Apple orchard pruning residues as a potential bioenergy source in South Tyrol: a LCA case study

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Abstract
Agricultural residues are among the cheapest and most widespread biomass resource. Pruning residues (PRs) from fruit orchards could integrate the traditional wood products for energy production. This study presents the life cycle assessment of energy production from apple pruning residues (PR). The case study is performed in the autonomous province of Bolzano-Bozen (N Italy), where apple orchards constitute the major agricultural cultivation. Two alternative systems are investigated: the reference scenario (S1) that represents the customary apple production and where PRs are chipped and let on the ground, and an alternative scenario (S2), which implies the use of PRs for energy purposes. Preliminary results show that PRs represent a suitable source of biomass for energy purposes, producing several environmental benefits, such as greenhouse gas emissions savings and a reduction in non-renewable energy consumption.

Introduction

The use of biomass for energetic purposes has increased enormously over the last years. However, the biomass production and conversion, and the bioenergy distribution do not automatically imply sustainability. To reduce possible negative consequences (i.e: deforestation, biodiversity loss, food-feed competition, additional pressure on water sources and increased demand of agricultural land, inputs and commodities) institutions provided basic guidelines for a sustainable management of bioenergy, at International, European and National level [1, 2]. A common suggestion is to use existing biomass resources, such as residues from agricultural and forest industries, from animal husbandry and from urban wastes [3,4], instead of cultivating dedicated energy crops. Pruning residues (from now on abbreviated PRs) from fruit cultivation could be a source of biomass for energy purposes [5].

In South Tyrol (N Italy), forest wood plays a key role as biofuel, especially for thermal energy production. However, the current forest biomass could not fully satisfy the energy demand [6]. PRs from apple orchards could complement the biomass need. In fact, about 24000 ha are dedicated to fruit cultivation, and the woody biomass obtainable reaches about 98200 m^3yr^{-1}[6]. Though PRs represent a useful biomass source for energy production, their harvesting and removal from the fields could influence negatively the soil fertility by exporting organic matter and nutrients [7,8]. Moreover, it is necessary to test if the bioenergy chain produces a significant reduction of greenhouse gases emissions respect the traditional oil-fuel chain.

The aim of this study is to assess the greenhouse gas emissions and other environmental impacts of harvesting apple (*Malus domestica*) orchards pruning residues (PR) for energy purposes, in order to give useful indications for a sustainable "agro-energy" chain. The assessment is carried out with the Life Cycle Assessment (LCA) approach, considered as one of the best methodology for the evaluation of the environmental burdens associated with biofuels production [9].

Material and Methods

The LCA is performed according to the ISO standards 14040:2006, using the software SimaPro7.3.3 developed by PRé Consultants (PRé Consultants bv, Amersfoort, The Netherlands). The goal of the study is to analyse the environmental performance of a system producing energy from apple orchard pruning residues. Indeed, two different scenarios are investigated: the production of apple involving the customary

management of PR (S1), where PR are chipped and let on the ground, and an alternative scenario (S2), which implies the harvesting of PR and their transformation in electricity and thermal energy. Moreover, the production of 1kW of electricity obtained from the PR transformed in a co-generating combustion plant of 6400kWth, and the production of 1kW of electricity from the national energy grid mix are compared.
The functional unit used is the production of apple during the entire life cycle (20 years) of 1 ha of a representative orchard in South Tyrol. The system boundaries comprise all the apple production phases (i.e: nursery, soil preparation, plantation, irrigation, fertilization, pest control, inter-raw grass management, etc.), pruning and chipping operations. In S2, PR harvesting and the energy conversion of PR in a medium scale co-generating combustion plant are also considered.
The majority of the data was provided by Laimburg Research Centre for Agriculture and Forestry (Ora, Italy), where specific field surveys have been also carried out. Literature sources, LCA databases, and expert advices were also consulted. The main input and outputs of apple cultivation are reported in Table 1. Direct land use change is taken into account too, according to the Ecoinvent guidelines [10]. In effect, when a land is converted to agro- or energy-production there could be positive or negative impacts, depending on the previous land use [9]. IMPACT2002+ method [11] is used for the Life Cycle Impact Assessment (LCIA) phase. The environmental impacts analysed in this work are: global warming potential (GW) expressed in kilograms of CO_2 equivalents (kgCO_2eq), non-renewable energy consumption (NRE) expressed in MJ of primary non-renewable energy (MJprimary), aquatic ecotoxicity (AE) and terrestrial ecotoxicity (TE), stated as kilograms of triethylene glycol equivalents into water (kg TEG water), and kilograms of triethylene glycol equivalents into soil (kg TEG soil), respectively .

Results

The preliminary results of this study are showed in Table 2. The auxiliary components (i.e: cement poles, steel cables and hail protection components) causes the higher impact of GW and NRE consumption, due especially for their transport. The cultivation phase, the fertilization and the pest management are the main responsible of the ecosystem quality damage (AT and TE). On the whole, the fossil fuel use for transportation and the land-use change produce the higher impact for resources depletion.
Compared to S1, the alternative system (S2) presents lower impacts for all the categories considered (Fig.1): S2 generates lower AE and TE impacts (of 67,92% and 81,48%, respectively), it generates a CO_{2eq} savings of about 3%, and a reduction of primary energy use of 3,32%.
Figure 2 points out as the production of 1kW of electricity using PR as bioenergy source produce significant environmental benefits respect the production of the same quantity of electricity derived from the national grid energy mix.

Table 1. Principal input and output of apple cultivation in the reference system (S1).

Parameter	Unit	per hectare	per kg of apple
		ha^{-1}	kg^{-1}
Apple yield	kg y^{-1}	6.982,50	1
Pruning residues	kg y^{-1}	4.215,90	0,604
Diesel	l y^{-1}	1.243,00	0,178
Irrigating water	l y^{-1}	3.553.400,00	508,901
N-fertilizer	Kg N y^{-1}	90,45	0,013
P- fertilizer	Kg P y^{-1}	32,30	0,005
K-fertilizer	Kg K y^{-1}	83,27	0,012
Fungicides	Kg AS y^{-1} *	27,52	0,004
Herbicides	Kg AS y^{-1} *	3,59	0,001
Insecticides	Kg AS y^{-1} *	10,51	0,002

*Active substances (AS)

Table 2. Environmental impacts caused by the main phases of the cultivation of 1 kg of apple in the customary scenario (S1).

Main operations	Impact categories*							
	Global warming (GW)		**Non-renewable energy (NRE)**		**Aquatic ecotoxicity (AE)**		**Terrestrial ecotoxicity (TE)**	
	Kg CO_2eq	%	MJ primary	%	kg TEG water	%	kg TEG soil	%
Nursery**	0,04	17,29	0,63	17,69	2,32	3,50	0,80	1,68
Cultivation§	0,02	9,69	0,33	9,25	22,78	34,41	19,39	40,63
Fertilization & pest control^	0,02	8,72	0,23	6,53	29,65	44,79	19,36	40,56
Ancillaries#	0,14	64,29	2,39	66,53	11,45	17,30	8,18	17,14
Total	0,22	100	3,59	100	66,19	100	47,74	100

*Impact categories from IMPACT2000+ method.

** Includes all the operation carried out in the nursery.

§ Includes all the operation of soil preparation, planting, irrigation, etc.

^ Includes all the operation of fertilization, pest management (use of herbicides, fungicides and insecticides).

Refer to the auxiliary components of the orchard (cement poles, steel cables and hail protection components).

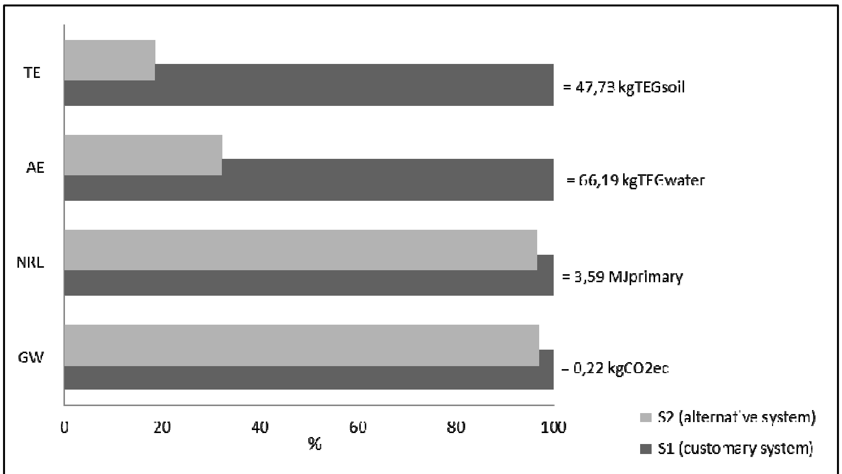

Figure 1. Environmental impacts of S1 and S2. Values are related to 1 Kg of apple.

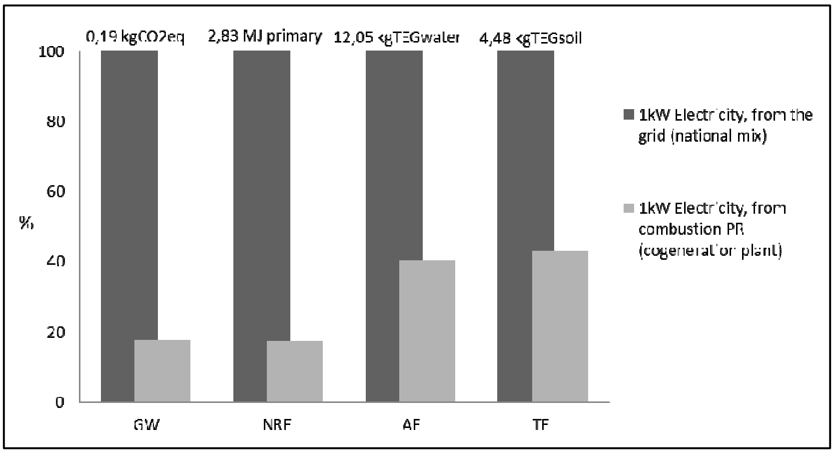

Figure 2. Environmental impacts of the production of 1 kWe of electricity obtained by the reference system (the national energy grid mix) and by the combustion of PRs in a co-generating plant (6400kWth); the reference system is assumed as baseline (index= 100%). Values are related to 1 kWe.

Conclusion and perspectives

The study demonstrates that PRs represent a suitable source of biomass for energy purposes, producing several environmental benefits, such as greenhouse gas emissions savings and a reduction in non-renewable energy consumption. The impact on aquatic and terrestrial ecotoxicity is reduced too. Nevertheless this result should be critically analysed. Harvesting agricultural residues produces a loss of macro- and micro-nutrients and a change in the soil carbon organic matter. According to previous study [12], we roughly estimated that, harvesting the PRs cause a loss of 819,7 Kg ha^{-1} y^{-1} of carbon (C), 16,5 Kg ha^{-1} y^{-1} of nitrogen (N), 3,3 Kg ha^{-1} y^{-1} of phosphorus (P) and 10,2 Kg ha^{-1} y^{-1} of potassium (K). Probably in S2 there will be the necessity to balance these losses increasing the amount of fertilizers, with repercussions on the environmental impacts. The discrepancy between S1 and S2 for AE and TE categories is due essentially to the removal of N and the heavy metals present in the PRs. We noticed that the removal of macro-, micro-nutrients and heavy metals contained in the biomass, is always considered a positive consequence by the software. However, the biomass harvesting could imply a further soil depletion, especially when the soil is sandy or poor in organic matter. As current LCA methods do not consider the risk of soil fertility depletion, as underlined by several authors [9, 13], further studies are necessary to implement the impact categories and improve the LCA software. Moreover it is necessary to analyse different energy production techniques, different plant-scales (i.e: combustion vs gasification, district heating vs house-scale plants) and implement the LCA analysis with economic and social studies, in order to identify the more sustainable PR-energy-chain.

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