Multi Criteria Analysis to Evaluate the Best

Location of Plants for Renewable Energy by Forest

Biomass: A Case Study in Central Italy

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Abstract

This paper presents preliminary results of a multi-criteria analysis (MCA) process in GIS environment for the identifications of sites suitable for building biomass plants. Today, environmental assessment needs of Decision Support Systems (DSSs) able to consider several aspects in a unique analysis framework. Biomass to energy projects are highly geographically dependent and the plant's profitability can be strongly influenced by its location. The complexity of interaction among ecological, economic and political variables and a widespread lack of data availability lead to difficulty in bringing together large-scale analysis and local planning systems. This gap can be solved through flexible tools able to relate large scale environmental assessment with medium and small scale DSS, useful for local decisions makers.

1 Introduction

According to the report of the Intergovernmental Panel on Climate Change (IPCC), biomass provides 10.2 % of the global total primary energy supply. The same IPCC has appointed experts to review scientific data to make a prediction, it was found that by 2050 the production of energy from biomass could vary from two to six times the current value, variable that depends on several factors, such as politics and the market trends, but also by the ability of planning and above all optimization of the available resources [Special Report on Renewable Energy 2012 "IPCC"].

In the EU-15, the production of biomass represents the 18.8 % of production from renewable sources [GSE Statistical Report 2011, Installations to renewable energy source]. Of the total production, 33.8 % belongs to Germany, followed with percentages around 11%, the United Kingdom and Sweden, Italy ranks in 5th place, contributing with 7.6%.

For the Italian situation the recent National Action Plan (NAP) for Renewable Energy expected to increase the use of biomass by 2020 (in respect of the European Plan 20,20,20), which will cover 44% of consumption from renewable sources. The provisions of the PAN arise from the observation of the trend of the last twelve years (2000-2011), in which the park of installations fueled by bio-energy has been marked by steady growth, with an average annual rate of 19 % [GSE statistical report 2011, renewable energy systems].

Under the EU legislation [Directive 2009/28/EC] on the promotion of energy from renewable sources, the term "biomass" shall mean "the biodegradable fraction of products, waste and residues from biological origin, from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste."

In Europe, the forestry is, along with agriculture, one of the primary factors for the supply of biomass, this is due to the fact that forests are one of the most important ecosystems in the European Union, covering 36.4 % of the total area, of which the majority is used for economic purposes. At 2009, in Europe (excluding the Russian Federation), about 8% of the forest area is protected, and less than 1% is part of the International Union for Conservation of Nature (IUCN) Category I protected areas [IUCN]; this means that the forests are for the most usable and that the potential of available forest resources for bio-energy is very consistent.

The Italian situation is well modeled on the European data, in fact, about one third (29.1%) of the Italian territory is covered by forests [CFS, 2007], and is gradually expanding at a pace of about 100,000 hectares per year, according to the statistics of the FRA 2005 [FAO, Global Forest Resources Assessment 2005].

Increasing the contribution of forest biomass in energy generation is therefore possible, and it is certainly an important step in the development of sustainable

communities, in addition to the reduction of emissions of greenhouse gases compared to those produced from fossil resources, this resource allows provide local energy at low cost, by reducing dependence on international fuel markets. Despite the abundant forest resource available, there are not always the conformation, structure and location suitable to use the individual forest compartments for energy purposes, for reasons both endogenous and exogenous. Therefore it is inevitable a preliminary feasibility analysis, in which the variables involved are varied and complex and can hardly run out through only a purely economic analysis. It is increasingly frequent, in these cases, the use of complex decision-making tools, able to manage a substantial amount of variables relating to aspects also very heterogeneous, managing to make the most possible holistic decision-making.

A decision-making tool can "take many different forms and can be used in many different ways " [Zhou et al., 2006], therefore its purpose is not to replace the decision maker, but rather to help the decision-making process of interrelation of complex data, leading to a more comprehensive vision of the synthesis possible. Decision support systems or multi-criteria decision-making methods have been used with great effectiveness in the areas of energy, the wind energy industry, for example, was the first to benefit greatly [Kiranoudis et al., 2001; Colantoni et al., 2013], but in general there is an increasing application of multi-criteria methods to issues of energy production from renewable sources since 2004 [Scott et al., 2012].

In this scenario, in last year, researches concerning the availability of biomass and relative best costs of transformation to produce renewable energy play a relevant role in supporting the best land use policy. Researches on ascertaining and reducing production costs have been undertaken extensively in North America and Europe. In this regard, several researchers conducted studies concerning the individuation of the least cost for the best suitable area for renewable energy plants, applying the Multi Criteria Analysis - MCA tools [Morey 1975; Eastman et al., 1993; Panichelli and Gnansounou., 2008; Recchia et al., 2010, Carlini et al. 2013], while other researches [Stuart et al., 1981; Watson et al., 1986] compared the costs of various harvesting systems at different scale. In Europe, the Swedish University of Agricultural Sciences has been running "The Forestry Energy Project", which includes research into effective forestry, including the use of forestland residues. In recent years, additionally to cost evaluations, several studies consider the problem of choosing the best location for renewable energy plant [Puttock, 1994; PhuaMui-How and Minowa, 2005; Zambelli et al., 2012; Colantoni et al., 2013; Perpifia et al., 2013]. In some cases, the problem consist of choosing simultaneously the location of more than one energy unit. In this context, the maximum radius approach is often used while avoiding overlap of collection areas. A maximum distance from the energy unit, coincident with the centroid of the collecting area, is established and all the biomass quantities inside this radius are supplied to the facility.

In this paper, we report preliminary results concerning the identification of suitable area for locating biomass plants in response to the European strategy for

promoting renewable energies. For this purpose Multi Criteria Analysis - MCA techniques, developed in GIS environmental, were applied using appropriate criteria and factors.

2 Materials and methods

2.1 The study area

Twelve Municipalities, about 720 Km2, located between Roma and Viterbo Provinces, in Lazio Region, represent the study area. Land Use for this area is characterized mainly by agricultural and forestry activities while human settlements represent a little percentage of the whole territory. At patch scale, land use classes present a high fragmentation value, especially for those classes characterized by human activities, first the agricultural one. For these reasons, this area is very representative of the environmental reality of central Italy. Regarding the capability for this territory in terms of biomass production, it is framed as a hilly environment and the presence of extensive state-owned forests, about 90 km^2, accounting for 12% of the whole territory, represent a potential value in terms of energy production from renewable sources. Figure 1 shows the location of the Municipalities with the state-owned forests and the land use map that evidences how this territory is characterized by rural landscape. In Table 1, for each Municipality, is reported the total surface and the percentage of state-owned forest.
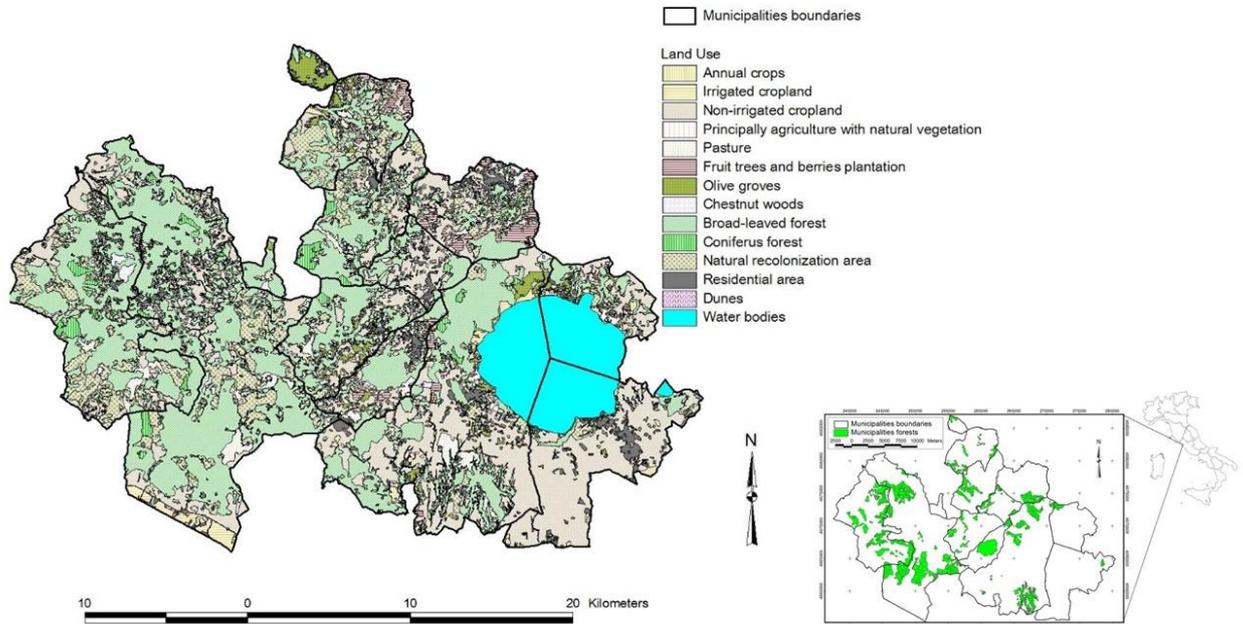

Figure 1. Location of the study area and Land Use Map.

Municipalities	Area	State-owned Forests	
	(ha)	(ha)	(%)
Allumiere	9181,7	1959,2	20,3
Anguillara Sabazia	7256,6	41,3	0,4
Barbarano Romano	3726,0	705,3	7,3
Bassano Romano	3761,9	352,9	3,7
Bracciano	14609,5	1330,7	13,8
Canale Monterano	3692,5	405,7	4,2
Manziana	2384,9	691,5	7,2
Oriolo Romano	1920,3	311,2	3,2
Tolfa	16767,3	3231,8	33,5
Trevignano Romano	3793,6	139,6	1,4
Vejano	4426,5	432,9	4,5
Villa San Giovanni in Tuscia	527,1	56,6	0,6
	72048,0	9658,7	100,0

Table 1. Municipalities area and state-owned forests with percentage values.

2.2 Multi Criteria Analysis

Multi-criteria decision making implies a process of assigning values to alternatives that are evaluated along multi-criteria. Multi-criteria decision making can be divided into two broad classes of multi-attribute decision making and multi-objective decision making. If the problem is to evaluate a finite feasible set of alternatives and to select the best one based on the scores of a set of attributes, it is a multi-attribute decision making problem. The multi-objective decision making deals with the selection of the best alternative based on a series of conflicting objectives. Both multi-attribute decision making and multi-objective decision making problems can be single-decision-maker problems or group decision problems. There are many classifications in place for the extensive formal methods and procedures for handling multi-criteria-decision making [Yue and Yang, 2007; Kinoshita et al., 2009; Sacchelli et al., 2013] Criteria and indicators are evaluated using GIS, remote sensing techniques, coupled with field data and literature. All the scores are standardized according to fuzzy logic because they are not non-commensurate. Preferences on the criteria and indicators are expressed as weights that are assigned by decision makers. Combining the weights and the indicator maps generates priority area for best plants location for production of renewable energy.

2.3 Data source

The most important phase and the one with a strong influence in the evaluation of potential sites for an installation or activity is the selection of the factors and

criteria that will have a direct influence on the activity in question. As can be expected, many different factors can be taken into account in this kind of studies and those finally selected will be in accordance with the required objectives, the information available, planner's experience, etc. In the present study all the criteria (factors and constraints) are reflected in the corresponding GIS thematic classes consulted from an extensive bibliography.

Several dataset were acquired to perform the analysis, some of them are available by institutional offices such as: Region Lazio environment department and Business Innovation Centre - BIC Lazio; while, in other cases, they have been acquired by photo interpretation. This is the case of geo-referenced dataset concerning roads networks that, in the present case study, represent one of the most significant factors in decision support making. Several researches, in addition, investigated about costs of different transportation systems because transport and distribution greatly affect the cost for utilizing woody biomass. Malinel [Malinel et al., 2001] estimated the amount of utilizable woody biomass assuming that the distance within forests is 250 m and the distance of transport by truck is 40 Km. When woody biomass is used instead for local heating, Sennbald [Sennbald, 1994] found that profits can be made when transport distance within the forest is less than 300 m and the distance of truck transport is less than 30 Km. Photo interpretation, in GIS environment, of aerial photographs detected in 2010 at a scale of 1:5.000 was conducted to acquire the roads network for the study area. Recently, Hamelinck [Hamelinck et al., 2005] found that profits can be made even if the distance of transportation is up to 100 Km.

To this aim, we classified all the roads as: main roads, secondary roads and harvesting roads. The first class, main roads, is represented by all the paved streets with 6-8 m wide track, while, the second class is represented by roads with 3-6 m wide track, the harvesting roads, instead, present the same characteristics of the secondary roads, but unlike these, fall inside the state-owned forests. [Gauss et al., 2008]. Figure 2 shows the roads network detected for the study area and the location of state-owned forests, while, Figure 3 shows the classification of the study area from the distance of main roads and the classification of state owned forests from harvesting roads distance.

Finally, in Table 2, we summarized factors and constraints used in the present AMC analysis based on fuzzy logic.
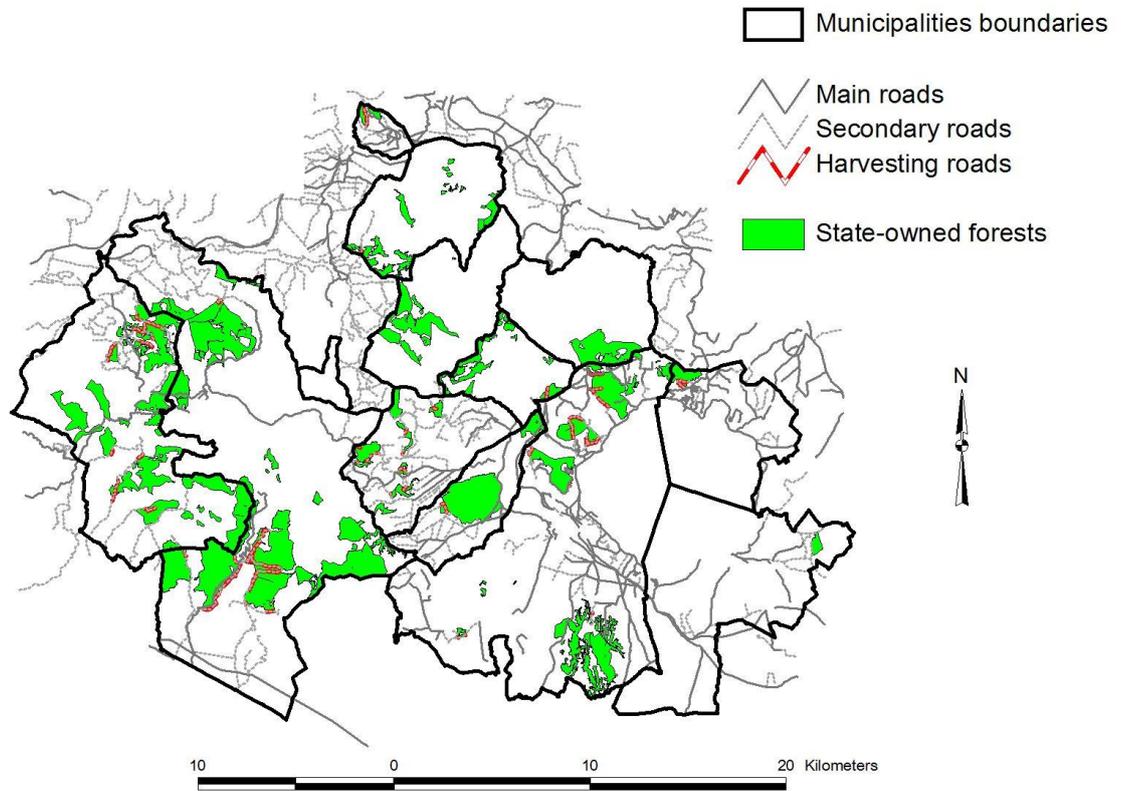
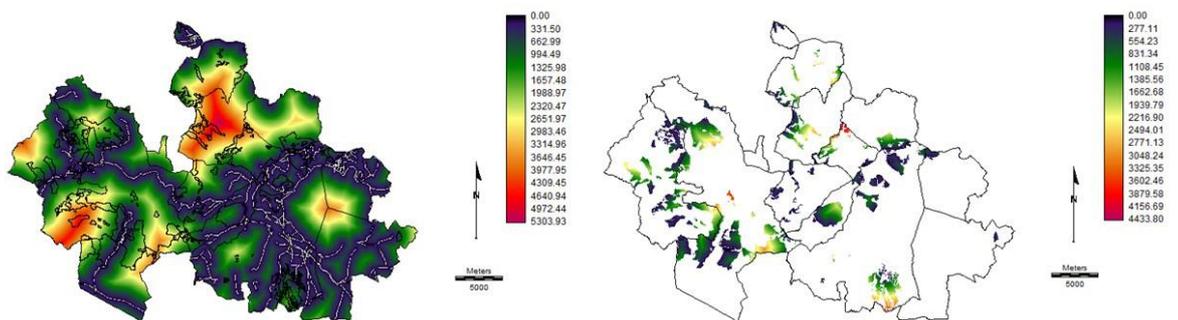Figure 2.Municipalities boundaries, state-owned forests and roads (main and secondary).

Figure 3.Layers showing the distances from main roads and classification of the state owned forests from secondary roads.

Data set	Factor	Constraint	Provided by
Land Use Cover	∨		Regione Lazio (Environm. Depart.)
State ownedforests	∨		Business Innovation Centre - BIC
Protected area	∨		Regione Lazio (Environm. Depart.)
Roads network	∨		Photo interpreted
Elements of the national heritage		∨	Regione Lazio (Environm. Depart.)
Archeological sites		∨	Regione Lazio (Environm. Depart.)
Water bodies		∨	Regione Lazio (Environm. Depart.)
Residential areas		∨	Regione Lazio (Environm. Depart.)
Slope	∨		Regione Lazio (Environm. Depart.)
Landscape constraint		∨	P.T.P.R. – Regione Lazio

Table 2. Classification of Data sets in factor and constraint.

3 Results

The analysis carried out shows that the study area presents high potential for the realization of a biomass plant for renewable energy production. The state owned forests, which account for over 13% of the whole territory, are homogeneously distributed in the study area and present an average size of 67 ha. These surfaces are able to provide, once planned for this purpose, a constant amount of biomass that justifies the realization of a plant for the production of renewable energy [Colantoni et al., 2013].

A limiting factor in the right choice for the location of a biomass plant is the density of the road network in the territory and the distance from the forests used for the production of biomass. For this aim, the analysis carried out of the roads network achieved in the present study evidences that in an area of about 720 km2 there are 668 m/Km2 of main roads and 742 m/Km2 of secondary roads. The density of harvesting roads has not been calculated over the entire study area, but refers only to the state owned forests and it is equal to 302 m/Km2. These values further confirm the good attitude of this territory in placement of a renewable bio-energy plant.

The analysis performed also shows how the decision-making for the best location of a biomass power plant is highly dependent on the slope of the ground that plays an important role not only for the individuation of productive forests, but also to identify the right place for the plant location.

Factors and constraints used in the multi-criteria analysis, according to fuzzy logic, Table 2, have allowed to discriminate the territory giving an increasing

degree of sustainability for best bio-energy plant locating.

Figure 4 shows the sustainability detected for the study area by AMC analysis. For the entire study area were identified about 700 ha of territory that presents a very high sustainability (230-252) in terms of localization of a biomass plant for the production of energy. Of these 700 hectares approximately 35% is concentrated in three areas that present the right data of distance, towards the road network, and environmental, in respect of the productive forests.
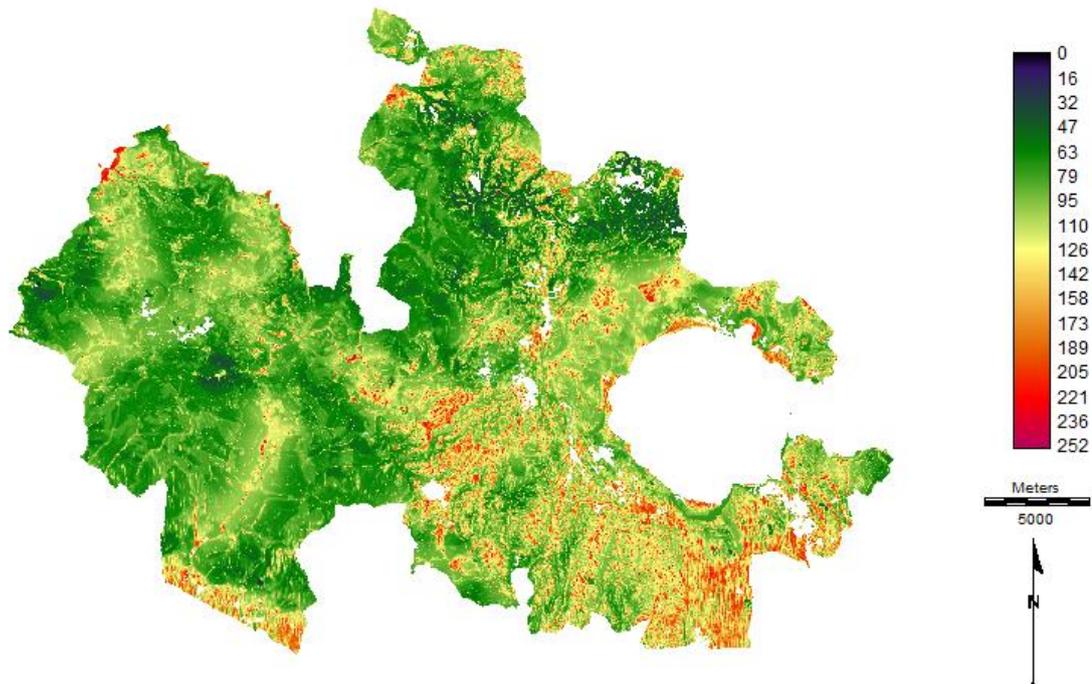

Figure 4. Suitability values for best bio-energy plant location.

4 Conclusion

The developed GIS-based model seems to be useful to predict the influence of several variables on individuation of best position for a biomass energy production plant at different scale of analysis. In particular, the increasing of input variables permits to extend the calculation from ecological to technical, logistical-political and economic availability.

The combination of MCE and GIS methods can therefore be seen as a powerful tool for solving power-planning problems, such as the best location of biomass plants. MCE-GIS can be used to answer a range of different questions: it can firstly be used to obtain territorial information for planning of power supplies, and secondly, it can provide the necessary tools to integrate this knowledge into the project's development to help in decision making and guarantee sustainable activities.

Considering the results obtained, the next step of this research will focus to increase the data-base with that data currently not yet available. In this regard, one of the most important data necessary to achieve the final goal is to acquire the residential sprawl layer that represents a typical urbanization process that has characterized this region from 70s to the present day. This information represents a very important feature as limiting factor for the individuation of the best place for the realization of a biomass plant for renewable energy production.

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