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Research paper

Provision of pulpwood and short rotation eucalyptus in Bahia, Brazil – Environmental impacts based on lifecycle assessment methodology

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ABSTRACT

Environmental impacts from cultivation of eucalyptus pulpwood and short rotation eucalyptus in northeast Brazil were investigated using lifecycle assessment methodology. The assessment considers all relevant inputs and outputs, as well as direct land use changes, assuming conversion of grassland (pasture) to areas for eucalyptus plantation. Results show that production of pulpwood eucalyptus is beneficial compared to short rotation eucalyptus in relation to all assessed impact categories, except for climate change (greenhouse gas emissions = 47 kg CO_2-eq. t DM^{-1} pulpwood eucalyptus and 35 kg CO_2-eq. t DM^{-1} short rotation eucalyptus). Excluding emissions from direct land use changes would increase overall GWP from investigated systems with around 5–6%, and changing the assumed land-use prior to land conversion is of decisive character for overall GWP-results from the assessed eucalyptus production systems. Modeling of nutrient balances in the short rotation production system shows a potential need to increase the input of mineral fertilizer in order to compensate for nutrient losses. This would increase environmental impacts from the short rotation system, making pulpwood eucalyptus preferable in relation to all assessed impact categories.

1. Introduction

Brazilian planted forest areas cover almost 6.7 million of hectares and are composed of 77% eucalyptus and 23% pine [1]. Brazilian forest plantations areas have increased by more than 100% between 2003 and 2012. The major part of this expansion is related to eucalyptus, with a yearly growth rate of around 7%, while pine plantations demonstrate a considerably slower expansion rate. The most contributing sector to the increase of planted eucalyptus in the year 2012 was the domestic pulp and paper industry [1]. More than 90% of the Brazilian eucalyptus is used as raw material in the pulp and paper industry, while 10% is used primarily for production of wood panels and energy provision in the steel industry [1]. Following the large expansion, producers of planted forests are increasingly requested to reduce the environmental impacts of their products. A growing interest for certification of plantations is a clear result of this. Currently, 63% of Brazilian forest plantations are certified by the Forest Stewardship Council (FSC) or the national Cerflor program (Programa Nacional de Certificação Florestal) [28].

Use of lifecycle assessments (LCA) can be an important strategy to identify the most relevant environmental impacts and the main hotspots related to the product system [5]. Such identification is the first step in an improvement process. Several LCA-studies have previously been performed to estimate environmental impacts from provision of planted eucalyptus [25]. estimate environmental impacts from production of eucalyptus in Galicia, with a wood production of 5.2 t ha^{-1}, yr^{-1} (dry basis) and a life cycle of 15 years. The assessment was based on field data, on-site collected by means of surveys and interviews. The comprehensive assessment considers production and use of fertilizers and pesticides, transport systems, provision and use of fuel, labour use and CO_2-assimilation in growing biomass (estimated to 1.83 kg CO_2 kg^{-1} dry biomass). Authors state that logging operations caused the highest impact to GWP, acidification and photochemical ozone formation, while the main contribution to eutrophication was related to the use of mineral fertilizers. In addition, CO_2-assimilation was of large importance to overall GHG-emissions from system [16]. estimated

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Abbreviations

PW	Pulpwood
SR	Short rotation
LCA	Life cycle assessment
LCI	Life cycle inventory
FU	Functional unit
DM	Dry matter
dLUC	Direct land use change
iLUC	Indirect land use change
SOC	Soil organic carbon
AGB	Above ground biomass
BGB	Below ground biomass

environmental impacts from production of eucalyptus in Portugal with a 42 year lifespan over three cycles. GHG-emissions from the investigated system were, according to the authors, around 2.8 times higher compared to previous assumptions, the main reason being inclusion of N_2O emissions from fertilizers applied to the soil [48]. investigated production of eucalyptus pulp-wood (PW) in Brazil, based on data from three Brazilian producers located in the southeastern parts of the country. Use of fertilizers and pesticides were responsible for the major part of contributions to eutrophication and ecotoxicity, while diesel used in forest machinery together with production of ammonium sulfate fertilizers were responsible for the major part of GHG-emissions [48]. Ref. [24] investigated the environmental impacts from production of PW and energy short rotation (SR) eucalyptus in France. Short rotation is defined by the FAO [22] as high-density, sustainable plantations of fast-growing tree species, with a rotation period of less than 30 years and with an annual woody production of at least 10 tonnes of dry matter or 25 m^3 per hectare [12]. Authors demonstrate the large impacts from used harvesting technique to the need of fertilization input, based on calculated nutrient export from fields. According to this study, the need for N-fertilizer decrease to 30% when using log harvesting compared to full-stem harvesting. In the case of P and K, the need decreased to 74 and 60% respectively [24]. Thus, authors concluded that the environmental benefits from accelerated biomass growth and simplified harvesting in production of energy SR eucalyptus (3-year rotation) compared to PW (7-year rotation) were outweighed by their larger necessity of fertilizer input.

A clear indicator of the interest to decrease environmental impacts from biomass-based industries is an increasing interest for integration of new products together with main outputs in biorefinery concepts. In this way, utilization of infrastructure and logistics can be optimized. Optimization can also be made in terms of feedstock provision. Several biorefinery concepts are based on the use of waste streams or by-products as input biomass [11,52,54]. In these cases, feedstock provision commonly gives a low contribution to overall environmental impacts connected to biorefinery products. However, in cases were feedstock provision is based on dedicated biomass provision of feedstock can be a main concern for the environmental performance of biorefinery products. Previous studies of biorefinery concepts have shown that provision of dedicated biomass as feedstock can correspond to 20%–80% of total systems GHG-emissions, depending on chosen biomass and biorefinery concept [9,37,49]. As the choice of biomass could be of large relevance to overall concept environmental sustainability, decisions should be based on results from thorough assessments of environmental consequences of one alternative in relation to the other.

While the PW eucalyptus production systems have been developed over decades in Brazil, reaching a high grade of optimization, production of SR eucalyptus is still under development. Selection of productive hybrids and clones, improved silviculture, and ideal soil and climate conditions of Brazil for eucalypt-based forestry have led to mean productivities of 40–45 m^3 ha^{-1}, yr^{-1} in commercial plantations across Brazil [55]. At the same time, the short rotation system is still under development with substantial optimization potentials. According to Ref. [36], the largest concentration of SR eucalyptus is seen in the states São Paulo and Minas Gerais. Previous studies have however shown large potentials for use of SR eucalyptus of the same species investigated here (*E. grandis*), in provision of biomass for energy production [14,20], and an expansion of SR eucalyptus could be expected over coming years. Thus, investigations of the environmental impact from use of this biomass in different applications are of large relevance.

Based on the above, the aim in present paper is to investigate two different systems for biomass production, potentially useful as feedstock for a pulp-plant integrated biorefinery concept, from an environmental perspective. This evaluation will be made using LCA methodology, with the aim of identifying the processes with largest contribution to overall environmental impacts from each one of the investigated biomass production systems, and suggest improvements that could reduce the negative impacts from these processes. The integrated biorefinery concept where the produced biomass supposedly would be used is located in Bahia (Brazil). Thus, data on growth rate, density and inputs needed in the biomass production process were collected from a production plant in Bahia. As production conditions vary in different parts of Brazil, results might not be representative for production of the same species in other parts of the country.

2. Material and method

In the present study, LCA methodology, following the standards ISO 14040 and ISO 14044 [34,35], is used with the ambition of creating a hierarchy between the two alternatives and identifying aspects of key relevance for this relation. The assessment includes upstream impacts from provision and transport of inputs, forestry operations and transports.

ISO standards [34,35] and the European Commission Joint Research Center [18] recommend consideration of all relevant impact categories as well as reporting and justification of any limitations with regard to the impact coverage of the assessment in the scope definition. In the present study, impact categories considered were limited to Global warming potential (GWP), Eutrophication (EP), Acidification (AP), Eco toxicity (ET) and Human toxicity (HT), using methods recommended by Ref. [30]. The categories GWP, EP and AP were chosen as they commonly are included in LCAs of biomass [2], and inclusion enables cross-study comparisons. ET and HT were seen as relevant in this particular study, due to the use of mineral fertilizers and pesticides in the cultivation systems.

2.1. Functional unit

The functional unit (FU) is the quantitative description of the function provided by the analyzed system, meaning what it does, how well and for how long. In the present study, production of 1 kg dry matter eucalyptus wood was chosen as FU [10]. state that use of dedicated crop as feedstock calls for an FU which is related to land use (i.e. impacts per hectare), since the available land for production of biomass raw materials is the main bottleneck in provision of bio-based products. Although other studies have shown that this