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Exploring the production of bio-energy from wood biomass. Italian case study

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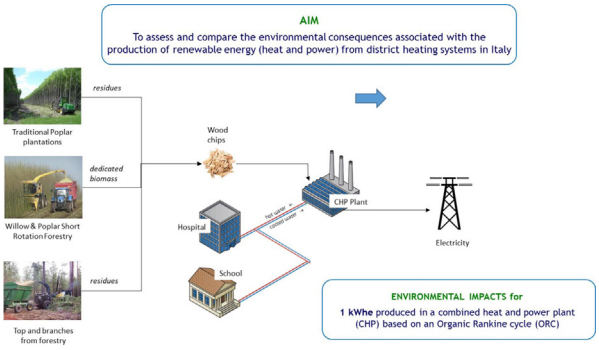
HIGHLIGHTS

- Environmental performances of firing woody biomass in a CHP plant are determined.
- Comparison with marginal electricity is performed.
- Feedstock distribution can be key to improve the profiles.
- Savings in GHG emission and fossil fuels demand are achieved using biomass.
- Use of biomass involves worse profiles in human toxicity and eutrophication.

GRAPHICAL ABSTRACT



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ABSTRACT

The concerns related to the environmental impact related to energy production from fossil fuel are increasing. In this context, the substitution of fossil fuel based energy by bio-energy can be an effective solution. In this study, the production of electricity and heat in Italy in a combined heat and power plant (CHP) based on an Organic Rankine Cycle (ORC) turbine from wood based biomass both from forest and agricultural activities has been analysed considering four potential alternative scenarios to the current energy status: biomass from very short rotation forestry (VSRF) poplar and willow stands as well as residues from natural forests and from traditional poplar plantations. The evaluation has been performed by applying Life Cycle Assessment (LCA) method and an attributional cradle-to-gate approach has been followed. The expected savings of greenhouse gases emission and fossil fuels demand have been quantified, as well as derived emissions of toxic pollutants and substances responsible for acidification, eutrophication and photochemical oxidant formation.The results have been also compared with the conventional Italian scenario considering the current Italian electricity profile and heat production from natural gas. Among the different scenarios, due to the lower transport distance, the use of biomass from traditional poplar plantation residues shows the lowest impact. The biomass combustion emissions are the main hotspot for several evaluated impact categories (e.g., particulate matter formation, human toxicity). In fact, when the produced bio-energy is compared to the reference system (i.e., electricity produced under the Italian electric profile) the results do not favor bio-energy systems. The results reported in this study support the idea that forest residues would be an interesting and potential feedstock for bio-energy purposes although further research is required specifically with the aim of optimizing biomass supply distances.

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1. Introduction

Mitigation of climate change and derived effects is a global challenge (IPCC, 2007) motivating the international community to introduce easing strategies (Oreggioni et al., 2017). Therefore, European Union's energy and climate change plans try to avoid the use of fossil-based energy by means of the promotion of bio-energy (Directive 2009/28/EC, 2009; Eurostat, 2018). In this sense, energy industries have contributed to ~32% of global CO_2 emission over the last 20 years (Janssens-Maenhout et al., 2012; Oreggioni et al., 2017) as well as heating and cooling processes are responsible for approximately 50% of the final European energy demand (Tsupari et al., 2017). Finally it is important to note that, in Europe, fuel combustion in energy industries is the most important contributor to anthropogenic climate change, with 28.5% of total greenhouse gases (GHG) emissions in 2015 (Eurostat, 2018).

Bio-energy is a critical issue for multiple reasons besides environmental concerns such as i) to guarantee energy security through a more diversified energy mix and less reliance on imported fossil-energy carriers, ii) the sustainable use of natural resources as well as iii) the need to revitalize rural economies (Buonocore et al., 2012; Börjesson Hagberg et al., 2016). Thus, an increased share of renewable energy is mandatory in energy system to satisfy the mentioned issues besides reducing greenhouse gases (GHG) emission. In addition, improvements in power plant efficiency and the incorporation of carbon capture and storage (CCS) processes are also required, receiving the latter special attention in recent years (Tsupari et al., 2017).

Bio-energy systems include a full range of products such as bio-ethanol, bio-diesel, biogas, electricity and heat, all of them from a large range of potential feedstocks – e.g., wood from forests, crops, seaweed and animal, forest and agricultural wastes (González-García et al., 2014). Moreover, biomass as its primary product is a versatile energy source that can be stored and converted to energy on-demand (De Meyer et al., 2014). The waste-to-energy concept is being highly promoted as a part of the efforts into sustainable development in energy sector (Ferreira et al., 2017). The use of forest and agricultural residues as well as other biomass waste from agricultural and industrial activities for bio-energy production (mainly electricity and heat) plays a key role in the energy system (Eurostat, 2015) and it is expected to increase over the next few years. According to MISE (2012), the share of energy from renewable energy sources should reach in 2020 the 17% of the total national energy consumption. In this sense, there is a clear potential for increased use of wood for energy purposes in the EU, mostly related to forest residues and complementary fellings (SFC-WGII, 2008).

However, discrepancies also exist regarding bio-energy supply from biomass mostly due to the high cost associated to the production of biomass-based electricity (Cleary and Caspersen, 2015). Therefore, to beat this economic barrier, many governments offer subsidies to encourage investment in bio-energy technologies. Bio-energy production costs, outside of the cost of feedstock production, tend to decrease with scale (Cameron et al., 2007; Dornburg and Faaij, 2001). Thus, supply-side funding programs frequently provide greater economic support for smaller-scale projects within a given technology class. However, the discontinuous availability and the relatively high maintenance and logistic costs hinder the economic convenience of biomass for large scale energy production (De Meyer et al., 2014). Therefore, numerous efforts are being carried out to make the whole process achievable from an economic approach (De Meyer et al., 2014).

Production of heat and electricity from woody residues either from forest or agricultural activities could considerably increase the contribution to energy security, reduce GHG emission and add value to waste materials (Matsumura et al., 2005; Fernandes and Costa, 2010; Aldana et al., 2014). Indeed, it is a common practice in factories such as pulp mills where pulp is generated together with heat and electricity (Sandin et al., 2015). Different studies evaluated the potential quantities of available forest biomass residues for energy production in countries such as Portugal (Fernandes and Costa, 2010; Viana et al., 2010; Lourinho and Brito, 2015) or Uganda (Okello et al., 2013). According to them, only if cogeneration is implemented the wood fuel resource should be sufficient to satisfay the required capacity demand. However, special attention must be paid into the biomass-supply competition with pellets production, one of the largest internationally traded solid biomass commodities for energy purposes mainly derived from wood residues (Sikkema et al., 2011; Monteiro et al., 2012).

Italy's energy profile relies to a very large extent on imports to meet its energy needs since Italian energy reserves are scarce. In this sense, Italy is a net importer of electricity and only 88.2% of demand is satisfied by a national production. Regarding its power production capacity, 15.3% corresponds to hydropower and 15.9% derives from renewable sources, and the remaining is produced from fossil sources (Terna, 2016).

Hence, its interest on promoting a sharp increase on power production from renewable sources, being Italy considered one of the European countries (together with France, Germany, Sweden, Finland, Spain and United Kingdom) with the main bioenergy markets in 2020 (Calcante et al., 2018; Scarlat et al., 2013).

Poplar and willow are short rotation coppice-species most cultivated in Italy, specially in Po Valley (Northern Italy), for bio-energy and industrial (e.g., pulpwood and paper) purposes (González-García et al., 2012; Bacenetti et al., 2016). Poplar and willow cultivation (either at short rotation or very short rotation forestry regimes, SRF and VSRF respectively) includes activities such as harvesting and biomass collection, which are repeated in different times depending on the cultivation regime. Both activities involve the production of leaves and stools that, usually, remains in the plantation as nutrient and carbon supplier (González-García et al., 2012). Nevertheless, they could be used for bio-energy applications (Muth Jr et al., 2013).

Traditional poplar plantation also exists in Italy mainly in Po Valley mostly destined to roundwood production for furniture sector (Verani et al., 2017). It involves a non-intensive management regime involving the production of potential woody biomass with only one harvesting event as difference to SRF and VSRF regimes.

In the case of Italy, forests are widespread in all the regions of the country being destined to firewood and roundwood production (Proto et al., 2017). Forestry with 10,467,000 ha cover about 34.7% of Italy (INFC, 2015). Although a variety of management systems exist for forests, shelter cut (high forest) in combination with natural regeneration is widespread. In this case, woody residues (mainly tops and brances), produced during logging operations, can be used for bio-energy applications.

In this study, the production of electricity and heat in Italy from wood based biomass either from forest and from agricultural activities has been analysed considering different production scenarios and final uses. The interest behind this study is the promoting use of biomass in small combustion installations in Italy as substitute for fossil fuels (Benetto et al., 2004; Caserini et al., 2010). Biomass from VSRF poplar and willow stands as well as residues from natural forests and from traditional poplar plantations have been considered for analysis. Attention has been paid on dedicated energy crops (i.e., willow and poplar) due to the current Italian interest on biomass power plants.

The results have been also compared with the conventional Italian scenario considering the current Italian electricity profile and heat production from natural gas. The assessment has been performed by applying Life Cycle Assessment (LCA) methodology in an attributional approach and a cradle-to- power plant gate perspective. A comprehensive and transparent analysis has been performed to facilitate comparisons between the proposed bio-energy scenarios.

2. Materials and methods

Life Cycle Assessment (LCA) is a widely used and standardised tool for the systematic evaluation of environmental aspects of a production