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BIOMASS & BIOENERGY

Optimisation of combustion bioenergy in a farming district under different localisation strategies

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ABSTRACT

A method to assess the energy balance and environmental and economic feasibility of a biomass-based energy supply system is presented. Biomass production, harvesting and transportation are considered together with capital investment and operating costs, for both thermal and cogenerative energy production. The location of plants and the definition of collection basins are optimised according to different criteria and allocation strategies: a district-wide planning vs. an incremental allocation. System performances are also compared under alternative technological choices. A case study in the province of Cremona, a major farming area in Northern Italy, is presented. Biomass exploitation has positive returns in terms of energy produced, emissions avoided and investment payback.

1. Introduction

Biomass is by far the most important renewable energy source of the overall EU27 primary energy production, supplying 4.9 EJ out of a total of 7.2 EJ from renewable sources in 2010 [1]. However, if we consider electricity generation, the contribution of biomass is limited to 18.6% of the 661.4 TWh produced from renewable sources. The challenge to increase the production of energy from biomass is to provide sustainable management, conversion and delivery of bioenergy to the market in the form of modern and competitive energy services.

The scientific literature devoted to energy analysis focuses on several important issues that characterise the use of biomass for energy. Because of biomass low bulk density, the distance between biomass plants and harvesting areas is a major issue [2]. Several studies assess the economic potentials, the optimal plant locations and the logistics of the supply chain [3–6]. The spatial information has also been taken into account, integrating GIS and mathematical programming [7–9]. Relative performances of centralised vs. distributed processing systems [10,11] have also been compared, in order to assess the trade-offs between larger plants, exploiting

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economies of scale, and higher transportation costs, to collect feedstock from larger areas. Regarding the environmental performances of bioenergy systems, a comprehensive evaluation of energy balances, atmospheric emissions of the energy system and of the supply chain have been performed by several authors [12–14].

When assessing the role of renewable energy, and specifically of bioenergy, there are three major questions that need to be answered: to what degree the overall system is a net energy producer, to what degree it reduces greenhouse gases (GHG) emissions and to what degree it is economically sustainable. These questions are addressed in the present article: the proposed biomass exploitation problem considers energy, environmental (in terms of GHG emissions) and economic performances as three distinct objectives to be optimised.

The modelling approach we present in this paper can be stated in terms of the more general location-allocation problem, whose formulation and applications are well known (see for instance [15]). Furthermore, the problem is formulated using a classical LCA approach, considering the overall biomass-to-energy chain from cultivation, harvesting and transport, to the energy conversion and final destination. Furthermore, we analyse different allocation strategies by comparing a district-wide planning and an incremental allocation of biomass conversion plants.

This paper is organised as follows. First, biomass exploitation alternatives are defined on the basis of both current (residues and by-products from agriculture, forestry and wood industry) and potential (short rotation forestry, SRF) availability at local scale and of conversion technologies. In Section 3, the optimisation problem is formulated for the location of energy conversion plants and the definition of biomass allocation basins. In Section 4 the methodology is applied to the province of Cremona, a major farming district in Northern Italy. The incremental solution of the model is presented in Section 5. Finally, we discuss the results and the possible generalisation of the methodology to larger areas.

2. Biomass exploitation alternatives

Different exploitation alternatives are available with regard to both biomass availability and conversion technologies. Energy, environmental and economic costs and benefits (energy requirements or savings, GHG emitted or saved, monetary costs or benefits) are associated with each step of the biomass exploitation chain (Fig. 1). The optimal biomass-to-energy system is defined through the solution of an optimisation problem that, on the basis of biomass availability, road network and energy demand, returns location and collection basin of each plant.

As already mentioned, in order to find the optimal facility location within the studied area, it is necessary to know biomass availability at the local level. The road network needs to be defined as well. Finally, it is necessary to characterise the conversion facilities, so that the biomass input and the final energy produced can be assessed in accordance to local energy demand.

We assume that lignocellulosic biomass can be collected from four main sources [16–18]: agricultural residues, timber and wood processing by-products, forestry residues and energy crops (in particular we will consider SRF). As described by Angelis-Dimakis et al. [18], methods to assess biomass can rely on census data [19,20], land use cartography [21], and sectorial studies [22]. Furthermore, there are models that can be used to estimate biomass availability. For examples, CO2FIX [23] and CBM [24] can be used to estimate biomass procurement from forests based on specific management practices; few applications exist in the literature [25,26].

Assumptions are necessary in order to estimate the amount of land devoted to SRF, since energy crops may compete with food/feed crops or with other land uses. In this paper, we will assume that only land currently abandoned or set-aside is devoted to energy crops, thus avoiding any conflict with the current food agricultural sector. More sophisticated approaches could be used, though. For instance, a general equilibrium agricultural sector model that incorporates a decision framework, such as profit maximisation, could be used to estimate biomass production from SRF; or one might employ Polysys, a model that describes the U.S. agriculture sector and that has also been applied to bioenergy analysis [27,28]. However, the development of these approaches would require large databases and is beyond the scope of this work.

Finally, to characterise exploitation alternatives, a conversion technology must be chosen. Many biomass conversion processes are available today (such as thermal conversion, gasification, pyrolysis) and expected for the near future (such as cellulosic processes to produce ethanol) [29,30]. From the many available, we selected the two most widespread biomass conversion systems for lignocellulosic biomass adopted in Italy [31]: state-of-the-art combined heat and power (CHP) plants and modern units for domestic heating. The method proposed in this paper is, however, not specific to these conversion processes, rather it can be adapted to suit many different processes, see for instance [11].

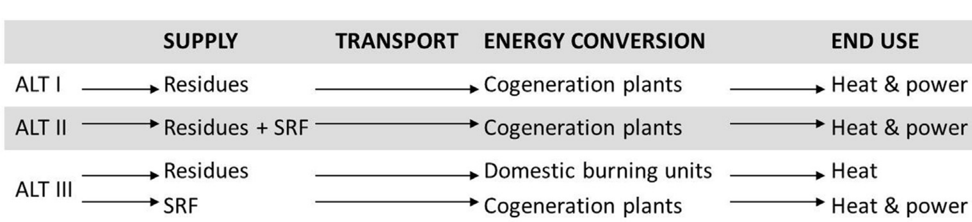

Fig. 1 – Biomass exploitation alternatives are defined by biomass quality (residues and/or SRF); by conversion technologies (cogeneration plants or domestic burning units); by the end use (producing heat or heat and power).