IDENTIFICATION OF ENERGY HUBS FOR THE EXPLOITATION OF RESIDUAL BIOMASS IN AN AREA OF WESTERN SICILY

Santo Orlando[1], Carlo Greco[1], Teresa Tuttolomondo[1-2], Claudio Leto[1-2], Ignazio Cammalleri[1-2], Salvatore La Bella[1-2].
[1] University of Palermo - Department of Agricultural, Food and Forestry Sciences
Viale delle Scienze, 13, - 90 128 Palermo
[2]Corissia Consorzio di Ricerca per lo Sviluppo di Sistemi Innovativi Agroambientali
Via delle libertà, 203 – 90143 Palermo
Corresponding author: Dott. Salvatore La Bella, E-mail: salvatore.labella@unipa.it

ABSTRACT: Recent years have witnessed a marked reduction in financial incentives for renewable energy production in Italy as a consequence of the fact that the nation has already reached its energy policy targets for 2020, However, incentives still persist in certain sectors, such as those of specialized crops for biomass and residual biomass. In order to increase use-efficiency of biomass resources, careful study is needed of their characteristics, and their distribution within an area and over time: biomass use is of interest when production is concentrated in a given area and sufficiently available throughout the year. In order to assess the competitiveness of the biomass energy sector, the logistics, organization and the financial aspects of the sector must be analysed on a large scale using land planning tools, such as land informational systems (LIS).This study represents a methodical approach to the development and application of a model of analysis focusing on the identification of possible hubs for the energy exploitation of residual biomass from crops grown in Western Sicily.
Keywords: residual biomass, land information systems (LIS), Western Sicily, transport.

1 INTRODUCTION

Biomass is often considered a renewable and unlimited resource, if used well; that is, if the rate of use of the biomass does not exceed its regeneration capacity. In reality, biomass is not an unlimited resource in quantity; quantities available for each type of biomass depend not only on the area of land dedicated to the species, but also on climate and environmental conditions, which tend to limit the number of species of financial interest in any given region. (2, 15)

The definition of biomass according to Italian law was given by Article 2 of Law 387 29th December 2003, and extended by the more recent Italian Law D.Lgs 28/2011 concerning the use of energy from renewable sources, and by "the implementation of Directive 2009/28/CE, repealing Directives 2001/77/CE and 2003/30/CE". Letter "e" of Article 2 defines biomass as "the biodegradable fraction of products, waste and residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fisheries and aquaculture, grass clippings and pruning residues from public and private parks and gardens, as well as the biodegradable fraction of industrial and household waste" (12, 24, 16, 19).

It is clear that the word *biomass* includes a large range of substances which have very different properties but which share the fact that they are all the most sophisticated form of solar energy accumulation (2, 4).

Photosynthesis allows plants to convert solar energy into chemical energy, storing it in the form of complex molecules with a high energy content, such as carbohydrates, lignin, protein and fats. Approx. 2×10^{11} tonnes of carbon are fixed in this way every year, with an energy content equivalent to 70 billion tonnes of crude oil: nearly 10 times the current world energy needs (7, 17).

In recent years, the word biomass is often linked to terms such as biofuels and bioenergy (23). The agricultural sector is, undoubtedly, the most important as regards dedicated and residual biomass production. Biomass residues (pruning residues from vineyards, olive groves and fruit groves, crop residues etc.) and, in particular, those found in large quantities and often not adequately reutilized, represent a huge potential source of energy which is still, as yet, largely unexplored and vastly underutilized. These residues are often disposed of simply by burning, with no financial or energetic gain (21, 22, 18).

The use of biomass for energy purposes can be considered financially viable when the biomass is concentrated in certain areas and sufficiently available throughout the year. If biomass is spread too thinly over the territory or harvesting is concentrated in certain periods of the year, then biomass collection, transport and storage become problematic and financially unattractive. A feature that nearly all types of biomass share is the need to transport large volumes with little economic value; this makes biomass of little financial interest when transport needs exceed a certain number of kilometres (28, 25, 9)

Biomass residues for energy purposes are found in various forms and are typically subdivided according to sector of origin. A number of sectors provide potential sources of biomass but the most prominent sectors are forestry, agricultural or livestock production, urban waste, waste from food processing industries, algae and a number of other plant species (29, 9, 27, 13, 15).

It is clear that in order to evaluate the financial viability of the biomass energy sector, large-scale analysis in terms of logistics, organization and financial parameters is required using land planning tools, such as land informational systems (LIS). The use of these tools allows us to optimize the location of each element along the energy production chain and to optimize the choice of CHP unit based on biomass available. This will also provide an evaluation of the effect of each element and seek to minimise energy production costs and any negative impacts (1).

This study represents a methodological approach to the development and implementation of a model of analysis which can identify possible hubs and, therefore, encourage energy production from biomass residues produced by crops currently grown in Western Sicily.

The territories in the study and data used

The area in the study covered Western Sicily and the towns of Agrigento, Palermo and Trapani (Fig. 1).

Figure 1: An overview of the area in the study

1.1 Land use based on Corine Land Cover

Corine Land cover (CLC) standard nomenclature includes 44 categories of soil cover grouped into 3 levels. The five main headings are *artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands* and *water bodies*. (20)

The complexity of Sicilian territories made soil-use category definition problematic, partly due to wide-ranging morphological features and partly to a long and difficult history of anthropization. Climate conditions and intrinsic low soil fertility found throughout large areas of the island compounded this process. These aspects often led to land use which is at the limit of financial viability and, therefore, at the limit of those classes defined by standard nomenclature (3, 20, 10)

Furthermore, areas that are more fertile are subject to huge pressures of intensive use and a high degree of subdivision, thus making categorization in single classes extremely challenging. In a detailed study carried out by the Sicilian Regional Environment and Land Management Authority (ARTA) using layers on a 1:10,000 scale, a series of modifications were made to standard use classes. In brief, changes were made according to land characteristics and concerned principally level 3; a number of subdivisions were also introduced regarding features specific to Sicily (table I).

Table I: Key for the Corine Land Cover adopted in Sicily

LAND USE CLASSES			
1st level	2nd level		3rd level
1 Artificial surfaces	11 Urban areas	111	Continuos urban fabric (settlements smaller than 25 ha)
		112	Discontinuos urban fabric
	12 Industrial and infrastructural areas	121	Indiustrial areas
		122	General infrastructures
		123	Port areas
		124	Airports
	13 Transitorial areas	131	Construction sites, excavations, earthworks
		132	Dumps
		133	Extractive areas (quarries smaller than 25 ha)
	14 Green urban areas and archaelogical areas	141	Urban parks, sport and leisure areas
		142	Archaelogical areas (areas smaller than 25 ha)
2 Agricultural areas	21 Arable land	211	Arable land irrigated and not, locally with tree crops: fodder, horticulture
		212	Green house and cultivations under plastic
	22 Permanent crops	221	Citrus groves
		222	Vineyards
		223	Olive groves
		224	Almond groves
		225	Orchards (f: pricly pear, K: carob, n: hazet, t: pistachio)
		226	Mixed groves
		227	Associations of olive and other groves
	23Heterogeneous agricultural areas	231	Complex cultivation patterns
		232	Associations of annual crops and vineyards
3 Forest and semi-natural areas	31 Forests	311	Broad-leaved
		312	Coniferous
		313	Mixed forest
		314	Partially wooded land or degraded forest
	32 Shrub and/or herbaceous vegetation associations	321	Shrubland
		322	Grassland
		323	Sparsely vegetated areas
	33 Open spaces with or no vegetation	331	Erosion scars, badlands, rock outcrops
		332	River beds
		333	Beaches
4 Wetlands	41 Inland wetlands	411	Inlands marshes
	52 Maritime wetlands	421	Coastal marshes
		422	Salines
5 Water bodies	51 Inland waters	511	Narural lake, antarged natural lakes
		512	Reservois
	52 Marine and transitional waters	521	Lagoons
		522	Coastal lakes

For the study and based on characteristics specific to Sicilian territories, the information shown in table II was extrapolated; it refers to agricultural areas only.

Table II: Surfaces considered 'agricultural' divided by soil use according to CORINE level 3 classification

LAND USE CLASSES	Agrigento	Palermo	Trapani	Totale
211 Arable land irrigated and not, locally with tree crops: fodder, horticulture	93,816	180,940	29,562	304,318
212 Green house and cultivations under plastic	338	0	359	697
221 Citrus groves	3,563	16,181	3,495	23,239
222 Vineyards	29,732	16,822	82,590	129,144
223 Olive groves	10,025	75,873	11,039	96,937
224 Almond groves	15,694	464	0	16,158
226 Mixed groves	37,967	4,877	25,167	68,011
227 Associations of olive and other groves	5,876	10,759	899	17,534
231 Complex cultivation patterns	29,956	35,643	18,914	84,513
232 Associations of annual crops and vineyards	22,026	10,377	19,178	51,581
322 Grassland	10,538	29,838	2,983	43,359
Total	259,531	381,774	194,186	835,491

2 METHODOLOGY USED

In order to identify potential energy hubs in the study area, a tool was used to evaluate soil suitability for this type of production; the tool was able to take into consideration land productivity, soil conservation and soil defence.

The use of this tool allowed us to identify energy hubs on a provincial, municipal and sub-municipal level based on available data and on the response of specific areas to production input, and, hence, to determine their subsequent rational use.

The model applies the *Framework for Land Evaluation* (5) and subsequent guidelines *Land Evaluation for Extensive Grazing* (14, 6) to the specific features of the territory. It is based on land features which can be measured directly in the field or can be obtained from common soil analyses or from official soil maps.

In order to evaluate land potential regarding biomass residues for energy purposes, the following characteristics were taken into consideration:

- slope gradient
- stone content
- road access

2. 1 Slope gradient

The gradient of the slope was determined using a recent edition of the Italian Regional 1:10,000 scale Topographic Map (CTR *Carta Tecnica Regionale, ed. 2008*). A digital elevation model (DEM) was created from terrain elevation data. Gradient classes were calculated through elaboration of the DEM, with a spatial resolution of 20 x 20 m and vertical resolution of 1 m. The terrain was then divided into 4 slope classes: 0-6%, 6-18%, 18 – 35% and > 35%.

Table III: Terrain distribution (ha) in the Province according to slope class (%)

Provinces	Total	< 6	6 – 18	18 – 35	> 35
Agrigento	302,525	66,972	143760	78,497	13,296
Palermo	498,562	59,614	212,269	168,525	58,154
Trapani	246,037	117,081	88,002	28,764	12,190

GIS analysis, which entailed overlaying the slope layer with the town boundary layer, provided further layers and allowed terrain slope classification both on a town level and on a provincial level.

2.2 Stone content

Regarding the classification of the stone content of terrains in the study area, ARTA Land Management Authority provided initial layers, previously created for the MEDALUS project (Mediterranean Desertification and Land Use). Layers were elaborated according to the ESA method (10) in order to study areas vulnerable to desertification and were applied to three Mediterranean country areas in the project (Italy, Portugal and Spain) (8).

Overlaying the stone layer with the town layer provided the data necessary to calculate stone content distribution within the various municipal areas and provinces in the study.

These maps were then cleared of artificial surfaces, forests, wetlands and water bodies (those with a level 1 CORINE code of 1,3,4 or 5) and of those areas which were not of interest for this study.

Table IV shows stone content in the various provinces, considering 'useful' surfaces only.

Table IV: Terrain distribution (ha) in the Province according to stone content

Provinces	Total	< 20%	20 - 60%	> 60%
Agrigento	266,144	79,877	185,043	1,224
Palermo	416,181	108,504	307,677	0
Trapani	197,926	102,493	94,573	860

2.3 Road access

Road access was acquired from OpenStreetMap data, a community of mappers who endeavour to develop and update data on roads, paths etc. all over the world (28). The freely available data is reasonably accurate and up-to-date. The system is based on local contributors who collect aerial photographs, GPS data and field maps to provide OSM with accurate data.

Road graphs in shape format were used as the base for identifying areas with road access suitable for residue/waste collection. Buffer zones of 500 m and 1000 m were created for the elements in that layer, representing optimal conditions and limits of accessibility.

2.4 Determination of energy obtainable from biomass residues.

Biomass residue calculations were based on yields and transformation values found in literature, held to be average values applicable even to large areas.

The energy value for each crop (B_{av}) was determined using the following equation (11):

$$B_{av} = f_g\, B_n\, a_n\, LHV_n$$

where

$$Bn = A_n\, Y_n$$

and where

B_{av} is the energy value of available biomass *(GJ * year^{-1})*
a_n is the amount of biomass available for energy production (%)
B_n is the theoretical potential biomass (t of residue * year^{-1})
f_g is biomass collection system efficiency (%)
LHV_n is lower heating value of the residue (GJ * t^{-1})
A_n is surface area dedicated to crop (ha)
Y_n is crop residue yield (t * ha^{-1} * year^{-1})

Lower heating values (LHV_n) for each crop, taken from literature (2, 11), are shown in table V, together with the characteristics of the main crops in the study area and their residues.

Table V: Characteristics of the biomass residues of crops in the study area

Crop	Type of residue	Yield (t/ha)	Moisture content (%)	Lower heating value (GJ t^{1})	Biomass suited to energy production (%)
Cereals	Straw	2.1	15	17.6	40
Citrus fruits	Branches	7.6	40	17.6	90
Grapes	Vine stems	2.1	35	17.5	80
Olives	Branches	2.8	50	18	90
Fruit trees (*apple, pear, peach, almond, hazelnut and apricot*)	Branches	7	40	18.2	90
Farm trees	Branches	6,5	40	18	90

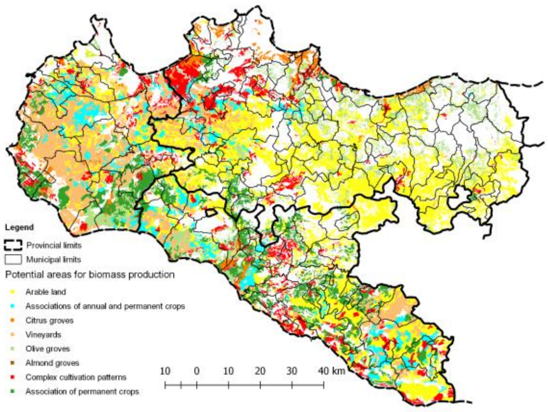

Figure 2: Map of areas producing biomass residues for energy purposes

2.5 Data analysis

An estimation of the potential energy production from available biomass required the development of a database using information on the various types of residues and their properties. The database was created in such a way as to combine these parameters and their relative surface areas to illustrate potential energy generation.

The GIS database, developed with open access software QGIS v. 2.6 was used to create thematic maps depicting potential energy production. It was used the GIS' functions of overlay topologic with dissolve, clip, merge, union and intersect.

This became the basis for identifying energy hubs for the bioenergy conversion of residues (26).

3 RESULTS

Figure 3 shows the surfaces which can be used for biomass residue production, divided by terrain-use class. The thematic map clearly shows distribution and the number of different crops in the area, both on a provincial and a town level.

Numerical data on potential biomass production and relative energy production on a provincial level are shown in tables VI and VII.

Table VI: Useable biomass residues calculated according to CORINE soil-use classifications using GIS in tonnes (t).

Province \ Crop	Cereals	Vines	Olives	Other trees	Total
Agrigento	34,859 (6.8%)	64,794 (12.7%)	21,116 (4.1%)	390,273 (76.4%)	511,042 (100%)
Palermo	58,244 (13.6%)	35,151 (8.2%)	158,816 (37.1%)	175,912 (41.1%)	428,123 (100%)
Trapani	9,403 (2.6%)	146,083 (40.8%)	23,052 (6.4%)	179,512 (50.1%)	358,050 (100%)
Total	102,506	246,028	202,984	745,697	1,297,215

From the data in table VI, it is clear that the greatest potential biomass production is found in Agrigento with 76.4% sourced from other trees, 12.7% from vineyards, 6.8% from cereals and 4.1% from olive groves.

In the Palermo area, the main biomass residue sources are from other trees (41.1%), olive groves (37.1%); cereals (13.6%) and vineyards (8.2%) represent less abundant sources of potential biomass in the province.

In the Province of Trapani, other trees are the main source (40.8%), followed by vineyards (40.8%), olive groves (6.4%) and cereals (2.6%).

Table VII: Energy values of useable biomass residues calculated according to CORINE soil-use classifications using GIS (GJ).

Province \ Crop	Cereals	Vines	Olives	Other trees	Total
Agrigento	613,519	1,133,906	380,088	7,102,970	9,230,483
Palermo	1,025,099	615,150	2,858,688	3,201,597	7,700,534
Trapani	165,494	2,556,458	414,936	3,267,118	6,404,006
Total	1,804,112	4,305,514	3,653,712	13,571,685	23,335,023

In order to evaluate the potential in an area based on road access, overlay analysis was performed using the earlier maps placed over buffer zone maps of 500 m and 1000 m from road access (Fig 3.2). In this way, simulation was provided with two levels of road access.

The maps with road access buffer zones (shown in figure 3 and 4) illustrate areas both within and outside the 500 m band and 1000 m band from the road network. It is clear from the maps that the Province of Trapani enjoys best access, even concerning the 1000 m buffer zone, with few areas lacking road access. The Province of Palermo seems to have the greatest number of areas lying outside the buffer zones (both in absolute terms and in percentage terms).

Overlay analysis of these layers with those layers depicting biomass and energy production helped determine the potential of any given area for each of the two bands (Figure 5); results were subsequently compared to earlier data on the Corine 'whole useable surface areas'.

Final data obtained for the provinces are shown in table VIII.

The table shows a dramatic decrease in yield potential (approx. 33%) when comparing data for the 'whole surface area' to data for the 1000 m buffer zone; this reduction was even more marked for Palermo (approx. 45%).

A decrease was also evident when considering the 500 m buffer zone: for all three provinces in the study, potential in the 500 m buffer zone was approx. 10% lower than that of the 1000 m buffer zone. In absolute terms, it represented a reduction of approx. 43% compared to potential for the 'whole surface area'. Once again, the greatest decrease was found in Palermo (54%) and a less marked decrease in Trapani (26%). This fact was already evident from the buffer maps, where Palermo is shown with a very poor road network, often with large areas lacking access (areas frequently over 2000 m from a road).

4 CONCLUSIONS

Results of this study showed the considerable volume of biomass residues of interest for energy purposes available in the study area. The results also allowed us to classify suitability or yield potential of the area based on road access – a critical issue in the evaluation off all biomass.

The use of this model enables identification of energy hubs for the exploitation of biomass residues based on the physical and structural characteristics of the territory, and on yield in the area. The identification of these areas is an essential element for correct energy planning; it would also aid decision-making on financial viability based on the potential of a given territory and its farms. This tool could help create a plan of action by ranking areas for targeted action according to greatest biomass residue yields.

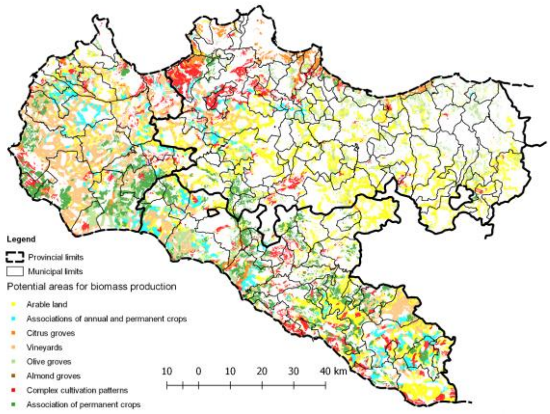

Figure 3: Map of road access buffer zones of 500 meters

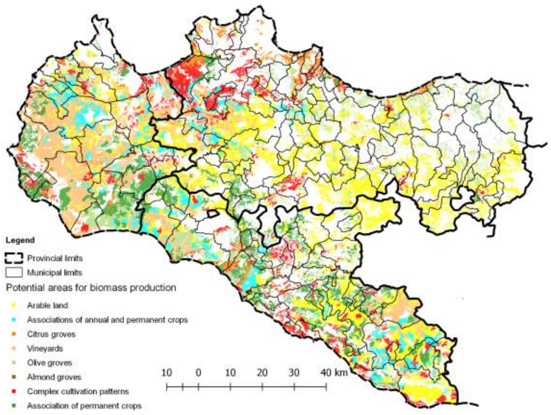

Figure 4: Map of road access buffer zones of 1000 meters

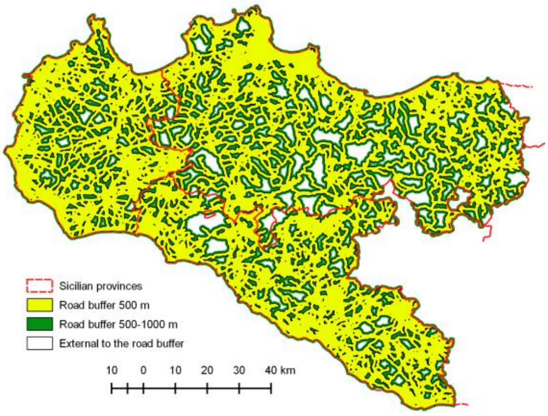

Figure 5: Map of road access buffer zones of 500 and 1000 meters

Table VIII: Yield potential in terms of biomass and energy regarding areas included in road access buffers of 500 m and 1000 m, and regarding the 'whole surface area'

	500 m buffer		1000 m buffer		Whole surface area	
Province	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)	Biomass (t)	Energy (TJ)
Agrigento	277,361 (-46%)	5008	319,528 (-37%)	5768	511,042	9230
Palermo	196,871 (-54%)	3551	235,819 (-45%)	4249	428,123	7700
Trapani	264,524 (-26%)	4736	312,247 (-13%)	5586	358,050	6404

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