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Environmental impacts of forest biomass-to-energy conversion technologies: Grate furnace vs. fluidised bed furnace

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ABSTRACT

Electricity production from biomass has the potential to significantly contribute to the power mix in Portugal with lesser environmental impact than non-renewable resources. This study focuses on electricity production from the combustion of residual forest biomass from eucalypt logging activities in Portugal using life cycle assessment. In Portugal, several power plants fuelled by residual forest biomass have been commissioned in the last few years. Most of the installations use fluidised bed furnaces, and the others use grate furnaces. This study aims to compare the environmental impacts associated with these two alternative combustion technologies. System boundaries include the stages of forest management, collection processing and transportation and energy conversion. The default impact assessment method used is that suggested in the International Reference Life Cycle Data System. In a sensitivity analysis, calculations are performed using the ReCiPe method. For all of the impact categories analysed, the fluidised bed presents the smallest environmental impact. Even when the grate furnace efficiency increases and the fluidised bed efficiency decreases in the sensitivity analysis, the fluidised bed has lower impacts than the grate technology and can be the best alternative in the implementation of new power plants.

1. Introduction

The demand for electricity is increasing in both developed and developing countries (EIA, 2016). Finding ways to provide less expensive and more environment-friendly electricity from renewable sources, namely, biomass, is becoming increasingly necessary to mitigate climate change (Nunes et al., 2016). Therefore, electricity production from forest biomass is one of the most important future markets for biomass worldwide. The primary energy supply of forest biomass used worldwide is estimated at about 56 EJ, thus indicating that woody biomass is the source of over 10% of all energy supplied annually. Overall, forest biomass provides about 90% of the primary energy annually sourced from all forms of biomass (WEC, 2016).

In Portugal, electricity production from forest biomass is being encouraged with the objectives of decreasing greenhouse gas (GHG) emissions, promoting the development of forest residue harvesting and reducing wildfire hazard (Conselho de Ministros, 2010). In Portugal, approximately 3.1 million hectares of land is covered by forests, which represent 35% of the national territory (ICNF, 2013), making Portugal a country with great potential for the exploitation of forest biomass. The annual production of residual biomass from forest logging in this country is estimated at 0.8–1.2 million dry tons per year (Viana et al., 2010; ENGASP, 2014), and about 47–58% of these residues come from eucalypt (Dias and Azevedo, 2004; Viana et al., 2010).

In 2016, residual forest biomass was responsible for the production of around 1% of the total electricity in the country (corresponding to 234 MW_e) (DGEG, 2016). However, this percentage is projected to increase through the new strategy implemented by the Portuguese government in 2017, which involves the concession of additional installed electricity production capacity for residual forest biomass plants (corresponding to an additional installed capacity of 60 MW_e) (Diário da República, 2017).

The technologies used in Portugal for residual forest biomass combustion are fluidised beds (13 plants in operation with an

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installed capacity of 192 MW_e) and moving grates (8 plants in operation with an installed capacity of 42 MW_e) (E2 p, 2017). Grate furnaces have been used for forest biomass combustion for heat and electricity production for years (Onovwiona and Ugursal, 2006; Liszka et al., 2013). However, fluidised bed furnaces have been proposed as the most suitable option for large-scale biomass combustion because of the growing awareness of environmental impacts linked to forest biomass combustion, energy efficiency and fuel flexibility, which are mostly related to the highly heterogeneous characteristics of biomass (Frey et al., 2003; Tarelho et al., 2011, 2015; Calvo et al., 2013).

The environmental impacts of such alternative forest biomass combustion technologies can be evaluated using life cycle assessment (LCA) methodology. LCA has been applied to quantify the environmental impacts of bioenergy production chains based on forest resources. However, most LCA studies evaluated the environmental performance of forest biomass to produce liquid biofuel or pellets (Gerbrandt et al., 2016; Jonker et al., 2016; González-García et al., 2011; Laschi et al., 2016), whereas only a few considered the environmental performance of using forest biomass for electricity production (Perilhon et al., 2012; González-García et al., 2014; Cambero et al., 2015). Most of these studies focused on the climate change impact category and disregarded other environmental impacts. Moreover, studies based on actual operating data, comparing fluidised bed furnaces with grate furnaces from an environmental perspective, are limited (Nussbaumer, 2003; Lombardi et al., 2015; Rummel and Paist, 2016) and not based on LCA methodology. Therefore, performing an objective and comprehensive comparison between the two technologies and their respective environmental impacts is crucial to provide support for decision making (Morin, 2014).

This work evaluated the environmental impacts resulting from electricity production in Portugal using eucalypt logging residues (composed of branches, foliage and tops) and considering two types of technologies: grate furnaces and fluidised bed furnaces. This assessment was performed using LCA methodology.

2. Methodology

2.1. Functional unit and system boundaries

The functional unit is the production of electricity from the combustion of eucalypt logging residues equivalent to 1 kWh delivered by the power plant to the Portuguese grid. Fig. 1 shows the system boundaries divided into three stages: (1) forest management (including site preparation, planting, stand tending and logging); (2) collection, processing and transportation (including bundling, forwarding, chipping, loading and unloading operations); and (3) energy conversion (including forest biomass combustion as well as treatment and final destination of wastes). The transport of workers and machinery as well as the production of capital goods (buildings, machinery and equipment) are excluded.

At the collection, processing and transportation stage, the processing of eucalypt logging residues has different configurations, namely, roadside chipping of loose residues, terminal chipping of loose residues and terminal chipping of bundled residues, as indicated in Spinelli et al. (2007) and Dias (2014). At the energy conversion stage, two different scenarios are considered: combustion in grate furnaces and combustion in fluidised bed furnaces. Therefore, six different scenarios are evaluated:

- S1A: Loose eucalypt logging residues are collected with a forwarder and chipped at the roadside using a mobile chipper. The chipped biomass is then loaded onto trucks and transported to the power plant. The conversion process of eucalypt logging residues into bioenergy is performed through combustion in a grate furnace.
- S1B: The loose eucalypt logging residue processing is similar to S1A. Energy conversion is conducted through combustion in a fluidised bed furnace.
- S2A: Loose eucalypt logging residues are collected with a forwarder and then transported by tractors with a semi-trailer to a terminal to be chipped. The chipped biomass is then loaded onto trucks and transported to the power plant. Energy conversion is conducted through combustion in a grate furnace.
- S2B: The loose eucalypt logging residue processing is similar to S2A, but energy conversion takes places through combustion in a fluidised bed furnace.
- S3A: Eucalypt logging residues are bundled into cylindrical bales in the clear-cut area with a bundler attachment mounted on a forwarder. The bundles are transported to a terminal by truck. Chipping takes place at the terminal before the transportation of chipped biomass to the power plant also by truck. Energy conversion is conducted through combustion in a grate furnace.
- S3B: The eucalypt logging residue processing is similar to S3A, but the energy conversion takes place by combustion in a fluidised bed furnace.

2.2. Allocation

Mass allocation is used at the forest management stage to allocate the environmental burdens among the different biomass outputs, namely, wood, logging residues, bark and stumps, removed from forest. Wood and bark are used by the wood-based industry, and the logging residues and stumps can be used for bioenergy or left on the forest floor. The amount of logging residues and stumps left on the forest floor depends on the technical and logistic restrictions as well as on ecological reasons; it ranges between 5% and 95% of the total quantity produced (CBE, 2004). In the current study, half of the eucalypt logging residues and stumps are considered to be left on the forest floor, and no environmental burden is allocated to these residues because they are not an output of the system.

The mass proportion of each biomass component is obtained on the basis of typical values (Tomé et al., 2006): 75.3% for wood, 10.3% for logging residues, 10.0% for bark and 4.4% for stumps.

2.3. Inventory analysis

2.3.1. Forest management stage

The operations included at the forest management stage are site preparation, planting, stand tending, eucalypt logging and infrastructure establishment.

Site preparation consists of clearing undesirable vegetation by disking, scarifying the soil (ripping followed by subsoiling) and fertilising with a ternary fertiliser (15% N, 12% P_2O_5 and 9% K_2O) and superphosphate (21% P_2O_5) applied together with subsoiling. Planting is a manual operation. Eucalypt stands are managed as coppiced stands in three successive rotations, each one at 12 years (Dias et al., 2007; Dias and Arroja, 2012).

Stand tending comprises cleaning, fertilisation and selection of coppice stems. Cleaning is conducted by disking at eight times per revolution (i.e. three successive rotations). Fertilisation is conducted with an N-based fertiliser (30% N) and a ternary fertiliser (15% N, 8% P_2O_5 and 8% K_2O) applied once per rotation. Coppice stems are selected with a chainsaw once in the second and third rotations.

Eucalypt logging in Portugal is usually performed with a harvester (when large areas are harvested) or a chainsaw. Harvesters are assumed to be used in eucalypt logging. Spinelli et al. (2009) also made a similar assumption.