GWP value can be used for estimating the potential future climate impact of different gases in a relative sense [15], and it is the basis of, for example, the Kyoto Protocol, the EU RED, and the US Renewable Fuel Standard for long-term emissions [16–18]. Also, a 100-year TH can be considered appropriate for forest bioenergy assessments in Nordic conditions, since harvested forests can be assumed to re-grow completely in 100 years [19–21]. The GHG emissions are given as CO_2 equivalents (CO_2eq).

2.2. GHG emission assessment—EU RED methodology

The steps presented by the EC for bioenergy life-cycle GHG emission assessments were followed in the work reported upon here [3,4]. Forest bioenergy supply in Finland is based on "Forest Land Remaining Forest Land" [22], meaning that there is neither direct nor indirect associated land-use change. It was also assumed that the removal of forest biomass follows sustainable forest-management practices [23] and that future forest growth is not affected. Furthermore, on a nationwide scale, the current annual growth of forests in Finland also clearly exceeds the amount felled, resulting in a net increment of wood volume and carbon stocks in living wood. This trend is expected to continue [11]. Therefore, the emissions related to carbon-stock changes caused by land-use change were assumed to be zero. Also, emission savings from soil carbon accumulation via improved agricultural management, carbon capture, and geological storage or replacement, and from excess electricity generation from co-generation for liquid biofuels, are not relevant for the bioenergy systems addressed in this paper. Accordingly, the EU RED calculation procedure for forest bioenergy is as follows:

$$E = e_{ec} + e_p + e_{td} + e_u$$

where E=for liquid biofuels, total emissions from the use of the fuel; for solid and gaseous biofuels, total emissions from the production of the fuel before energy conversion, e_{ec}=emissions from the extraction or cultivation of raw materials, e_p=emissions from processing, e_{td}=emissions from transportation and distribution, e_u=emissions from the fuel in use.