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Forest operations in coppice: Environmental assessment of two different logging methods

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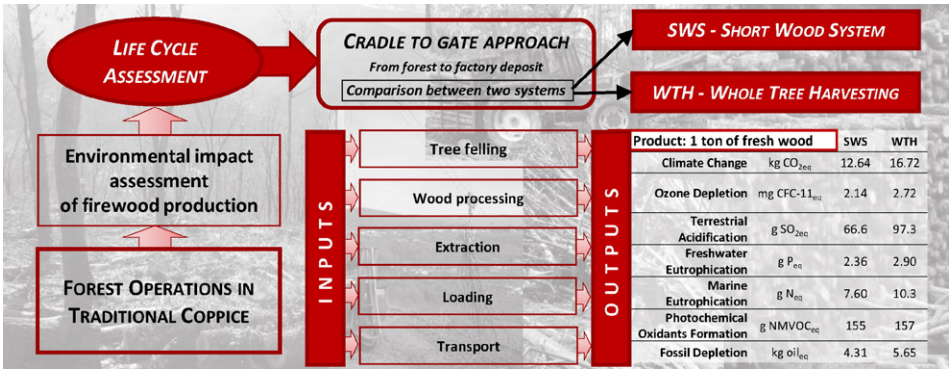
HIGHLIGHTS

- An environmental evaluation of firewood production in coppice was performed.
- Emissions to air, water and soil were evaluated by means of Life Cycle Assessment.
- Extraction phase was the environmental hotspot, due to high power requirements.
- Workers' transport to work-site added a not negligible amount of emissions.
- Emissions related with soil modifications after forest operations were considered.

GRAPHICAL ABSTRACT



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ABSTRACT

Wood is a renewable resource and it actively contributes to enhance energy production under a sustainable perspective. However, harvesting, transport and use of wood imply several consequences and impacts on environment. There are different ways for managing forests dedicated to wood production and a sustainable approach is fundamental to preserve the resource. In this context, Life Cycle Assessment (LCA) is a useful tool for estimating the environmental impacts related to renewable resources. Traditional coppice is a common approach for forest management in several areas, including southern Europe and, specifically, Italy, Spain and the Balkans.
Due to different terrain conditions, different types of forest operations are considered for wood extraction from coppices, where the main product is firewood used in domestic heating. The aim of this work was to compare the main common systems for firewood production in two different terrain conditions ('flat/low steep' and 'steep/very steep' terrains), in a representative environment for Mediterranean area, located in central Italy, by means of LCA. Seven different impact categories were evaluated in a cradle-to-gate perspective taking into account all the operations carried out from the trees felling to the firewood storage at factory.
Results showed that the extraction phase was the most important in terms of environmental burdens in firewood production and the use of heavy and high-power machines negatively influenced the emissions compared with manual operations. Finally, considering the general low-inputs involved in wood production in coppice, the transport of workers by car to the work site resulted on consistent contributions into environmental burdens. An additional analysis about the modifications of CH_4 and N_2O exchanges between soil and atmosphere, due to soil compaction in the extraction phase, was made and based on bibliographic information. Results showed a sensible difference between disturbed and undisturbed soil.

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1. Introduction

Forests cover almost one third of above sea level lands (Keenan et al., 2015). A multi-functional approach in forest management is applied in Europe (Sacchelli et al., 2013a) in order to guarantee constant wood production yields together with other ecosystem services such as recreational activities, environmental protection and hydro-geological protection (Saarikoski et al., 2015).

World energy demand is increasing (EIA, 2013) and a future key-role of wood in energy supply, as renewable resource, is expected (Haberl et al., 2013). Through the Renewable Energy Directive (RED) 2009/28EC (EU, 2009), European Union fixed the objective to reach the 20% of energy from renewable resources in 2020, being the 42% of total renewable energy production derived from wood. Hence, the importance of renewable energies, in particularly wood, from a perspective of emissions reduction, becomes evident. In the context of woody biomass production for energetic uses, coppices have an important role. In coppice systems the regeneration of broadleaved species consists mainly of sprouts originating from cut stumps and rotation period are shorter than high-forests (Bottalico et al., 2014). There are two main ways for coppice management: the Short Rotation Coppice (SRC) and the traditional management (Hauk et al., 2014; Spinelli et al., 2014). The first one is an industrial management focused on the maximisation of the biomass yield per year (Gasol et al., 2010; Picchio et al., 2012b; Roedl, 2010), while the second is an extensive management largely used in southern Europe (Jansen and Kuiper, 2004; Spinelli et al., 2014) with longer cutting period and lower biomass annual increment than SRC. SRC follows an agricultural approach and the highest amount of biomass is obtained by means of the cultivation of fast-growing tree species performing intensive forest operations such as tillage, mechanical plantation, fertilisation and, sometimes, irrigation (Roedl, 2010). The tree species commonly used are *Salix* spp. and *Populus* spp. (Weih, 2004) and the rotation period is normally between 2 and 6 years. The interest related to traditional coppice in terms of sustainability is associated to the extensive management of this type of forests and to the low impacts derived from these productive forests (Picchio et al., 2009). The main product in traditional coppices is generally firewood, even though in the last decade chips production has increased, mainly due to the extraction and chipping of logging residues (branches, tree tops, and other thin material) (Sacchelli et al., 2013b). In traditional coppice the rotation period is longer than in SRC, generally ranging from 18 to 35 years. Moreover, regeneration is natural, mainly from stump resprouting, while the renovation of died stumps is guaranteed by seeds (Piussi, 1994). For these reasons, plantations are not necessary in traditional coppice. Firewood has been the most consumed woody biofuel, with a worldwide annual production in 2013 of 1.9 Mm^3, satisfying the heating and cooking requirements of the 40% of world population (Guo et al., 2015). Despite the increasing consumptions of innovative products as wood pellets and briquettes, Europe still uses more firewood than any other industrial wood product for energy (Manzone and Spinelli, 2014). Firewood is the most successful wood product for domestic heating also in Italy (ISTAT Italian National Institute of Statistics, 2014), and coppice forests cover a surface of more than 3.5 million ha ("INFC - National Inventory of Forests and Carbon Sinks", 2005).

Extraction, transformation, use and disposal of renewable materials and fuels involve several processes with consequences on environmental spheres. Related environmental impacts should have to be identified and quantified to obtain their environmental profiles and determine their environmental sustainability versus fossil ones (Sumper et al., 2011). In this context, Life Cycle Assessment (LCA) become an interesting and appropriate method to evaluate the impacts related to the production and use of renewable materials (International Organization for Standardization, 2006). Effectively LCA is an internationally recognised methodology, which identifies, quantifies and environmentally analyses all the inputs and outputs involved in the entire life cycle of a product or service, including the production, use and disposal of it. For these reasons, LCA is used not only in industrial systems, where it was born, but nowadays it is largely employed also in forest sector (Klein et al., 2015).

LCA based studies have been discussed in the forest sector for the last 20 years (Klein et al., 2015), but there is still a poor amount of reliable information based on scientific research (Heinimann, 2012). Klein (Klein et al., 2015) tried to find the reason of this lack of information in the fact that, in forestry related LCA studies, the forest production is not the main objective of the study, and related information "is only deduced from literature or calculated starting from the latest stage of the forest product chain". However, there are some available studies which focused their attention on forest operations managing primary data in wood supply chain (González-García et al., 2013b, 2014b; Heinimann, 2012; Morales et al., 2015). Moreover, in the last years a huge number of environmental studies have been focused on forestry, especially in industrial forests (Berg and Karjalainen, 2003; Michelsen et al., 2008) and short rotation coppices (Bacenetti et al., 2016; González-García et al., 2014a, 2012; San Miguel et al., 2015). Very few studies analysed local woody supply chain, close-to-nature management (Mirabella et al., 2014; Pierobon et al., 2015) or traditional products (González-García et al., 2013a) probably attributable to the large differences in forest conditions, forest operations techniques and type of woody products at regional and national scale. The high variability in forest management, wood extraction, woody products manufacture, typical of forest sector, is well represented in Italy where forests cover more than ten million hectares (34.9% of total country surface) ("INFC - National Inventory of Forests and Carbon Sinks", 2005) along north to south, and where industry of wood biomass is well developed (Scarlat et al., 2013). Considering coppice forests under traditional management, Italy has a key role in Europe both for land occupation and firewood production (Sacchelli et al., 2013b; Suchomel et al., 2011).

The aim of this study was to investigate the environmental profile of wood biomass production considering the most used harvesting system for two different terrain conditions ('flat/low steep' and 'steep/very steep' terrains), in traditionally managed coppice forests. The analysis was planned in order to obtain a general overview in terms of environmental impacts related to wood biomass (mainly firewood) production. Moreover, an in-depth Life Cycle interpretation, focused on the potential role of soil modifications attributable to forest operations on the environmental profile in the analysed cycles, was carried out. Furthermore, an environmental comparison between the two systems was obtained considering work conditions and technical differences involved. The entire analysis was based on a cradle-to-gate approach under a LCA perspective.

2. Materials and methods

Life Cycle Assessment (LCA) is a standardised tool which allows assessing the potential environmental impacts related to the entire life cycle of a production system (International Organization for Standardization, 2006). In this study, forest operations in two different terrain conditions were analysed. Two different systems of wood extraction following a cradle-to-gate analysis were assessed, starting from the forest felling to the biomass stocking, ready to be distributed. Considering the high variability in the market of wood biomass, due to the different strategies of marketing and distribution, further activities such as wood distribution from the factory to final users, use and disposal (e.g. ashes) were excluded.

2.1. Description of the study

In this study, the productive chain of wood biomass from coppices under regional-scale in Tuscany region was analysed following the ISO 14040 guidelines (International Organization for Standardization, 2006). In particular, the main product obtained in coppice harvesting