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

Highlights

- An economic and environmental analysis drawing on the results of spatial analysis is carried out.
- This work contributes to the search of synergies between typically olive-vine-growing area and urban settlements.
- Results from Network Analysis are utilized to locate the storage facilities and the power generation plant.
- Environmental impacts of medium agro-energetic chain and economic results are compared.

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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 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 2,559 farms operating in the area take up a total agricultural area of 14,876 ha, 80% of which is used for cultivation (UAA –utilised 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 1,759 farms for a total area of 6,320 ha) cultivates owned land.

Arable land is mainly occupied by cereals and fodder plants, while among tree crops olive groves (1,461 ha) outnumber vineyards (338 ha). Both crops are highly fragmented, with cultivated areas of less than one hectare.

Fig. 1 – Study area. (A) Geographical location. (B) Physical and administrative framework.

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 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~~[1]~~ 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. ~~so as to allow the transit of farm machinery.~~

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)~~, and we considered areas with a slope of less than or equal to 30%.~~.

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

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~~[1] All results are obtained using the analysis tools provided by the ArcGIS 9.3 software.~~

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~~n~~ 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 is represented by the farmer-processor and biomass is handled and transported within a maximum distance of 5-10 Km. The long chain involves a series of intermediaries and an end-user using large plants. Biomass is usually first transported to a processing-storage facility, within a 5-10 Km distance, and then to the end-user, with distances that can exceed100 Km [1].

The analysed agro-energetic chain in this study is medium[2] and it involves a consortium of biomass producers field collecting and chipping raw materials, using their own or third parties' machines and labour. Transportation takes place in two steps: biomass is first transported from field to municipal storage facilities (with average travel distance from 3.2 to 14 km) and then from here to the end-use facility (with average travel distance from 2.8 to 11.5 km), where the power plant is located. Biomass is used in the centralised production of energy to be distributed to households within the investigated municipalities (with distances that not exceed 25 Km).

2.3.1 Biomass supply and processing

The technical-economic analysis of biomass supply and processing phases was carried out using data reported in literature [29, 30, 9]. The study examined olive groves of vase-trained Frantoio and Leccino olive trees with a plant spacing of 5x5, and vertical-trellised vineyards with a 3,500 vine/ha density. Vine-shoots are collected, field chipped and loaded on a trailer for transport.

Data were used to estimate the biomass supply cost for each municipality, drawing on remarks and results of spatial analysis.

Agricultural diesel consumption was thoroughly analysed, in order to compare energy content of used diesel with energy content of produced wood chips and to assess the impact of fuel costs on biomass supply costs (see Table 1).

Table 1 – Agricultural diesel consumption

~~[2] According to supply methods three different types of chain can be distinguished: short, medium, and long chains. The short chain is represented by the farmer-processor and biomass is handled and transported within a maximum distance of 5-10 Km. The long chain involves a series of intermediaries and an end-user using large plants. Biomass is usually first transported to a processing-storage facility, within a 5-10 Km distance, and then to the end-user, with distances that can exceed100 Km [1].~~

From each municipal storage facility dry biomass is moved to the single processing facility by renting a lorry with a load capacity of 32 t. On the basis of the results obtained, the type of power plant was chosen and start-up costs evaluated.

2.3.2 Biomass value and economic viability of the plant

The energy value of one tonne of dry biomass (moisture content of 30-35%) was calculated on the basis of the energy produced by its combustion and of the price paid for power fed into the grid at subsidised price (0.28 €/kWh). This value amounts to 81.99 €/t, gross of plant power consumption, and falls to 80.35 €/t, when considered net of plant operation power consumption.

By calculating power plant operation costs, the maximum biomass supply cost in two different situations was assessed. In the first case the plant is fired only by biomass coming from pruning residues of olive groves and vineyards; in the second case the plant is operating at its full capacity.

Operating costs include several items. Maintenance expenses amount to € 11 per tonne of dry biomass used, while costs for labour and administrative/management activities are estimated at € 8 per tonne of dry biomass used, half of which for labour (3 hours per day at € 12.50 per hour are required to handle 8 tonnes of dry biomass) and the other half for administrative/management activities. Costs for ash disposal amount to 3% of the total biomass used, with a withdrawing cost of € 4 per tonne (ashes are considered as waste according to the Italian decree no. 152/2006 and subsequent amendments, therefore they are landfilled). Depreciation is calculated assuming a plant average service life of 15 years. Energy costs are not considered as cost item in the balance sheet and they are deducted from the value of the energy produced by the plant instead.

2.4 Environmental analysis

Environmental analysis mostly consisted in assessing CO_2 emissions produced in the different process phases, using the ~~Life Cycle Assessment~~Ecoinvent v2.0 database. Such an analysis aimed to determine whether the use of pruning residues from olive groves and vineyards for energy production contributes to reducing greenhouse gas emissions released into the atmosphere, and thus to reducing global warming (GWP), as required of renewable energy chains by current national and international legislation. The chain energy balance was estimated so as to verify whether the conditions of energy efficiency are met.

2.4.1 CO_2 emissions

CO_2 emissions for the whole chain were determined by adding emissions from each process phase together. Emissions were identified as follows: a) according to the required shredder operating hours, for biomass shredding; b) according to the fuel used to handle biomass with a tractor pulling a trailer with a load capacity of 1.6 t, for biomass transport from fields to municipal storage facilities; c) according to the fuel used by a lorry with a load capacity of 32 t, for biomass transfer from municipal storage facilities to the single storage and processing facility; d) by processing data provided by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale, Institute for Environmental Protection and Research) on a comparable plant, for combustion, and thus power production. Growing and pruning were excluded from the analysis, since corresponding CO_2 emissions are attributable to the main production process, not to its residues.

Emissions related to the shredding phase were estimated using the formula provided by ~~the Ecoinvent LCA database~~Ecoinvent Report 15a [31]. Emissions are represented in grams per operating hour of the agricultural machine, according to the following formula [31]:~~:~~

$$WG\ [g\ WU] = WGrif\ g/h * \text{operating time}$$

where:

WG: total gas emissions;

WU: work unit;

WGrif: reference gas value in grams per hour.

Reference values provided by the Ecoinvent v2.0 database are: 46 g/h for CH_4; 836 g/h for NO_2; 139 g/h for CO_2.

Emissions released by biomass transport from fields to municipal storage facilities, and from these to the single storage facility, were calculated using the IPCC reference approach [32~~1~~]:

$$CO_2 \text{ Emissions} = \sum a \text{ [Fuel a * EF a]}$$

where:

EF a = emission factor (kg/TJ). It corresponds to the fuel carbon content multiplied by 44/12.

∑a = summation of the different types of fuel used (e. g. petrol, diesel, LPG, etc.), expressed as energy content (Tj).

Diesel emission factor, based on the fuel total oxidation, is 74.1 t/Tj [32~~1~~]. Since this emission factor is expressed in kilograms of fuel, to estimate the kilograms of fuel required, we first calculated the total kilometres to be travelled and estimated the fuel consumption in litres. The result was converted into kilograms and its energy content determined.

This calculation procedure based on fuel consumption was also used to determine shredding CO_2 emissions, already calculated using the Ecoinvent ~~LCA~~ v2.0 database. In so doing, we were able to highlight how two different calculation methodologies can produce significantly different results.

As for power plant, emissions released by the biomass-fired boiler were taken into account. These emissions are generally considered zero.

Thanks to the data provided by ISPRA on daily emissions in June 2011 and referring to a comparable power plant, total emissions for the power production phase could be assessed.

The whole chain greenhouse gas emissions for one tonne of biomass were estimated, although partially. This value was obtained by relating total emissions to total biomass and by then proportioning emissions to a single input unit, corresponding to one tonne of biomass.

2.4.2 Energy balance

To calculate the energy balance of the examined agro-energetic chain, energy consumption for every phase of the production process was quantified (chipping, transport, combustion, storage) and total energy consumption was compared with the energy produced by the combustion plant.

3. Results and Discussion

3.1 Spatial Analysis

3.1.1 Identification of production areas and estimate of available biomass

Cadastral parcels destined to olive growing are mainly located in two territorial belts and the highest production area is represented by Assisi. Parcels destined to vineyards are more dispersed within the study area: the highest concentration is found in the municipality of Assisi, followed by Bettona and Cannara. Bastia Umbra is the municipality with the lowest number of both vineyards and olive groves (see Table 2).

Table 2 – Estimate of potentially available biomass per municipality

3.1.2 Identification of storage and power production facilities

On the basis of the minimum and maximum distance between cadastral parcels destined to biomass production and municipal storage facilities, the average distance was determined, taking into account the results of the analysis of loads and slopes.

Network Analysis results located the single storage facility in the Assisi municipality, 3.2 km away from the municipal storage facility, 5.24 km away from the Bastia Umbra facility, 10.51 km from the Bettona one and 13.99 km from the Cannara facility (see Fig.2).

The single storage facility is located near a fast-flowing state road, away from urban buildings. Therefore, this area could be usefully destined to siting the power generation plant so as to connect the storage site to the processing one.

Fig. 2 – Identification of storage facilities and paths between municipal storage facilities and single storage facility

3.2 Economic Analysis

3.2.1 Biomass supply and processing

The results highlight that the 1,715 hectares available to implement the agro-energy district may produce 2,671 tonnes of fresh biomass, corresponding to approximately 1,714 tonnes of dry biomass (see Table 2). Supply costs would amount to more than € 170,000, 55% of which for shredding and loading, and 45% for transport and transfer.

Obviously, the distribution of costs for each municipality reflects their production density: 67% of costs is concentrated in Assisi, 18% in Bettona, 13% in Cannara, and 2% in Bastia Umbra (see Table 3).

Table 3 – Estimate of the cost of fresh biomass shredding, loading, transport and transfer for each municipality

Energy content of produced wood chips is higher than energy content of used agricultural diesel, when comparing the two values. However, social (noise, traffic, road accidents) and structural (road maintenance) damage caused by the great number of kilometres totally travelled to reach the four municipal storage facilities should be taken into account. Assuming that biomass is transported with loads of 1.6 t, corresponding to 8 m^3, approximately 3,338 (return) journeys are necessary. Average travel distance depends on the facility location. Drawing on the results of spatial analysis, it amounts to 8.1 km for the municipality of Assisi, to 11.5 km for Bastia Umbra, to 4.9 for Bettona and to 2.8 km for Cannara. This means that, overall, at least 23,132 km should be travelled, with their impact in terms of CO_2 emissions.

The estimated impact of agricultural fuel costs on supply costs amounts to around € 61,000, corresponding to 36%.

On the basis of the structure of the assumed agro-energetic chain, the biomass processing plant is located within the single storage facility. Therefore, dry biomass has to be moved from each municipal storage facility to the processing facility.

3.2.2 Power Production

When choosing the power plant, we opted for an INGECO turbo-generator, 125 kW Organic Rankine Cycle (ORC), with a 110 kW efficiency, equipped with a Uniconfort Global 90 boiler. This plant can burn 9 tonnes of shredded dry biomass per day and requires three labour hours per day to handle ashes and biomass. The plant has an annual operational capacity of 7,900 hours (approximately 11 months) and requires a plant downtime of 860 hours (approximately 1 month) for annual maintenance.

Power production at full operating capacity (329 working days per year) amounts to 785,400 kWh/year and requires 2,682 t of biomass. With dry biomass from olive and vine prunings available in the study area being estimated at 1,713 t, the plant would be used 190 days per year, ensuring a power production of 501,600 kWh/year (power production gross of plant operation power consumption), resulting in 491,568 kWh/year made available on the energy market (power production net of plant operation power consumption, corresponding to 2% of power production). Power production can be fed into the grid at subsidised price (0.28 € /kWh), covering the average annual demand (2,640 kW/h) of around 186 households.

The construction of plant and storage facilities requires an investment of € 923,000, allocated as follows: € 600,000 for the 125kW ORC system; € 200,000 for the boiler; € 60,000 for the storage facility; € 80,000 for other costs and unexpected expenses, estimated at 10% of the investment. The general "other costs and unexpected expenses" item, estimated at 10% of machinery costs, was included in cost items for prudential reasons, since, due to the limited number of plants built at national level to date, the construction of a biomass-fired power plant is still surrounded by some uncertainties (used area, connections to the grid, etc.).

3.2.3 Biomass value and economic viability of the plant

Total plant management costs add up to € 94,253 per year, if the plant is fired only with biomass available in the study area (vine and olive prunings), and they rise to € 112,784, if the plant operates at its full capacity. It results that converting one tonne of biomass into energy (net of biomass supply cost) costs € 55.02, if the plant is fired only with available biomass from pruning residues of olive groves and vineyards. This figure falls to € 42.05 if the plant operates at its full capacity.

By comparing the biomass energy value net of plant power consumption (80.35 €/t) with plant unit costs, we assessed the maximum sustainable biomass supply cost, which corresponds to break-even budget. Supply cost amounts to 25.33 €/t, if the plant is fired only with available biomass from pruning residues of olive groves and vineyards, and it rises to 38.30 €/t, if the plant operates at its full capacity (see Table 4).

Table 4 – Estimate of the maximum biomass supply cost

Costs for shredding and loading, for transport from fields to municipal storage facilities, and for transfer from municipal storage facilities to power production plant (vehicle rental + fuel consumption) totally amount to € 172,923. Considering the tonnes of dry biomass made available, it results that the unit cost per tonne is € 100.92. The cost of pruning residue disposal is to be deducted from this value, in case prunings are not used in the agro-energetic chain. This cost was estimated taking into account shredding (40 €/ha) and field burial by surface ploughing (20 €/ha). Therefore, alternative disposal costs add up therefore to about 60 €/t and they are slightly higher than the estimated costs for pruning shredding and loading (€ 54.13) (see Table 5). Biomass supply cost, net of alternative disposal costs, ultimately amounts to 40.87 €/t, that is 2.56 €/t higher than the estimated maximum supply cost net of plant consumptions, with the plant operating at its full capacity.

The overall balance of the agro-energetic chain is therefore negative, showing an overall loss of € 4,395 if the plant operates at its full capacity. This loss rises to € 26,624 (15.54 €/t of dry biomass), if the plant is fired only with available biomass from pruning residues of olive groves and vineyards.

Table 5 – Biomass supply costs

The results thus confirm that using pruning residues for power production in an area where plots are scattered and fragmented is difficult, because of high supply costs, notably biomass transport and transfer costs.

Should one be able to reduce transport and transfer costs by 10% (case B in Table 6), the agro-energetic chain balance would achieve a positive result, corresponding to 1.95 €/t of used biomass. This result increases to 8.06 €/t, if transport and transfer costs are reduced by 15% (case C in Table 6).

Table 6 – Economic balance of the agro-energetic chain (values €/t of dry matter)

These results highlight, once again, low profit margins in implementing a medium agro-energetic chain like the one assumed in the present study. They also underline how any positive margins are associated with minimum payments to farmers. In case C too, if the positive margin were entirely paid to the farmer, he/she would only obtain a 8.00 € income.

The real economic viability of implementing medium agro-energetic chains is further questioned if we consider that in the balance-sheet any interest costs related to taking out a loan to build the power plant are not taken into account. Similarly, any likely reduction of the power selling price due to changes in the feed-in tariff scheme is not considered.

3.3 Environmental Analysis

3.3.1 CO_2 emissions

Greenhouse gas emissions related to shredding and transport phases were assessed. Based on the Ecoinvent v2.0 database, the CO_2 emitted by shredding 2,671 t of biomass amount to 0.043 t as against the 25.52 t obtained when calculating emissions on the basis of the operating machine fuel consumption.

Greenhouse gas emissions for the whole agro-energetic chain attributable to one tonne of biomass were estimated, although partially (see Table 7). This value was obtained by relating total emissions to total biomass and by then proportioning emissions to a single input unit, corresponding to one tonne of biomass.

According to CO_2 emissions estimated on the basis of fuel consumption for shredding, loading and transport (net of emissions released by combustion, which are confirmed as being slightly relevant according to available data), CO_2 emissions per tonne of used biomass would be 136.91 t. Since this quantity corresponds to a power production of 293 kWh, this means that CO_2 emissions for each kWh are estimated at 273 grams.

To provide a benchmark, equivalent CO_2 emissions per kWh produced by the entire life cycle of the coal energy chain range between 780 and 910 grams.

Table 7 – Estimate of CO_2 emissions for the use of 1 t of biomass for power production

3.3.2 Energy balance

When comparing total energy consumption of the different production phases with power produced by the combustion plant, it emerged that to produce the estimated 293 kWh by burning one tonne of dry biomass from vine and olive pruning residues approximately 146 kWh are used. Energy ratio is therefore almost 2 to 1 (see Table 8).

Table 8 – Total energy consumption for power production from wood chips and energy balance

4. Conclusions

This study analysed 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.

The results obtained from the economic and environmental analysis ~~there~~ are not satisfactory. The medium agro-energetic chain proved not to be sustainable from an economic point of view, despite being environmentally interesting. In fact, only by reducing transport costs by 10%, the farmer earns a profit, though small, while, environmentally, energy balance is positive and it is possible to reduce CO_2 emissions.

Transport proved to have the greatest impact, essentially due to farm fragmentation that is the real problem of the hill olive-growing areas. However, it should be noted that alternative treatments of prunings entail an environmental impact as well, because of the emissions released into the atmosphere by biomass transport to the landfill or by biomass burial. Actually, in case of mandatory residue landfilling, biomass is to be transported from fields to waste collection points, involving CO_2 emissions anyway (emissions vary depending on the distance from the collection point).

The results of this study suggest that economic results can be improved. Pruning residues produced in the municipality of Bastia Umbra could be excluded. Building a single storage facility in the municipality of Assisi would avoid double handling biomass. By identifying other plant residues available in the study area, the power plant capacity could be fully exploited. Finally, the possibility of creating more short agro-energetic chains to use energy within local production facilities (wineries, oil mill, craft enterprises) should be assessed. Further investigations are needed to understand if a medium agro-energetic chain ~~it~~ could help the preservation of a traditional cultural landscapes.

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

Table 1 – Agricultural diesel consumption

Tractor diesel consumption for chipping		
Wood chipping, l diesel/m^3 (*)	l/ m^3	0.72
Number of cubic metres per tonne of wood chips	m^3/t	5
Wood chipping, l diesel/t	l/t	3.6
Tractor diesel consumption for wood chip loading		
Wood chip loading, l diesel/m^3 (**)	l/ m^3	0.36
Number of cubic metres per tonne of wood chips	m^3/t	5
Wood chip loading, l diesel/t	l/t	1.8
Tractor diesel consumption for transport		
Transport by wagon with a load capacity of 1.6 t (***)	l/km	1.59
Average cost of agricultural diesel		
Average cost 28 October 2011 in central Italy (****)	€/l	0.746

Notes: (*) Source: Enama; (**) Estimated at half of chipping consumption; (***) Our estimate based on data provided by Mescalchin *et al.* (2009); (****) Source: Associazione provinciale imprese di meccanizzazione agricola, Apima.

Table 2 – Estimate of potentially available biomass per municipality

	Olive groves and vineyards in areas with a slope ≤ 30%		Annual fresh biomass production		Annual biomass production	
	Olive groves (ha)	Vineyards (ha)	Olive groves (t)	Vineyards (t)	Total fresh matter (fm) (t)	Total dry matter (dm) (t)
Assisi	984	191	1,378	420	1,798	1,164
Bastia Umbra	5	20	7	44	51	29
Bettona	236	64	330	141	471	301
Cannara	153	62	214	136	351	220
Total	1,378	337	1,929	741	2,671	1,714

Table 3 – Estimate of the cost of fresh biomass shredding, loading, transport and transfer for each municipality

Municipality	Olive groves and vineyards in areas with a slope ≤ 30%		Annual fresh matter (fm) production		Estimated shredding and loading cost (fm)		Estimated transport and transfer cost (fm)	
	Olive groves(ha)	Vineyards (ha)	Olive groves (t)	Vineyards (t)	Olive groves (€)	Vineyards (€)	Olive groves (€)	Vineyards (€)
Assisi	984	191	1,378	420	41,879	19,329	39,950	12,186
Bastia Umbra	5	20	7	44	213	2,024	203	1,276
Bettona	236	64	330	141	10,044	6,477	9,582	4,083
Cannara	153	62	214	136	6.512	6,274	6,212	3,956
Total	1,378	337	1,929	741	58,648	34,104	55,947	21,501

Table 4 – Estimate of the maximum biomass supply cost

	Unit	Plant fired with available biomass	Plant operating at full capacity
Available dry biomass	t	1,713	2,682
Gross power production	kW/h/yr	501,600	785,400
Plant operation power consumption	kW/h/yr	10,032	15,708
Power production net of plant operation power consumption	kW/h/yr	491,568	769,692
Depreciation with a 15-year economic life	€/yr	61,500	61,500
Maintenance costs (*)	€/yr	18,843	29,504
Workforce (**)	€/yr	13,704	21,458
Ash disposal (***)	€/yr	206	322
Total - Plant management costs	€/yr	94.253	112.784
Total - Plant management costs per unit	€/yr/t	55.02	42.05
Maximum biomass cost gross of plant consumption	€/t	26.97	39.94
Maximum biomass cost net of plant consumption	€/t	25.33	38.30

Notes (*) Maintenance cost is estimated at € 11.00 per tonne of dry biomass used; (**) Labour cost is estimated at € 8.00 per tonne of dry biomass used; (***) Ashes correspond to 3% of used dry biomass and the cost of disposal is € 4 per 100 kilograms.

Table 5 – Biomass supply costs

	t/yr fresh matter	t/yr dry matter	€
Annual biomass production	2,671	1,714	
Shredding and loading cost	34.73	54.13	92,752
Transport cost	21.00	32.73	56,083
Transfer cost	8.00	12.47	21,365
Vehicle rental cost (transport from municipal storage facilities to single facility)	0.92	1.43	2,458
Fuel cost (transport from municipal storage facilities to single facility)	0.10	0.15	265
Biomass supply cost	64.75	100.92	172,923
Cost of alternative disposal by (*):			
Field shredding - Estimated cost	26	40	68,600
Burial by surface ploughing - Estimated cost	13	20	34,300
Cost of alternative disposal by shredding and burial	39	60	102,900
Biomass supply cost net of alternative disposal costs	26.22	40.87	70,023

Note (*) Estimate carried out assuming an average shredding cost of 40 €/ha and an average burial by surface ploughing cost of 20 €/ha.

Table 6 – Economic balance of the agro-energetic chain (values €/t of dry matter)

	Situation		
	A	B	C
Shredding and loading cost	54.13	54.13	54.13
Transport cost	32.73	29.46	25.04
Transfer cost	12.47	11.22	9.54
Vehicle rental cost (transport from municipal storage facilities to single facility)	1.43	1.43	1.43
Fuel cost (transport from municipal storage facilities to single facility)	0.15	0.15	0.15
Biomass supply cost	100.92	96.40	90.30
Cost of alternative disposal by shredding and burial	60.05	60.05	60.05
Biomass supply cost net of alternative disposal costs	40.87	36.35	30.24
Total plant management costs at full operating capacity	42.05	42.05	42.05
Biomass energy value net of plant consumption	80.35	80.35	80.35
Revenues - costs	-2.56	1.95	8.06

Table 7 – Estimate of CO_2 emissions for the use of 1 t of biomass for power production

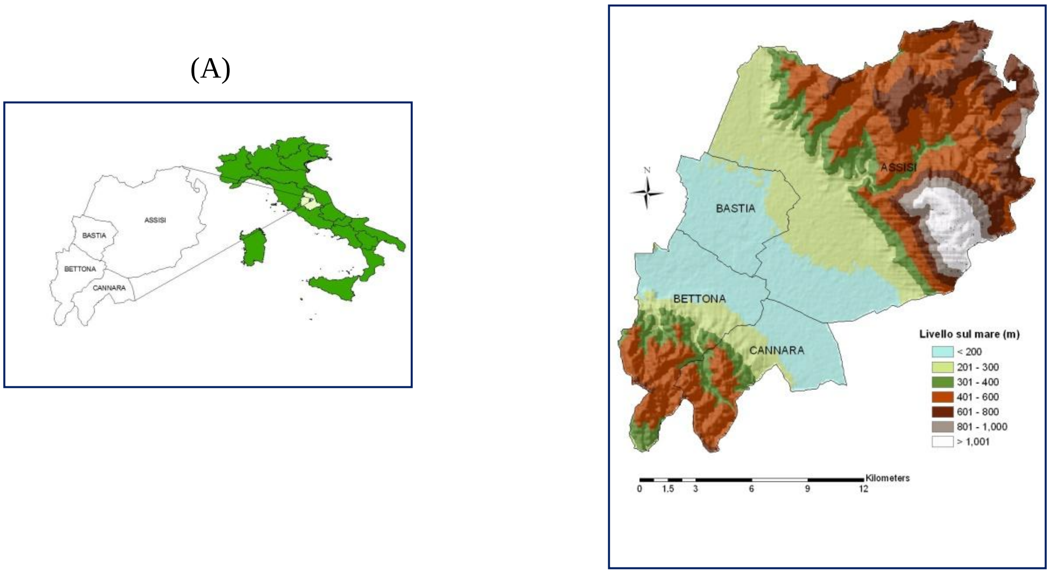
	Total CO_2 emissions (t)	CO_2 emissions per unit (t CO_2/t of biomass)	CO_2 emissions in grams per kWh (g/kWh)
Shredding	25.52	0.01	51
Loading	12.76	0.01	25
Transport	98.63	0.06	196
Total	136.91	0.08	273

Table 8 – Total energy consumption for power production from wood chips and energy balance

	l/t	kWh
Tractor diesel for chipping	3.60	39.60
Tractor diesel for wood chip loading	1.80	19.80
Tractor diesel for transport	6.89	75.74
Lorry diesel for transport	0.11	1.22
Storage facility	0.36	3.96
Power plant		6.00
Estimated energy consumption for 1 t of used biomass		146.31
Energy content of 1 t of wood chips at moisture content of 40%		293.00
Energy balance		146.69

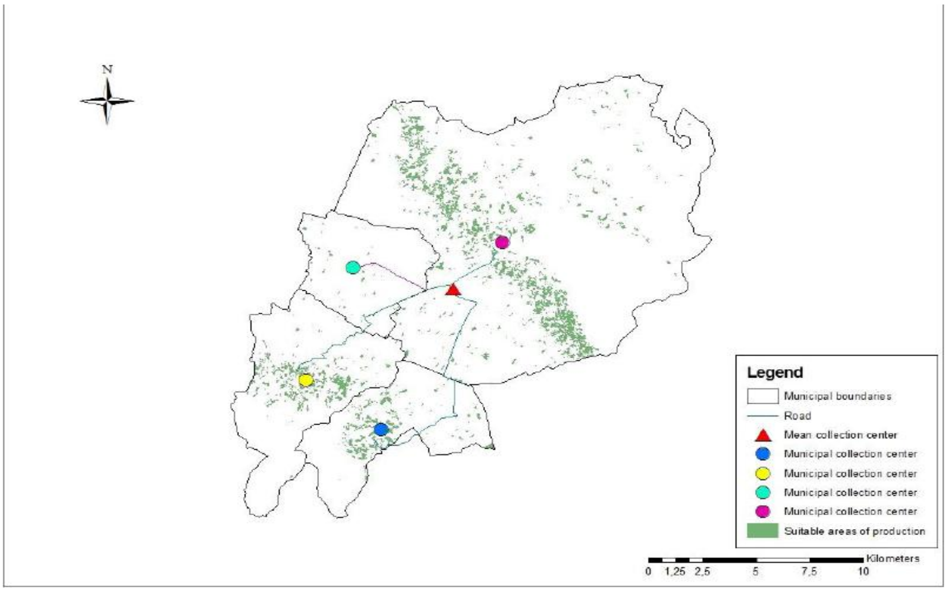
Figure

Fig. 1 – Study area. (A) Geographical location. (B) Physical and administrative framework.


(A)

(B)

Fig. 2 – Identification of storage facilities and paths between municipal storage facilities and single storage facility



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

Appendix A

Table A.1 – Land use (data in hectares)

Municipality	Total area	Forests and semi-natural areas	Wetlands and water bodies	Utilised agricultural areas	Artificial (built-up) areas
Assisi	18,680	7,094	692	9,491	1,385
Bastia Umbra	2,759	69	25	1,937	726
Bettona	4,514	1,801	27	2,367	317
Cannara	3,264	895	144	1,977	246
Total area	29,217	9,859	888	15,772	2,674

Source: Our elaborations on data Corine Land Cover, 2000.

Table A.2 – Production structure of olive groves and vineyards

	Olive groves		Vineyards	
Cadastral parcel size	Number of cadastral parcels	Hectares	Number of cadastral parcels	Hectares
Less than 1 ha	5,097	973	897	183
Between 1.1 and 2 ha	204	280	59	84
Between 2.1 and 3 ha	42	101	11	2
Between 3.1 and 5 ha	25	90	7	2
More than 5.1 ha	3	17	3	20
Total	5,371	1,461	977	338

Table A.3 – Cost of fresh biomass shredding, loading, transport and transfer

	Shredding/loading (*)	Transport (**)	Transfer (***)	Total
Vine, €/t of fresh matter (fm)	46.0	21.0	8.0	75.0
Olive, €/t of fresh matter (fm)	30.4	21.0	8.0	59.4

Notes: (*) Operating scenario: 2 tractors, 1 shredder Berti, 1 trailer and 2 workers. Source: Porceddu (2007); (**) Operating scenario: 1 tractor, 1 trailer with a load capacity of 1.6 t (8 m^3) and 1 worker. Source: Mescalchin et al. (2009); (***) Transfer from one plot to the other with the same operating scenario as in biomass transport. Source: Mescalchin et al. (2009).

Table A.4 –Power production and value of plant produced energy

	Unit	Values
Gross power production per tonne of biomass	kWh	293
Net power production per tonne of dry biomass	kWh	287
Energy selling price	€/kWh	0.28
Energy value of biomass gross of plant consumption	€/t	81.99
Energy value of biomass net of plant consumption	€/t	80.35

Table A.5 – Average distance between cadastral parcels and municipal storage facilities

Municipality	Average distance (km)	Standard deviation 95% of fields	Minimum distance (km)	Maximum distance (km)	Number of cadastral parcels
Assisi	8.15	3.94	0.035	25.93	4,250
Bastia Umbra	11.48	1.62	7.844	15.24	121
Bettona	4.87	3.27	0.002	13.42	1,058
Cannara	2.79	3.33	0.002	15.59	687

Table A.6 – Comparison between diesel energy content and wood chip energy content

Energy content of 1 t of wood chips at moisture content of 40%	kWh	2810
Energy content of 1 l of diesel	kWh	11
Diesel consumption for the supply of 1 t of biomass (distance: 8+8 km)	l	30.84
Energy content of 30.84 l of diesel	kWh	339

Table A.7 – Estimate of the kilometres travelled to transport fresh biomass from olive groves and vineyards to municipal storage facilities and estimated fuel cost

Municipality	Average distance (km)	Fresh biomass production t/yr	Number of return journeys with 1.6 t loads	Total travelled km	Total fuel cost (*)
Assisi	8.147	1,798	2.247	18,308	21,714
Bastia Umbra	11.479	51	64	732	868
Bettona	4.869	471	589	2,868	3,401
Cannara	2.794	351	438	1,224	1,452
Total		2,671	3.338	23,132	27,435

Note (*): With a consumption of 1.59 l/km and an average agricultural diesel cost of 0.746 €/l (1.186 €/km)

Table A.8 – Estimate of the kilometres travelled from municipal storage facilities to the single storage facility and estimated fuel cost

Municipality	Distance municipal storage facilities - single facility (km)	Annual dry biomass production (t)	Number of return journeys with a 32 t load capacity	Total travelled km	Total fuel cost (*)
Assisi	3.2	1,164	73	232.80	97.78
Bastia Umbra	5.24	29	2	9.42	3.95
Bettona	10.51	301	19	197.72	83.04
Cannara	13.99	220	14	192.14	80.70
Total		1,714	107	632.08	265.47

Note (*): With a consumption of 0.3 l/km and an average diesel cost of 1.4 €/l (0.42 €/km).

Table A.9 – Cost of vehicle rental for biomass loading, unloading and transport from municipal facilities to the single biomass storage and processing facility

Municipality	Travelled km	Required time per unit (min) *	Total required time (h)	Estimate of vehicle rental days** (d)	Vehicle rental cost*** (€)
Assisi	233	68	82	12	1,524
Bastia Umbra	9	73	2	0.3	40
Bettona	198	85	27	4	496
Cannara	192	94	21	3	398

Total	632	132	19	2,458

Notes: (*) 45 minutes for loading, 15 minutes for unloading and a travel speed of 50 km/h were estimated; (**) 7 hours of rental per day were estimated; (***) Vehicle rental cost is 130 €/day.

Table A.10 – Operating characteristics of the power plant

Description	Unit	Value	Value at full operating capacity
Dayly operating hours	No.	24	24
Dayly biomass input	t/d	9	9
Annual biomass (dry matter)	t/yr	1,713	2,682
Annual operating days	No.	190	329
Annual operating hours*	No.	4,560	7,900
Part-time workers	No.	1	2
Rated power	kW/h	125	125
Actual power	kW/h	110	110
Power production	kW/h/yr	501,600	785,400
Plant power self-consumption	kW/h/yr	10,032	15,708
Power production net of plant consumption	kW/h/yr	491,568	769,692
Energy selling price	€/kWh	0.28	0.28

Note: (*) 860 hours of machine downtime per year are necessary.

Table A.11 – Greenhouse gas emissions from shredding

Municipality	Annual fresh biomass production (t)	Shredding required time (*) (h)	CH_4 (g)	NO_2 (g)	CO_2 (g)
Assisi	1,798	212	9,729	176,819	29,399
Bastia Umbra	51	6	276	5,016	834
Bettona	471	55	2,550	46,344	7,706
Cannara	351	41	1,897	34,483	5,733
Total	2,671	314	14,453	262,661	43,672

Note: (*) The shredder operating capacity was estimated at 8.5 t/h.

Table A.12 – Estimate of CO_2 emissions from shredding, based on diesel consumption

Municipality	Annual fresh biomass production (t)	Diesel consumption (*) (l)	Diesel consumption(**) (Kg)	Energy consumption (***) (MJ)	Energy consumption (TJ)	CO_2 emitted (****) (t)
Assisi	1,798	6,472	5,391	231,823	0.2318	17.18
Bastia Umbra	51	184	153	6,576	0.0066	0.49
Bettona	47	1,696	1,413	60,760	0.0608	4.50
Cannara	351	1,262	1,051	45,209	0.0452	3.35
Total	2,671	9,614	8,009	344,370	0.3444	25.52

Notes: (*) With a diesel consumption for shredding of 3.6 l/t; (**) Conversion factor of litres to kilograms is 0.833; (***) 1 kg of diesel is equivalent to 43 MJ of energy; (****) The consumption of 1 TJ of energy emits 74.1 of CO_2.

Table A.13 – Estimate of CO_2 emissions from biomass transport

Municipality	Diesel consumption (l)	Diesel consumption (*) (Kg)	Energy consumption (**) (MJ)	Energy consumption (TJ)	CO_2 emitted (***) (t)

Assisi	29,250	24,365	1,047,704	1.0477	77.63
Bastia Umbra	1,169	974	41,879	0.0419	3.10
Bettona	4,678	3,897	167,579	0.1676	12.42
Cannara	2,062	1,718	73,866	0.0739	5.47
Total	37,160	30,954	1,331,028	1.3310	98.63

Notes: (*) Conversion factor of litres to kilograms is 0.833; (**)1 kg of diesel is equivalent to 43 MJ of energy; (***) The consumption of 1 TJ of energy emits 74.1 of CO_2.

Table A.14 – Estimate of greenhouse gas emissions from biomass combustion

	Average daily emissions (mg)	Average emissions per tonne of used biomass (mg)	Total emissions for the use of 1,714 t of biomass (g)
CO_2	8.86	0.984	1.69
NO_2	152.45	16.939	29.03
SO_2	33.52	3.724	6.38

Source: Our estimates on ISPRA data.