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Research paper

Using tree crop pruning residues for energy purposes: A spatial analysis and an evaluation of the economic and environmental sustainability

Biancamaria Torquati [a,*], Daniela Marino [a], Sonia Venanzi [a], PierRiccardo Porceddu [b], Massimo Chiorri [a]

[a] Department of Agricultural, Food and Environmental Sciences, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy
[b] Department of Civil and Environmental Engineering, Via Goffredo Duranti, 93, 06125 Perugia, Italy

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ABSTRACT

The use of biomass for energy production is one of the promising alternatives identified by the European Union to reduce greenhouse gas emissions and to ensure energy supply security. The aim of this research is to analyse the potential energy production from pruning residues of vineyards and olive groves in four municipalities of the Umbria Region, along with its economic and environmental sustainability. Geo-spatial, economic and environmental analyses were carried out. The integrated approach was used to estimate the total quantity of biomass produced in that area and to identify a logistic network for its transportation. Assuming a power plant whose size and technical properties were based on the analysis results, chain costs and potential profit margins were also calculated and resulting CO_2 emissions estimated. The results show that the fragmentation and dispersion of agricultural activities, as well as technical and logistical decisions noticeably affect the economic and environmental sustainability of the proposed agro-energetic chain, in terms of both energy balance and CO_2 emissions.

1. Introduction

The great interest in bioenergy in the EU arises from the need to increase the use of renewable energy sources, in order to reduce dependence on fossil fuels, to protect the environment and to develop the agro-forest sector by generating new sources of income [1]. The sector of renewable energy produced from agricultural raw materials is extremely complex. On the one hand different types of biomass are available and different producing companies are involved, on the other a plurality of chemical, physical and thermal processes can be used. Particularly interesting is the sector of waste biomass represented by products that should be disposed of in any case, such as vine shoots and olive tree prunings.

Due to its complexity, the analysis of the agro-energetic chain requires a multidisciplinary approach that integrates the socio-economic dimension with institutional and environmental aspects. Four main approaches can be distinguished in the study of agro-energetic chains: spatial, technical-engineering, economic, and environmental analyses.

The GIS-based spatial approach aims at identifying areas that can provide biomass for energy production. Studies variously assess land suitability of the areas [2–4], administrative boundaries, land cover [5], and logistic networks for the transportation of biomass [6,7].

Technical-engineering approaches essentially evaluate the performances of biomass shredders [8–10], the technical characteristics of biomass conversion plants [11,12], and the physic-chemical properties of biomass itself [13,1].

Studies on the economic viability of agro-energetic chains have been carried out at different levels. Some authors estimated the profitability and sustainability of the plant, through investment analysis and cost-benefit analysis [14–18]. Other studies examined alternative techniques for mechanized recovery of olive tree pruning residues for energy use in different geographic areas [19,20]. In other case studies, the costs of transporting biomass from field to plant were assessed [21]. Specific studies investigated the optimal capital structure according to the cash flows generated

* Corresponding author.
E-mail addresses: bianca.torquati@unipg.it (B. Torquati), marinodaniela@yahoo.it (D. Marino), soniavenanzi@gmail.com (S. Venanzi), pierriccardo.porceddu@unipg.it (P. Porceddu), massimo.chiorri@unipg.it (M. Chiorri).

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by a biomass-fired cogeneration plant [22]. Finally, modelling systems were developed to evaluate the cost of the energy produced from biomass [23], as well as to find the least cost location for siting a bioenergy plant [24].

Studies on the environmental impact of agro-energetic chains tried to assess the environmental impact of renewable energies and to identify technologies minimizing greenhouse gas emissions [25], socio-economic impacts [26], or to support public decision makers [27].

The present work is based on an integrated approach to the agro-energetic chain and it originally carries out an economic and environmental analysis, drawing on the results of spatial analysis. The study aims to verify the possibility of using pruning residues from vineyards and olive groves for energy purposes. The methodology is applied in a case study area of approximately 290 km^2 in the Umbria Region (centre of Italy) and describes a model of agro-energetic chain where raw material comes from small-sized tree plantations and land ownership is extremely fragmented.

The aim of the analysis is to evaluate whether the use of residues may represent an economic opportunity for agricultural farms, by benefitting from incentive policies introduced by the Italian legislative decree no. 28/2011, which transposes the Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The study also aims at assessing whether energy produced from tree crop residues and used to satisfy the energy needs of public and private buildings contributes to reducing CO_2 emissions.

2. Material and methods

2.1. Choice of the study area

The study area is represented by four neighbouring municipalities in the province of Perugia, geographically and statistically comparable: Assisi, Bastia Umbria, Bettona and Cannara.

The area is located in the Umbrian valley, with intensive agricultural areas, urban settlements and production plants.

North-eastern and south-western there are two low-hilly belts, typically olive-growing areas recognized as a traditional cultural landscapes; agro-forest areas are found at higher altitudes (see Fig. 1).

Agricultural areas cover 56% of the study area, forests and semi-natural areas represent 34% of the area, while built-up areas account for 9% and wetlands and water bodies for 3%.

The 2559 farms operating in the area take up a total agricultural area of 14,876 ha, 80% of which is used for cultivation (UAA –utilized agricultural area). Farms are mostly small sized and family run: 92% of them employs less than one work unit, 4% between one and two units and the remaining 4% more than two work units. 70% of the farms (corresponding to 1759 farms for a total area of 6320 ha) cultivates owned land.

Arable land is mainly occupied by cereals and fodder plants, while among tree crops olive groves (1461 ha) outnumber vineyards (338 ha). Both crops are highly fragmented, with cultivated areas of less than one hectare.

2.2. Spatial analysis

Spatial analysis was carried out by using a database created on the basis of the information provided by holding files of farms operating in the study area which applied for Community Agricultural Policy (CAP) funding in 2010 and 2011. Data refer to the municipality, cadastral sheet and cadastral parcel of the areas declared for the purposes of CAP premiums. This information, appropriately processed, can be linked to geo-referenced maps of the centroids of cadastral parcels.

Spatial analysis was used, first of all, to obtain the geographical distribution of farm data, which were imported into a GIS system, provided by the ArcGIS 9.3 software, integrated and mapped. Then, we 1) identified slopes; 2) formulated exclusion criteria to identify areas unsuitable for pruning residue collection; 3) identified areas with the highest density of production; 4) assessed the type and quantity of available biomass; 5) located biomass storage facilities for each municipality on the basis of the road network; 6) located the single dry biomass storage facility and power plant.

2.2.1. Identification of production areas and estimate of available biomass

As for the use of pruning residues, we chose vineyards and olive groves with slopes of less than or equal 30%, because we considered only those areas that allow the transit of farm machinery, and therefore the mechanized collection of pruning residues.

To identify these areas, we used the Digital Elevation Model (DEM), in which a slope value was attributed to each pixel at 90 m resolution (Consultative Group on International Agricultural Research, 2008).

Biomass potentially available was estimated at 2.8 t/ha of fresh matter (fm) for olive groves – corresponding to 1.9 of dry matter (dm) – and at 2.2 t/ha of vine shoots (fm) – corresponding to 1.2 of dry matter (dm) [28]. As regards olive groves, available biomass was considered on an annual basis and the corresponding figure was obtained by dividing the pruning yield by two, with pruning being traditionally made every two years in the area.

2.2.2. Identification of storage facilities and power plant

In order to identify the areas with the highest density of production, "Kernel density" was calculated through GIS mapping. In the calculation, a 680 m range was used and available biomass per square kilometre was quantified. In particular, Spatial Statistics tools allowed us to give greater weight to bigger cadastral parcels. Storage facilities for fresh biomass were then identified for each municipality, taking account also of distances between the centre of each cadastral parcel and the nearest road. These distances were calculated by converting the borders of cadastral parcels into "points", using Hawth Tools extension. In this way, the length of a hypothetical private agricultural road was estimated. Calculations were repeated considering the study area as a whole so as to locate a single storage facility for fresh biomass, as well.

Network Analysis was used to calculate both the average distance between cadastral parcels destined to biomass production and municipal storage facilities, and the shortest travel path connecting each municipal biomass storage facility to the single facility serving the whole reference area.

Due to the lack of detailed information on secondary roads, the study used subsequent approximations, selecting cadastral parcels as close as possible to each other and able to satisfy the maximum capacity of a vehicle with a load of 1.6 t. Production areas were also divided into two slope categories (areas with a slope of less than or equal to 10% and areas with a slope between 10% and 30%), in order to take the road tortuosity factor into account. Road network properties, such as path tortuosity index, traffic conditions, stop points and unavoidable slowdowns, were considered, as well.

The minimum and maximum distance between cadastral parcels destined to biomass production and municipal storage facilities was calculated and the average distance determined, on the basis of the analysis of loads and slopes.

2.3. Economic analysis

According to supply methods three different types of chain can be distinguished: short, medium, and long chains. The short chain