Optimal location and size for a biomass plant: application of a GIS methodology to the "Capitanata" district

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Abstract: The aim of this work is to outline a methodological procedure to assess the most advantageous logistic use of agricultural residues (such as straws) in order to supply a biomass energy plant using the economic criterion of the maximization of the NPV (Net Present Value). A GIS (Geographic Information System) neighborhood statistics procedure was applied in order to locate the biomass plant.
Results showed that the optimal radius of the supply basin was not related to (but independent of) both total amount and spatial distribution of biomass resources within the basin; differently, biomass availability strongly affected the size of the plant and the corresponding NPV. Therefore, the optimal plant location was at the center of the geographical area constantly characterized by the highest biomass density at different orders of scale.
Keywords*: straws, biomass plant, optimization, GIS, neighborhood statistics.*

1. Introduction

"Capitanata" is a geographical area of the Apulia region with a very large availability of straws, agricultural residues obtained from winter cereal crops. The total area considered in this study takes into account a part of "Capitanata" called "Tavoliere" and comprises neighbouring districts that belong to three different southern regions of Italy: Puglia, Basilicata and Campania, respectively (*Fig.1, A*); within a total area extended 665,000 hectares, 400,000 hectares are cultivated with winter cereals (average surface fraction F=0.6) from which 480,000 tons of straws are annually potentially produced.
As the size of the power plant (P) increases also the total amount of electricity produced and sold increases; however, the greater amount of feedstock needed to satisfy plant demand requires greater transportation distances, thus increasing the total hauling costs (*Leboreiro and Hilaly, 2011*). As a result of these competing factors, an optimal radius of the supply basin and an optimal plant size which maximize the profitability of the investment should be detected. The optimum plant size is also significantly impacted by the economies of scale; for the sake of simplicity, we have not considered this aspect in the present short paper. The economic criterion applied to reach these "optimal" solutions is to maximize the NPV (Net Present Value) of the overall project investment. We were specifically interested in defining three main features: 1) the "optimal" radius of the biomass supply basin (R^*); 2) the "optimal" geographic location of the plant within the same basin; 3) the "optimum" size (or capacity) of the plant (P^*).
Land planning in the bioenergy sector requires the processing of geo-referenced data, with particular emphasis on the spatial distribution of the available biomass resources (*Rozakis et al., 2001a*). On this respect, GIS software applications are an essential tool to work out spatial analysis from digital maps of land use and of the road network.

2. Materials and Methods

2.1 Preliminary spatial procedures. The spatial analysis was performed using ESRI ArcGIS software package 9.1. The database employed is the CASI-INEA land use map (2001); the land class “non-irrigated arable land” is strictly related to the presence of winter cereal crops from which straws derive.

Firstly, a regular grid (each cell being 2,000 x 2,000 meters corresponding to S=400 hectares) was overlapped to the vector land cover map so that it was possible to estimate the wheat surface fraction (F_i) in each reference unit (*cell*). The available straw per unit of cultivated area (Y) was estimated equal to 1.2 t ha^{-1} y^{-1} of dry biomass. The “biomass map” was then obtained multiplying, in each cell, S by Y and by F_i (*Fig.1, B*). Secondly, taking into account the provincial and national road networks, downloaded from the National Cartographic Service, it was possible to compute the distance between whichever hypothetical plant location and the centroid of each cell belonging to the whole area under study (*Alfonso et al., 2009*) so that the transportation cost of the total biomass could be determined.

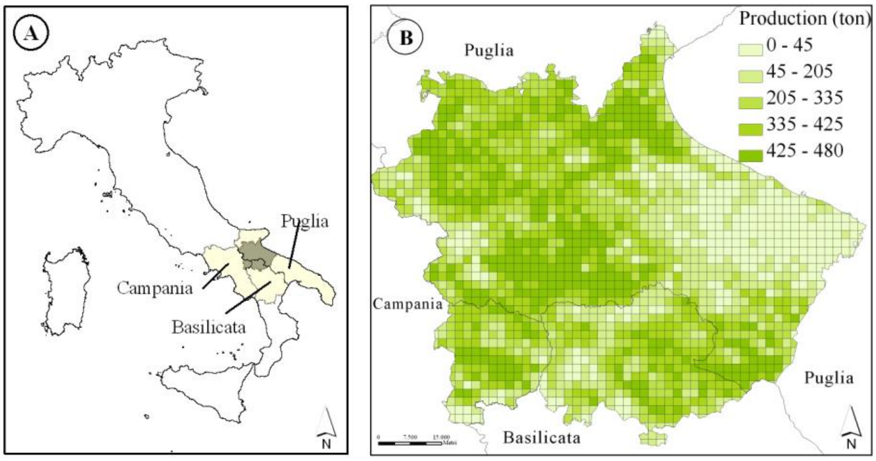

Figure 1. *A: area under study (in dark gray); B: map of the potentially available biomass from straws.*

2.2 Calculation of NPV. To calculate the NPV, the revenues (*Rev*) and total costs (*Cst*) regarding the annual plant operation were determined. The resulting difference (*Rev-Cst*) is the “net benefit”, a constant annual cash flow that is financially brought back to the starting year of investment, applying a discount factor. Subtracting from this discounted capital the initial investment, the NPV is obtained; it represents the net profitability resulting from the overall activity undertaken.

Considering a hypothetical cell of the grid and supposing to locate the plant inside it, the distances D_i of each other cell from the chosen one can be determined. With respect to each cell, the corresponding F_i value can also be assigned. The cost estimation exactly followed the procedures reported by *Caputo et al., 2005*.

To test the effect exerted on R, P and NPV by different patterns of biomass spatial distribution, F_i has been changed from the actual values to those reconstructed in order to simulate three different conditions: *1.* the highest F_i values are assigned to clustered cells close to the plant (spatial decreasing biomass density); *2.* the highest F_i values are still assigned to clustered cells but far away from the plant (spatial increasing biomass density); *3.* constant F_i values (spatial uniform biomass density). These three different simulation scenarios were compared with each other. In a second set of simulations, the economic model was applied to the actual F_i but three different Y values (the reference value, an increase and a decrease equal to 30%, respectively) were considered, the total available biomass being

$$Q_{tot} = \sum Q_i = S \cdot Y \cdot \sum F_i \,.$$

2.3 Spatial analysis. The plant location was determined applying a spatial “neighborhood” statistic function to the raster “biomass map”. The statistic function is the “mean” and the neighborhood is a circular moving window. A “moving window” consists of a subset of the raster map; the result of the function is assigned to the central cell of the window, and the whole process is repeated for each cell in the map (*Varela et al., 2009*). In this study, the average biomass density of the grid parcels (t ha^{-1}) was considered. According to this procedure, spatial variation at the local level can be quantified and more details are revealed with a general smoothing effect on the original dataset (*Zhang et al., 2007*). In particular, as the window size used for calculation of neighborhood statistics increases, the smoothing effect of this statistical procedure became stronger, resulting in clearer patterns which emphasize the persistence of a certain number of areas with very high density values which can be eligible to plant location. For this purpose, six density maps were produced performing a neighborhood statistics according to a circular moving window whose radius varied from 2 to 7 cells (corresponding to 4 and 14 km).

3. Results

The “optimal” radius of the biomass supply basin, the one corresponding to the maximum NPV, showed to be independent of the particular spatial distribution of the F_i value within the grid (*Fig. 2.A*); this was invariably observed with respect to any of the three different F_i vector (decreasing, increasing and constant F_i values, respectively). Since the average F value was fixed and equal to 0.6 for the three vectors, P* and Q_{tot} are the same for the three simulations (*Fig. 2.A*). The “optimal” radius is also unaffected by the total available biomass Q_{tot} (*Fig.2.B*); clearly, an increased amount in the available biomass leaded to an increase in the value of P* and, consequently, in the maximum NPV. We can conclude that, at a certain R^*, the higher is the value of Q_{tot} and the higher is the biomass density close to the plant location, the higher is also the NPV. *Fig. 3* shows the different spatial patterns which derive applying the neighbourhood statistics by increasing the radius of the moving window, from 2 to 7 cells. A progressive loss of details in spatial variation is associated to a simpler and clearer spatial biomass pattern. The smoothing effect tends to create larger homogeneous areas with lower

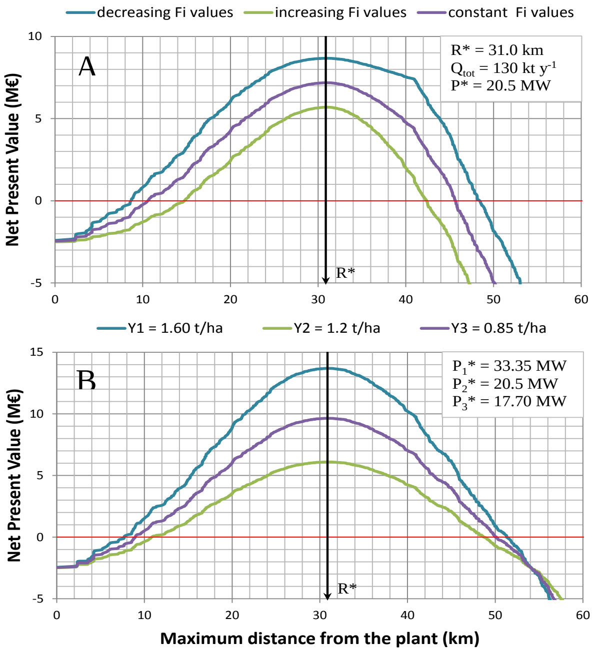

Figure 2. *Simulation results of the economic model. A: set of three different Fi vectors; B: set of three different Q_{tot} values.*

values of biomass density; nevertheless, the persistence of some cells with very high density values is still registered. The areas that are characterized by a persistently high biomass density, through different orders of scale, can be considered the most suitable for the location of the facility.

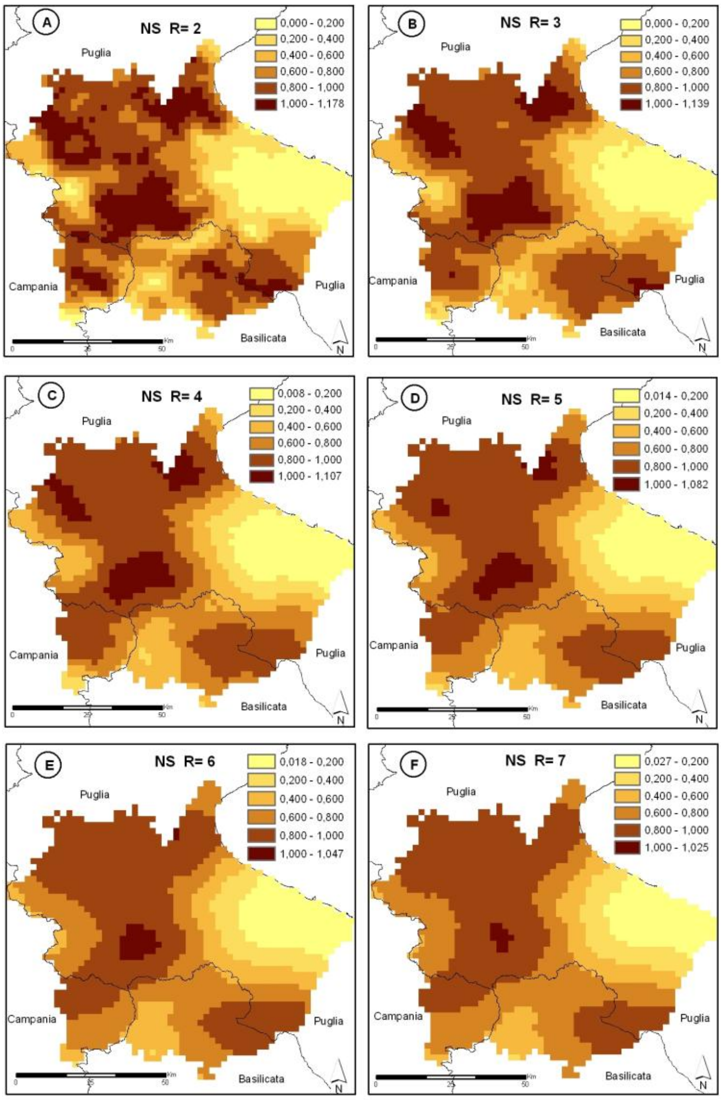

Figure 3. Spatial distribution of the average biomass density values calculated using neighbourhood statistics (NS) with an increasing moving window radius (R from 2 to 7 cells).

4. Concluding remarks

Results showed that the optimal radius of the supply basin was not related to (but independent of) both total amount and spatial distribution of biomass resources within the supply basin; differently, biomass availability strongly affected the size of the plant and the corresponding NPV. Therefore, the optimal plant location was at the center of the geographical area characterized by the highest biomass density.

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