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Comparing environmental impacts of different forest management scenarios for maritime pine biomass production in France

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ABSTRACT

Forest activities are receiving special attention in recent years concerning the quantification of their environmental profiles in order to be competitive. This study aims to evaluate the environmental profile of the production of maritime pine (*Pinus pinaster* Ait.) biomass in France under two different management scenarios (an intensive scenario: IMS and an extensive one: EMS), representative of the real practices in the country. Life Cycle Assessment (LCA) methodology was applied to evaluate the environmental loads from a cradle-to-gate perspective. According to the results, the choice of the best management scenario will depend on the impact category considered. Thus, IMS has lower fuel requirements and it is the best option in categories directly related to fuel consumption by forest machineries, such as abiotic resources depletion, cumulative energy demand, global warming potential and photochemical oxidants formation. On the contrary, EMS will be preferred in terms of acidification and eutrophication potentials with reductions of up to 26%. The reason behind these reductions is based on the fact that these categories are considerably affected by the fertilizing process, which is not conducted under extensive conditions. Regardless the scenario, the logging stage and specially, the final cutting process, can be considered as the main environmental key factors, playing a major role in all categories. Both the production of the triple superphosphate and pruning processes play leading roles in the IMS and EMS, respectively.

The comparison of these environmental profiles with those corresponding to maritime pine in Portugal highlights that the differences observed between both scenarios are related to the intensity of the forest practices as well as the biomass yield.

1. Introduction

The European forest sector is characterized by a great diversity of forest types, forest cover, socio-economic conditions and ownership structure (Berg et al., 2012). Nowadays, special attention is being paid to the promotion of forests as carbon sequesters for the mitigation of global warming (Briceno-Elizondo et al., 2006), being a key issue for forest managers. However, the management of forest systems involves other emissions and environmental effects which occur during their life cycle (e.g. fossil CO_2 emissions associated to fuel consumption, nitrogen based emissions from fertilizer application or changes in the content of organic carbon in soil). Therefore, the forestry sector has focused its efforts on providing information concerning its environmental performance in order to be competitive, especially in countries with a large forest tradition such as Norway (Michelsen et al., 2008), France, Germany or Sweden (Berg et al., 2012).

Maritime pine (*Pinus pinaster* Ait.) is an important forestry species in Europe, specifically in Portugal, North-western Spain and South-western France (Berg et al., 2012). It is characteristic of an Atlantic climate (de la Mata and Zas, 2010) and well adapted to sandy soil (Bercetche and Pâques, 1995). This study is focused on the identification and quantification of the environmental impacts associated with the maritime pine production in South-western France. The interest on this French region is based on its relevance in terms of maritime pine wood production in Europe. In fact, maritime pine represents 57% of the annual harvest in the South

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Atlantic Arc and more than half of the harvest is performed in this French region (Berg et al., 2012). Thus, maritime pine is dominant in 1.1 million hectares, representing 7% of the total forest area of the country (IGN, 2012).

The identification of the environmental burdens associated with forest systems is useful to support forest management decisions. Life Cycle Assessment (LCA) is a quantitative procedure to evaluate the environmental burdens associated with a product or a process and to identify opportunities to attain environmental advantages (ISO 14040, 2006). In fact, a number of environmental studies have been performed concerning forest systems by using LCA methodology. Forest activities related with Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) have been environmentally analysed in detail in countries such as Sweden, Norway and Finland (Berg, 1997; Berg and Karjalainen, 2003; Berg and Lindholm, 2005; Michelsen et al., 2008; González-García et al., 2009a). A similar approach has been followed for Mediterranean tree species, where Eucalyptus (*Eucalyptus globulus* Labill.) and Maritime pine plantations have been assessed in Spain and Portugal (Arroja et al., 2006; González-García et al., 2009b; Dias and Arroja, 2012).

This study aims to assess the environmental impacts derived from Maritime pine stands management in France by means of the LCA methodology, from a cradle-to-gate perspective (i.e. from the extraction of the raw materials to the loading of the logs onto trucks ready to be delivered to wood based industries). The choice of Maritime pine as the target species offers the possibility of analyzing its management under different production regimes (intensive and extensive), which potentially encounter differences not only regarding the biomass yield but also on the environmental profile.

2. Materials and methods

The environmental assessment was performed following the ISO 14040 (2006) standard in order to identify and evaluate the environmental profiles associated with Maritime pine biomass production in South-western France.

2.1. Goal and scope definition

Two different productive scenarios were constructed based on real forest management practices performed in this European country: an intensive management scenario (IMS) and an extensive management scenario (EMS). The purpose of this LCA study was to identify the best production management scheme from an environmental perspective in order to obtain high quality pine biomass for industrial applications (e.g. boards, paper pulp or furniture).

2.2. Functional unit

The function of this study is the production of maritime pine roundwood to be processed in forest sector related industries. According to the literature, one of the most common functional units considered in LCA studies of forest systems is the volume of harvested wood under bark (ub) (Berg and Lindholm, 2005; Michelsen et al., 2008; González-García et al., 2009a; Dias and Arroja, 2012). This functional unit is used by forest industries specifically when wood is destined to pulp or fibreboards production.

Therefore, one m^3 ub of fresh wood ready to be delivered to industry was considered as the reference for calculations. The basic density (weight of dry wood divided by the volume of green wood) is typically around 395 kg m^{-3}, the green density is 988 kg m^{-3} and the average moisture content is 60%. The average bark content (in volume) of the harvested wood is 16% (1 m^3 of fresh wood $\sim$0.84 m^3 of fresh wood under bark).

2.3. System boundaries

Two different forest management scenarios (IMS and EMS) of Maritime pine production located in South-western France were assessed from a cradle-to-gate perspective. Both scenarios were proposed because diverse silvicultural practices are applied depending on the forest managers. Remarkable differences between both scenarios were identified based on the requirement or lack of mineral fertilizers and herbicides and the repetition of certain forest activities such as the thinning step, variations which imply different biomass yields and rotation periods. While the IMS presents a rotation period of 28 years and an average biomass yield of 330 m^3 ub ha^{-1}, the production under extensive conditions (EMS) presents a higher biomass yield (394 m^3 ub ha^{-1}) obtained after 47 years.

The assessment under a cradle-to-gate perspective considers all the forest processes performed from soil preparation to wooden biomass delivery. The yield for each silvicultural scenario was taken from (AFOCEL, 2007). Both scenarios were built according to Chaperon and Cremière (1994), Gendreau (2008) and (AFOCEL, 2007). Advices from the regional center of forest ownership (CRPF) of Aquitaine, which aims at helping forest owners to manage their forest, were also considered. Therefore, both forest management scenarios were divided in three main phases:

- Phase 1: Site preparation. This stage includes the processes related with the soil fitting-out such as cut-over clearing, ploughing and agrochemicals application (fertilizers and herbicides) when necessary.
- Phase 2: Stand establishment and tending. Processes such as planting or seeding (depending on the scenario), cleanings and mechanical weed controls, thinnings, forwardings and loading onto trucks were included here.
- Phase 3: Logging. This phase considers the final cutting of the wooden biomass together with the corresponding forwarding and loading onto trucks.

System boundaries are schematically represented in Fig. 1. The production of capital goods such as tractors, tillage machineries, harvesters, pruning saws, forwarders and cranes as well as the infrastructure establishment (road and firebreak building and maintenance) were included within the system boundaries. The secondary haulage of wood from the forest roadside to the end-point was not considered since transport routes may be very different depending on the final use of the biomass. Other minor items such as the transport of workers and delivery of forest machinery and materials (herbicide, fertilizer, diesel, gasoline and lubricant oil) up to the forest land were excluded due to the lack of available information (Dias and Arroja, 2012).

2.4. Allocation

Allocation is one of the most critical issues in LCA studies. It is required for multi-functional processes and the selection of an allocation approach can have a strong effect on the results. In this cradle-to-gate analysis, allocation was not required since the total wooden biomass produced was considered as a single product, including the biomass from the thinning and final cutting steps. Forest waste generated in the pruning, thinning, harvesting, forwarding and loading steps (leaves, stools and branches) was not computed in the analysis since they are commonly left in the