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Assessing environmental costs and impacts of forestry activities: A multi-method approach to environmental accounting

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ABSTRACT

Concerns about greenhouse gas emissions and a possible future shortage of fossil resources are leading to a growing demand for wood biomass as a renewable material and energy source. In this context, forestry activities are increasing to meet the larger demand for wood biomass supply. Hence, there is also an increasing need for assessing environmental costs and impacts of forestry operations, considering both direct and indirect inputs supporting wood production systems as well as main outputs, co-products, and by-products. In this study, a multi-method assessment encompassing material, energy, and emergy demand as well as relevant emissions was implemented to explore the environmental performance and sustainability of timber and wood biomass production in the Alpine context of Fiemme and Fassa Valleys, Province of Trento (Italy). The Energy Return On Investment (EROI) calculated for timber and wood chips production was 51.9 and 28.1. These output/input energy ratios showed that the products' energy content was high compared to the direct and indirect fossil energy invested in both production processes. The global to local ratio of abiotic material calculated for timber and wood chips was 3.58 and 2.95, proving that about 2 times more matter flows were extracted and processed elsewhere than locally to supply the production processes. The fraction of renewable emergy calculated for timber and wood chips was 81% and 75% while the Emergy Yield Ratio (EYR) was 4.57 and 3.86, respectively, proving that the forestry system is considerably supported by renewable and locally available resources. The release of CO_2 was 855 and 133 t CO_2/yr when considering the whole Fiemme and Fassa Valleys. These last figures, compared to the potential of the two valleys for greenhouse gas mitigation, showed the ability of the investigated forestry sector to perform within the limits of the local carrying capacity in terms of CO_2 emissions. Finally, the scenario analysis highlighted the maximum production level compatible with a sustainable forest exploitation. In conclusion, the development of a multi-method approach to environmental accounting allowed a comprehensive assessment of forestry operations, providing a tool useful for local managers and policy makers committed to implement an environmentally sound management of forestry activities.

1. Introduction

Concerns about greenhouse gas emissions, rising energy prices and shortage of natural resources have led to an increasing interest for wood biomass as a renewable material and energy source. One target of the European Union is to reduce greenhouse gas emissions and use of fossil fuels by increasing up to 20% the share of renewable energy by 2020.

Forests in Europe are growing at a high rate as only two-third of their annual increment of wood biomass is removed by felling. Still, Europe remains one of the main roundwood producers in the world and, therefore, the proportion of increment that is utilized is likely to increase in the future (FAO, 2011; Köhl et al., 2011). The balance between net annual increment and annual felling has been the main criterion for assessing the sustainable exploitation of forest ecosystems over time.

Many studies on forestry operations have focused the attention on greenhouse gas balance (Kilpeläinen et al., 2011; Lindner et al., 2002; Routa et al., 2011; Sonne, 2006; White et al., 2005). CO_2 and other greenhouse gases are emitted as a consequence of harvesting, management, and logistic operations related to wood biomass production. The carbon neutrality of biomass production and use has been questioned due to indirect emissions of CO_2 and other greenhouse gases (Pyörälä et al., 2012). Furthermore, direct inputs (inputs that are directly used and locally managed) and indirect inputs (energy and material flows used by upstream processes) are needed to support wood production systems. For this reason, it is important to account for both direct and indirect energy and

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material demand as well as output emissions due to forestry activities and management (Franzese et al., 2009; May et al., 2012).

In previous studies, life cycle assessment (LCA) has been used to evaluate the environmental impact of forest ecosystem exploitation. Seppälä et al. (1998) carried out a LCA of the Finnish forest industry whereas Berg and Lindholm (2005) investigated energy use and environmental impacts of forest operations in Sweden. May et al. (2012) evaluated wood production from Australian softwood plantations compared to native hardwood forests, paying particular attention to embodied energy and water use. Franzese et al. (2009) compared the use of Gross Energy Requirement and Emergy Accounting to explore the sustainable production of short rotation willow production in Sweden.

LCA has also been used to study the environmental sustainability of wood production and bioenergy chains in Italy. Valente et al. (2011) performed a LCA for evaluating the impacts of a wood biomass supply chain for heating plants in the Italian Alpine region. Cambria and Pierangeli (2012) evaluated the environmental impact of high quality timber production in southern Italy. Fantozzi and Buratti (2010) employed the LCA methodology to evaluate the efficiency and sustainability of wood pellet production in Italy by considering the whole process, from field growth to ash disposal. Similarly, Caserini et al. (2010) compared the environmental impact of wood biomass use in small domestic appliances and centralized combined heat and power plants in northern Italy, mainly focusing on net savings of greenhouse gas emissions when using wood biomass instead of fossil fuels.

Other authors like Lindner et al. (2010) and Päivinen et al. (2012) assessed the sustainability of forestry-wood chains by implementing a multi-criteria assessment integrating environmental, economic, and social aspects.

Evaluations based on only one criterion and disregarding the whole life cycle of forestry operations may lead to partial and often misleading results. Therefore, a life cycle assessment perspective and multi-criteria assessment frameworks should be widely applied to reach a more comprehensive understanding of human–environment interactions through a large set of indicators (Buonocore et al., 2012; Franzese et al., 2008, 2009, 2013; Häyhä et al., 2011; Ulgiati et al., 2006, 2010, 2011; Viglia et al., 2011).

In this study, an extended LCA perspective was applied by integrating different environmental accounting methods within a consistent assessment framework capable of evaluating direct and indirect inputs of matter and energy as well as emissions and related impacts due to forestry operations. The multi-method approach was implemented to investigate the environmental performance and sustainability of forestry activities in Fiemme and Fassa Valleys (Province of Trento, North Italy), by focusing on the environmental costs and impacts of two integrated forestry operations: timber and wood chips production.

2. Materials and methods

2.1. The study area

The Province of Trento is an Alpine region located in northeastern Italy. It covers a surface of about 620,700 ha in which more than half of the land area (345,180 ha) is covered with forest. Therefore, forest ecosystems play an important role in this region in generating provisioning ecosystem services such as timber, food (berries, mushrooms, and game), fodder, and wood biomass for energy purpose (Goio et al., 2008). In addition, other important ecosystem services provided by the forest ecosystem are: supporting (primary production, soil formation, nutrient cycling), regulating (climate regulation, water purification, hydro-geological protection), and cultural ecosystem services (education, recreation).

Fiemme and Fassa Valleys are located in the northeastern part of the Province of Trento and embrace a productive forest area of 40,000 ha. Norway spruce (*Picea abies* L.) is the dominant species mixed with larch (*Larix europaea* Mill.) and Scots pine (*Pinus sylvestris* L.). European larch and Scots pine are two pioneer tree species and, consequently, these species are abundantly present on abandoned rangelands and on steep slopes. The Swiss stone pine (*Pinus cembra* L.) is found at the higher elevations up to the timberline. Silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.) are quite rare as their presence is restrained by the continental climate and human management, which always favored spruce because of its most valuable timber (Pollini et al., 1998; Price and Butt, 2000).

In the Province of Trento all forestry activities take place according to forest management plans which are key planning documents for ensuring the sustainable management of local forest ecosystems. The forest management plans allow maintaining and fostering the implementation of multiple long-term sustainability goals (Carbone and Savelli, 2009). In particular, the forest management plans, regulating forest resource use over a medium term of 10 yrs, are drawn by forestry experts and approved by a local administrative office in charge for governing landscape and environmental resources of the Province of Trento. Forest management plans give indications regarding all actions needed to improve forest structure and growth, and suggest selective cutting practices allowing the remaining forest to naturally regenerate over time. The total forest area is divided into forest blocks representing homogenous forest areas. The balance between increment of wood biomass and felling ensures the sustainability of timber production over time. In the study area, the rate of wood production is relatively constant over time. The average annual increment for Fiemme and Fassa Valleys is 4.5 $m^3\ ha^{-1}$ while the average annual felling is 2.8 $m^3\ ha^{-1}$. The average amounts of timber and wood chips produced in Fiemme and Fassa Valleys are about 106,000 and 9000 m^3/yr (PAT, 2010). In the Province of Trento, herbicides and fertilizers are not used in the forest management practices.

Wood is annually assigned to forestry companies for cutting, preparation, yarding and transport. Logging operations start at the forest stand where trees are felled with chainsaws. The whole trees can be extracted with mobile cable yarders to a landing area where tree branches are removed and the stem is cut into appropriate lengths. Trees can also be felled, delimbed and bucked with chainsaws at the stump and then tree lengths are extracted by cable yarder or winches. By considering both forestry practices, more than half (57%) of the total amount of branches, bark and tree tops produced in the valleys is converted into wood chips for local bioenergy production while the remaining fraction (43%) is left on the soil for nutrient cycling.

2.2. The multi-method assessment framework

In this study, timber and wood chips production in Fiemme and Fassa Valleys was investigated by implementing a multi-method assessment framework including several environmental accounting methods jointly applied to provide a comprehensive set of intensive and extensive indicators referring to multiple scales and dimensions (Ulgiati et al., 2011). Extensive indicators account for total (direct and indirect) flows of environmental resources supporting the investigated system, also including hidden flows occurring at larger spatial and time scales. Extensive indicators are related to the physical size of the system while intensive indicators are relatively independent on the physical size of the system and provide a measure of environmental performance in relation to generated products (e.g., material or energy used per unit of generated products).