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A spatial analysis model to assess the feasibility of short rotation forestry fertigated with urban wastewater: Basilicata region case study

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ABSTRACT

The large-scale cultivation of energy crops irrigated with non-conventional water resources could reduce the negative impacts of fossil fuel use, while still saving potable supplies and decreasing pollution in surface water, particularly in water-deficient environments, like the Mediterranean region. Energy planning is a complex process involving multiple decision makers and criteria. Given the spatial nature of the problem, the research proposes a spatial analysis model to assess the agronomic and economic feasibility of vegetation filter systems in Basilicata region, southern Italy. The model chosen for land suitability analysis is the ordered weighted averaging (OWA) with the use of linguistic quantifiers. The suitability map obtained from the OWA model was used as input in the spatial analysis functions to quantify the productivity and irrigation needs of the species, the potential irrigable service area of the wastewater treatment plants (WWTPs), as well as the distances between them and SRF, which are all key elements in the economic evaluation. The results show that the distance is the main element that influences the feasibility: only 25 out of 163 WWTPs are cost-effective and can actually irrigate 864 ha of SRF. The research demonstrates that there is a great potential for bio-energy development in the region with significant economic advantages; in fact, there is a large number of sites with positive NPV up to 50,876.43 €/ha and payback period between 3 and 10 years. The implementation of vegetation filter systems could create chains with a high number of local actors (farmers, intermediaries, forest nurseries, etc.) and contribute to promoting territorial development and employment.

1. Introduction

Bioenergy has a significant potential to mitigate greenhouse gases (GHGs), provided that sustainable strategies are adopted to develop resources, and efficient bioenergy systems are used (Styles and Jones, 2007; IPCC, 2011). Considered as the most promising renewable resource in the short and medium term (Hoogwijk et al., 2003), bioenergy is expected to play an increasing role in Europe, in view of achieving the targets recently established by the European Union on energy supply security and in compliance with international agreements on emission reductions. Within this context the biomass produced on agricultural soils will play an important role (Bernetti et al., 2004; EEA, 2013), related in particular to short-rotation forestry (SRF) (Dornburg et al., 2008, 2010; Romano et al., 2013a,b). Actually, following the IPCC report on renewable energies (IPCC, 2011), it would be possible to obtain up to 700 EJ/year from dedicated biomass crops grown on abandoned lands and/or on soils not planted with food crops. In the Basilicata Region, southern Italy, marginal farmland areas are being increasingly abandoned due to their low productivity in terms of output and product type, and as a result of the major reforms of the EU Common Agricultural Policy (Romano and Cozzi, 2008). It follows that there is a large availability of soils suitable for bioenergy crops, but there is still a need to convince farmers of the cost effectiveness of growing bioenergy crops. Several studies show that the gross margin for SRF cultivation is positive only if biomass production is >9 tDM/ha × year (Rosenqvist and Dawson, 2005a; Dimitriou and Rosenqvist, 2011; IEA Bioenergy, 2011). In Italy the yield values of SRF vary from

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North–South, mostly as related to the existing precipitation levels; surveys conducted in southern Italy (Bergante et al., 2013) report yield levels ranging between 5.6 and 6.1 tDM/ha × year, respectively, for poplar and willow, against values ranged between 7–10 and 14–16 tDM/ha × year for poplar and willow in northern Italy (Bergante and Facciotto, 2006; Facciotto et al., 2012). Irrigation and the application of fertilizers become, thus, necessary to achieve high productivity levels, especially in Mediterranean environments, characterized by water deficits notably in summer (Barbera et al., 2009). In those environments, the use of unconventional water resources is an excellent strategy to reduce the use of fresh water resources in agriculture while still supplying crops with water and nutrients (FAO, 2010); actually the European Union is stimulating and encouraging the spread of such a practice (European Commission, 2012).

The implementation of multifunctional SRF plantations has, thus, become a sound alternative to conventional SRF for the considerable economic and environmental benefits associated with them (Rosenqvist and Dawson, 2005b; Berndes et al., 2008; Ericsson et al., 2009; Dimitriou and Rosenqvist, 2011). These plantations, irrigated with wastewater and consisting of species such as willows (*Salix* spp.) and poplars (*Populus* spp.), are defined "*vegetation filter systems*" and are intended for the production of energy biomasses and phytoremediation (Guidi et al., 2008). Wastewater supplies plants with water and nutrients, notably nitrogen and phosphorus, thus favouring crop growth; the plants, characterised by high transpiration rates, clean water by uptaking the dissolved elements, including heavy metals (e.g., cadmium) (BIOPROS, 2008).

Despite the many economic and environmental benefits proved by experimentation conducted in North-Central Europe countries (Rosenqvist and Dawson, 2005a,b; Börjesson and Berndes, 2006; BIOPROS, 2008; Dimitroiu and Aronsson, 2011; Dimitriou and Rosenqvist, 2011; Holm and Heinsoo, 2013) and although the Italian legislation allows the use of wastewater in agriculture1, the applications in Italy of multifunctional SRF for the production of biomasses and water purification are limited (BIOPROS, 2008; Guidi et al., 2008).

This work has as its main objective the development and application of a GIS-based spatial analysis model aimed at identifying areas potentially suitable for creating vegetation filter systems. Based on the existing wastewater treatment plants (WWTPs) in a given area, the use of a large scale land analysis model would enable public and private decision-makers to make targeted investments (Cozzi et al., 2013). The above model has been applied to the Basilicata region, characterized by a typically Mediterranean climate with summer water deficits that justify the use of unconventional water resources for irrigation for not undermining drinking water supply in urban areas. The idea stems from the research conducted at the University of Basilicata that has developed a system for urban wastewater treatment based on "conventional activated sludge"; this system enables the production of water with a varying load of organic carbon, nitrogen and phosphorus, so as to adapt water to the needs of irrigated crops, thus reducing the treatment costs by about 20–30% (Lopez et al., 2006; Masi et al., 2008).

The whole model has been designed to focus not only on environmental sustainability (proper use of wastewater, exclusion of nitrate-vulnerable zones) but also on the cost effectiveness of growing SRF fertigated with urban wastewater, all core potential elements for the spreading of these systems.

2. Potentials of vegetation filter systems

Most studies on vegetation filter systems have focused on their environmental and economic impacts and have shown that they are viable only if the use and management of urban wastewater is safe for the environment (minimum leaching of nutrients in ground water), if the purification efficiency of these systems is equal to that of other treatment methods and if it is allowed by the national legislation (Dimitriou and Rosenqvist, 2011). It has been demonstrated that the treatment efficiency may be even higher than that of conventional treatments (Hasselgren, 2003), with retention up to 96% for nitrogen and 94% for phosphorus (Dimitroiu and Aronsson, 2011), whereas leaching processes depend on the load of nutrients contained in wastewater more than on irrigation flow rates (Dimitroiu and Aronsson, 2004; Rosenqvist and Dawson, 2005b). Hence, the pretreatment of water (Aronsson, 2000; Carlander and Stenström, 2001) and the calculation of crop irrigation requirements (Guidi et al., 2008) can ensure high efficiency of these water treatment systems without any risk for the environment. At the same time, the application of water rich in nutrients results in a substantial increase of crop yields. If 100% yield increases have been recorded in north Europe countries (Börjesson and Berndes, 2006), more sustained increases have been observed in Mediterranean environments. In a study conducted in Italy, yield values are reported to increase from 6.6 to about 64 tDM/ha for willow and from about 9 to 44.4 tDM/ha for poplar, when crops are irrigated with wastewater (Guidi et al., 2008). These results are due to the higher evapotranspiration rate observed in arid climates, where large volumes of wastewater may be actually treated. This produces economic benefits both for farmers who can rely on higher returns related to higher crop yields and a 25–30% cut of production costs, and for the companies working in urban wastewater treatment that can largely reduce purification costsby using the vegetation filter systems as an alternative to conventional treatments (Rosenqvist and Dawson, 2005b; Börjesson and Berndes, 2006; Dimitriou and Rosenqvist, 2011).

Despite the many experiences, which prove the considerable economic and environmental benefits, the spread of SRF fertigated with wastewater is limited. Different literature studies have proposed GIS-based land use suitability models for identifying the most potentially suitable soils for SRF (Salvati et al., 2007; Romano et al., 2013a), but none of them has produced a model specifically targeted to identify the WWTPs that can be used for the fertigation of those soils. The use of this large scale analysis model would facilitate public and/or private decision-making for the establishment and spreading of vegetation filter systems.

For building the spatial analysis model wholly developed using GIS, this work has focused on the following practical aspects that impact directly on the real potential of vegetation filter systems (BIOPROS, 2008; Guidi et al., 2008):

1. Use of urban wastewater for fertigation in agriculture allowed by law.
2. Land suitability for SRF plantations.
3. Local availability of urban wastewater.
4. Short distances of treatment plants from SRF plantations, so as to reduce the investment costs of the conveyance pipeline.
5. Benefits resulting from multifunctional SRF plantations for farmers, society and the environment.

An additional economic aspect needs to be taken into account to minimize the investment costs of fertigation system: SRF planted areas should be located downstream of treatment plants to reduce water pumping costs.

The Italian legislation (see footnote 1) allows for the reuse of wastewater in agriculture, provided that the legal limits are complied with; in this work wastewater is assumed to be pretreated by the "conventional activated sludge" systemto make it compliant with legal limits and to meet crop requirements.

Land suitability was assessed using a multicriteria geographical analysis model that was used to identify exactly the areas destined for SRF plantations with poplars and willows (see Section 3.1).

As for the availability of water to be used for fertigation, the first step was to calculate the potential irrigable service area of WWTPs, meant as the area of land that can be irrigated with the effluent of each WWTP. This required the calculation of the irrigation water requirement (IWR) for each crop under analysis (see Section 3.2).

The second step was to build the analysis model aimed to delimit the vegetation filter systems as a function of their distances from the WWTPs (see Section 3.3).

The model was supported by an economic analysis intended to assess the benefits resulting from these systems. This analysis resulted in the identification of the areas where investments are cost effective.

In this work, we considered the SRF plantation with a 12-year life cycle, biennial coppicing and plant density of 10,000 plants/ha.

3. Materials and methods

3.1. Land Suitability

The land suitability analysis for willow and poplar SRF plantations was conducted using a Multi-Criteria Evaluation (MCE) and Geographical Information Systems (GIS) approach. This integration may be conceived of as a process that combines and transforms spatial and non-spatial data (input) in a decision-making result (output), by defining a relation between input maps and output maps as influenced by geographical data and decision preferences, handled following specific combination rules (Malczewski, 2004; Bernetti et al., 2011).

The multi-criteria evaluation methods applied for GIS-based land use suitability analysis are overlay Boolean operations, Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA) methods (Heywood et al., 1995; Jankowski, 1995; Barredo, 1996; Beedasy and Whyatt, 1999; Malczewski, 2004; Romano and Cozzi, 2006; Romano et al., 2013a).

The method applied in this work is the OWA operator combined with relative linguistic quantifiers, as proposed by Romano et al. (2013a). The choice of this method is justified by its greater flexibility as compared to MCE methods: actually a linguistic quantifier can better represent the decision maker's qualitative information than its perceived relation between different evaluation criteria, notably when a high number of maps are involved in the analysis.

Table 1
Some RIM (Regular Increasing Monotone) linguistic quantifiers and their properties.

α	RIM quantifier	ORness
$\alpha \to 0$	At least one	1.0
$\alpha = 0.1$	At least a few	*
$\alpha = 0.5$	A few	*
$\alpha = 1$	Half (identity)	0.5
$\alpha = 2$	Most	*
$\alpha = 10$	Almost all	*
$\alpha \to \infty$	All	0.0

Given a set of criterion maps standardized by fuzzy functions [0,1] (Zadeh, 1965), the method involves the calculation of two series of weights: criterion weights and order weights. While the former are calculated using the AHP (Analytical Hierarchy Process) method (Saaty, 1980), order weights are determined by the following equation:

$$v_j = \left(\Sigma_{k=1}^{i} u_{\mathrm{k}}\right)^{\mathrm{a}} - \left(\Sigma_{k=1}^{j-1} u_{\mathrm{k}}\right)^{\mathrm{a}} \quad (1)$$

where v_j is the criterion weight rearranged based on the value of the criterion map (j), for $j = 1, 2, ..., n$, and α is the parameter associated with the RIM (Regular Increasing Monotone) linguistic quantifier (Yager, 1996; Malczewski, 2006) (Table 1). It results that for determining order weights it is important to arrange in a decreasing order criterion maps standardized based on their value, so as to rearrange associated criterion weights and choose the appropriate linguistic quantifier that best describes decision makers' preferences.

The criterion maps and fuzzy functions used in the analysis are those proposed by Romano et al. (2013a). The maps arranged according to their value and the value of calculated weights are shown in Table 2.

As for the choice of the linguistic quantifier that has allowed for the calculation of order weights, some remarks have been made. The success of an SRF plantation depends on two conditions: (i) that the species finds the optimal soil and climate conditions (notably water and nutrient supply) and (ii) the plantation management might be based on crop requirements (mechanization, irrigation). Therefore, it is evident that the higher the number of criteria included in the analysis, the more real the result. The linguistic quantifiers that best express this concept are: All, Almost all and Most, which are associated with a low degree of ORness (Malczewski, 2006), namely, the degree of risk associated with the analysis.

Table 2
Criterion and weights used in Ordered Weighted Averaging analysis.

Species	Criterion map (j)	Ordered criterion values	Reordered criterion weights uj	Ordered weights vj
Populus spp.	Elevation	0.9430	0.0242	0.1556
	Soil depth	0.9340	0.1646	0.2789
	Mean temperature in the coldest month	0.8390	0.0354	0.0390
	Soil reaction	0.7820	0.1143	0.1083
	Mean annual temperature	0.7780	0.0354	0.0297
	Carbonates	0.4990	0.2381	0.1708
	Soil texture	0.4550	0.2381	0.1397
	Average annual precipitation	0.4490	0.0534	0.0285
	Slope	0.3300	0.0178	0.0093
	Average precipitation in summer months	0.0200	0.0787	0.0402
Salix spp.	Elevation	0.9630	0.0221	0.1487
	Soil depth	0.9340	0.0449	0.1102
	Soil texture	0.6570	0.0671	0.1074
	Carbonates	0.4990	0.0311	0.0403
	Mean temperature in the coldest month	0.4830	0.1476	0.1528
	Mean annual temperature	0.4490	0.1013	0.0842
	Slope	0.3300	0.0166	0.0128
	Soil reaction	0.2960	0.0671	0.0493
	Average annual precipitation	0.1650	0.2101	0.1358
	Average precipitation in summer months	0.0200	0.2921	0.1586

If this is true in the traditional management of SRF, where only supplemental irrigation is applied, in the specific case, we contribute to the success of the crop by using wastewater – submitted to simplified treatment – that is rich in organic matter and nutrients available all the year round. Based on the above, a greater risk may be reasonably accepted in the evaluation process; for this reason the linguistic quantifier "A few" has been preferred for determining order weights that will result in a more optimistic analysis scenario than those generated by previously mentioned quantifiers.

It is noteworthy that the analysis excluded the soils whose land suitability did not allow SRF, such as artificial areas, permanent crops, wooded areas, wetlands and water bodies.

3.2. Irrigation requirements and productivity

In order to estimate the area of land that can be irrigated with the effluent of each WWTP, a thorough analysis of the irrigation water requirements of each crop was performed.

Irrigation water requirement (IWR) is the amount of water that has to be applied in addition to rainfall to serve crop water requirements. For irrigation planning, it is determined as the difference between crop evapotranspiration (ET_c) and that part of rainfall which is effectively used by plants (Pe) (FAO, 1986):

$$\mathrm{IWR} = \mathrm{ET_c} - \mathrm{Pe} \tag{2}$$

The ET_c is calculated by multiplying the reference crop evapotranspiration (ET_0) by a crop coefficient (K_c) (FAO, 1998):

$$\mathrm{ET_c} = \mathrm{ET_0} \times K_c \tag{3}$$

In the case of vegetation filter, ET_c also represents the maximum amount of wastewater that can be supplied to the plantation reducing environmental risks of pollution from nutrient leaching to the groundwater (Pistocchi et al., 2009).

In the present study, considering SRF with biennial coppicing, the monthly ET_c (mm) was calculated for both growing seasons, using raster images representing the monthly ET_0 (mm) and the K_c values of tested crops, already calculated in a work conducted on vegetation filters in Mediterranean environments (Guidi et al., 2008).

Effective rainfall was calculated by the formula proposed by the Soil Conservation Service of the United States Department of Agriculture (USDA, 1993), adjusted for units converted from inches to mm:

$$\mathrm{Pe} = f_c(1 \cdot 253 \times P^{0 \cdot 824} - 2 \cdot 935) \times 10^{0.001\mathrm{ET_c}} \tag{4}$$

where f_c is the correction factor depending on the soil available moisture; for the present work it is assumed to equal 1 (standard soil condition); P, total monthly rainfall.

In this way, the monthly and seasonal *IWR* values were calculated for both growing seasons (two-year cropping cycle) and subsequently converted to cubic meters.

The biomass productivity was calculated from the water-use efficiency of productivity (WUE) (Fischer et al., 2011). The WUE was obtained by dividing the biomass produced, expressed as organic dry matter, by the water lost by transpiration or whole evapotranspiration (de Wit, 1958; Lindroth et al., 1994; Cienciala and Lindroth, 1995; Linderson et al., 2007; Forrester et al., 2010; Fischer et al., 2011). Vice versa, by multiplying the WUE (expressed in grams of dry biomass per kilo of water lost by evapotranspiration) by the seasonal ET_c you determine the potential production of annual dry biomass.

For the sake of consistency in the estimates, the WUE was determined from Guidi et al. (2008) and was equal to 2.14 and 2.4 g of dry biomass per kg of water lost by evapotranspiration, respectively for willows and poplars. Considering the biomass produced in two growing seasons, we obtained the raster of two-year productivities expressed in tons of dry matter, subsequently converted to tons of fresh matter, assuming roadside sale of wood chips. The estimated productivities were very high, averaging 73 tDM/ha in the two-year period, nearly the double as compared to the yields obtained by Guidi et al. (2008). This is due to higher evapotranspiration rates than those recorded in the specific environments and under the tested conditions.

3.3. Spatial model analysis

A Geographic Information System (GIS) may be defined as the complex system including hardware, software, human and intellectual resources used to collect, process, analyze, store and return – in a graphic and alphanumeric form – the data concerning a territory (ENEA, 2006). GIS software makes use of a set of spatial analysis tools useful to create, query, map and analyze cell-based raster data, perform integrated raster/vector analysis, derive new information from existing data, query information across multiple data layers and fully integrate cell-based raster data with traditional vector data source (ESRI, 2001). A GIS model generally returns output as derivatives of base maps, and can comprise whole hierarchical trees of data and functions. A GIS model is built up from data and handling software.

In the model applied in the present work (Fig. 1), the input geographic database is made up of a set of maps characterizing the land area and includes information concerning the criterion variables useful for the analysis (Fig. 2).

The database of WWTPs consists of an attribute table containing information about the identification number, the monthly and seasonal flow rate (m^3), and the elevation. Where relevant, the vector data has been converted to raster images for the execution of spatial analysis functions. The raster regarding land rent (the income derived from each plot with the existing crop) reports the values per hectare of arable lands, meadows and rangelands for different agricultural regions. The area under study covers the whole Basilicata regional territory, represented through a reference grid resolution of 100 m, using Gauss Boaga East on Monte Mario Roma 1940 Datum as geographical reference system. The choice of this spatial resolution is related to a merely practical aspect: the area of each pixel, equal to one hectare, is the optimal reference unit for the analysis in question.

The spatial analysis functions applied in this work, which are common to most commercial GIS software, are summarized in Table 3.

As shown in Fig. 1, the development of the model has followed a logical path, based on which there is the raster relating the areas of influence of WWTPs. Identified from the map of plant localization through the distance allocation function, each of them was assigned the identification number of the relevant treatment plant, so that any information collected within each area may be easily associated with it.

For determining the potential irrigable service area of WWTPs, given by the ratio of the flow rate (m^3) to the seasonal IWR (m^3/ha), the raster relating the second growing season irrigation requirement was taken. This choice is based on the consideration that the potential irrigable service area should be calculated on the maximum IWR, which occurs exactly in the second year as a result of higher evapotranspiration rates.

3.4. Economic analysis

The possibility to use agricultural land to create vegetation filter systems depends on the cost effectiveness of these systems. To that purpose, some economic indicators were calculated that are a reference point for farmers in alternative investments.

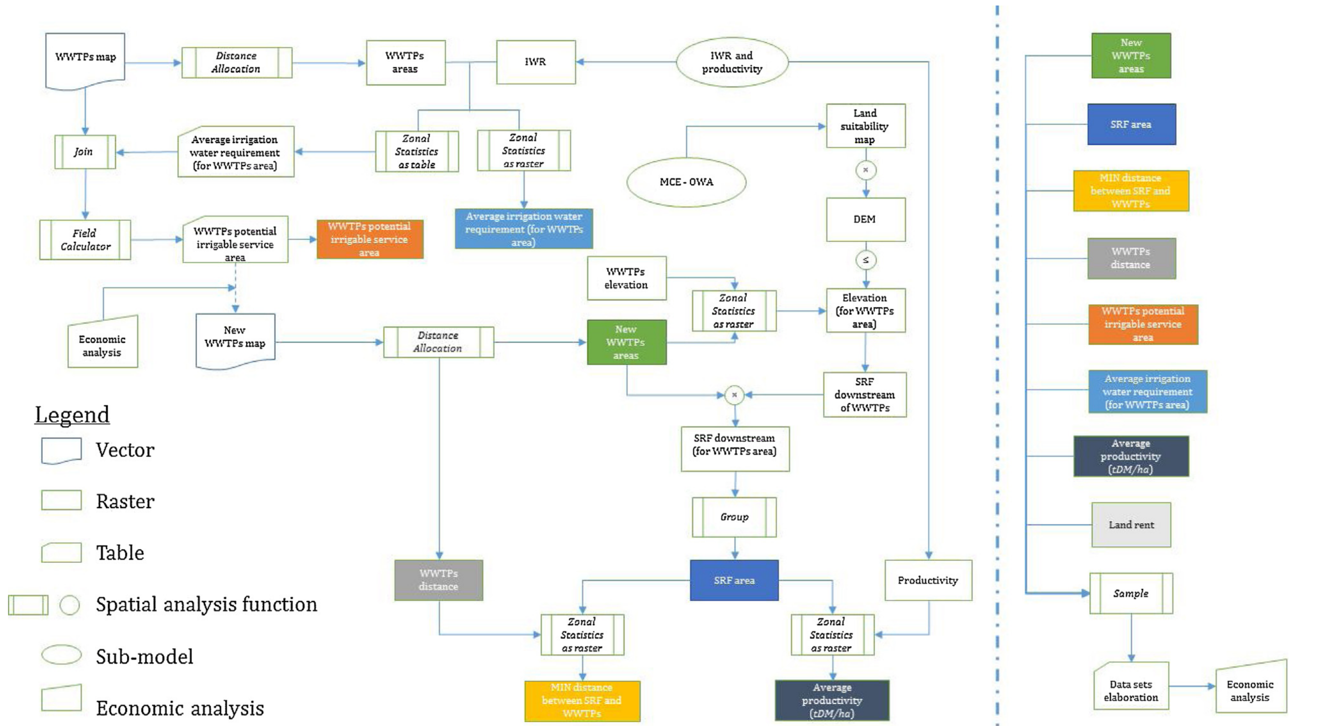

Fig. 1. Hierarchical tree of spatial analysis model.

Table 3
Spatial analysis function.

Function	Description
Distance allocation	Performs spatial allocation using either distance surfaces, calculating the distance/proximity of each pixel to the nearest of a set of target pixels or points
Zonal statistic	Summarizes the values of a raster within the zones of another dataset (either raster or vector) and reports the results as a table or a raster
Join	Joins the item definitions and values of two tables based on a shared item
Field calculator	Allows performing calculations on the basis of existing attribute values or defined functions
Map calculator	Enables solving complex spatial problems, working with raster, through the use of mathematical and logical expressions
Group	Classifies pixels according to contiguous groups. For each cell in the output, the identity of the connected group to which that cell belongs is recorded. A unique number is assigned to each group
Sample	Creates a table that shows the values of cells from a raster, or set of rasters, for defined locations. The locations are defined by raster cells or by a set of points

More specifically, the analysis concerned the calculation of the Net Present Value (NPV) and the Payback Period (PBP) of the areas planted with SRF fertigated with wastewater:

$$\mathrm{NPV} = \Sigma_{k=0}^{n} \frac{\mathrm{FC}_k}{(1+r)^k} \tag{5}$$

FC_k: flux at year k obtained from the benefits at year k minus the costs at year k;

k: project length in years;

r: cost of capital.

$$\mathrm{PBP} = \frac{\mathrm{InIv}}{\mathrm{ChIFP}} \tag{6}$$

InIv = Initial Investment.

ChIFP = Cash Inflow per Period.

Table 4
Cropping management costs of Short Rotation Forestry.

Operations	Costs	Measurement unit	Year
Plowing	200	€/ha	0
Rotary tillage	70	€/ha	0
Coppicing	4300	€/ha	0
Transplanting	4300	€/ha	0
Chemical weed control	100	€/ha	I, III, V, VII, IX, XI
Harrowing between rows	120	€/ha	I, III, V, VII, IX, XI
Chipping	20	€/tonn (fresh matter)	II, IV, VI, VIII X, XII
Eradication	8400	€/ha	XII
Setting up of irrigation system	2000	€/ha	0

The NPV expresses the increase in wealth generated by the project as compared with the existing situation, expressed as if it were immediately available at the start of the conversion (Bernetti et al., 2004; Ciccarella and Carbone, 2006); the PBP is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment.

The logical procedure followed for the evaluation involved the determination of the costs (investment and running costs) and benefits (revenue generated by the investment) produced by the areas planted with SRF and the setting up of the fertigation system.

The length of the production cycle is estimated to be 12 years with biennial coppicing and plant density of 10.000 p ha^{-1}. The costs for the setting up, management and restoration of the land (Table 4) are calculated on the basis of market prices of farm inputs, as well as the experimental trials conducted (Spinelli et al., 2006; ENAMA, 2008; F.I.M.A.V, 2012). Moreover, the discount rate was estimated to 4.5%. It was obtained on the basis of the return of ten-year Italian Treasury Bonds (Index-linked BTPs) (Banca d'Italia, 2013). As to the land rent, its value is contained in the geographic database (see Section 3.2).

The benefits associated with the investment derive, however, from the sale of chips; they have been obtained by multiplying bien-

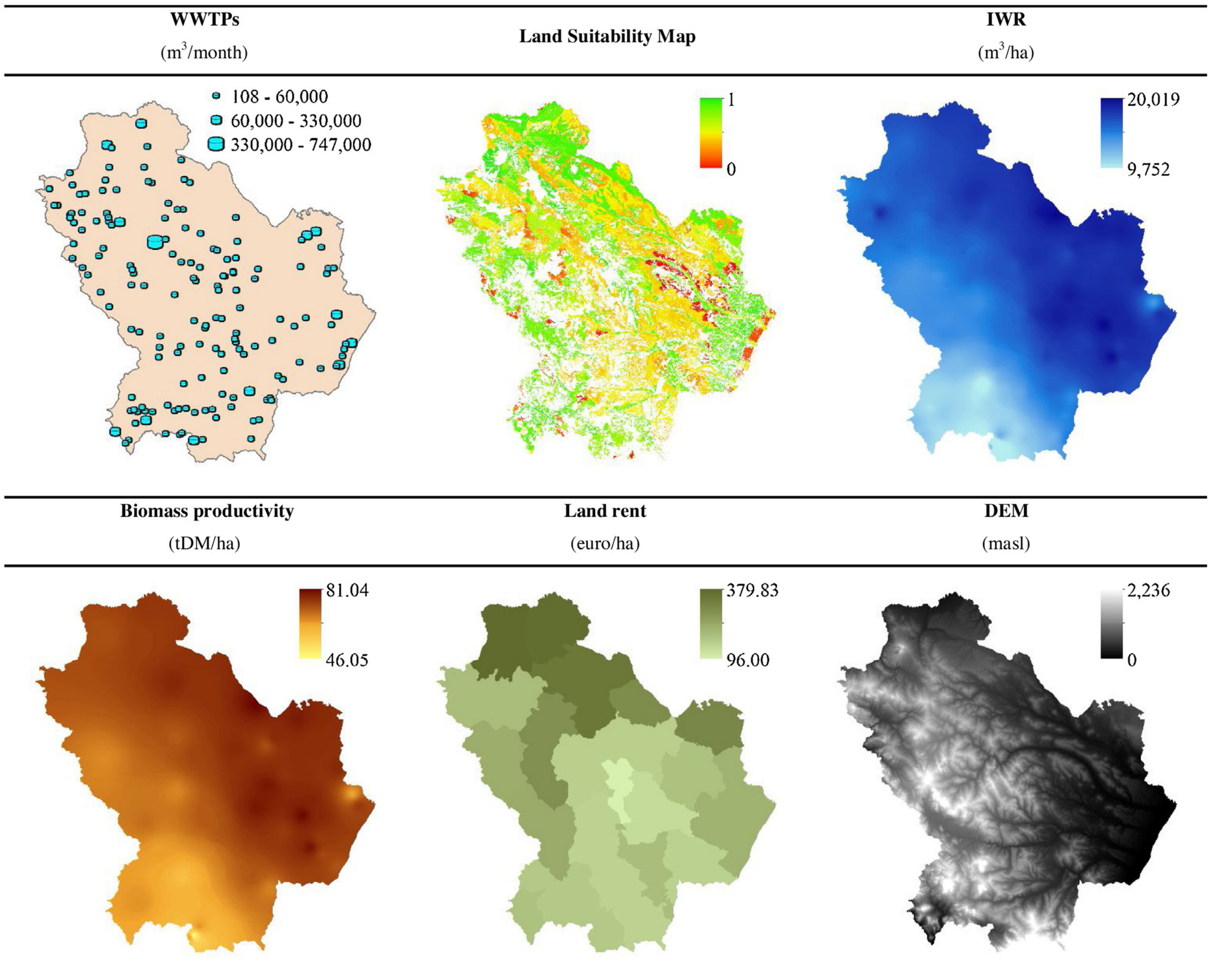

Fig. 2. Input data.

Table 5
Costs for the setting up of fertigation system.

Components of fertigation system	Measurement unit	Costs
Conveyance pipe	€/m	200
Storage tank	€	50,000
Pumps, filters	€	50,000

nial production (see Section 3.2) by the selling price of fresh matter (50% WC) that amounts to €55/t at roadside. The latter value has been deduced from measurements taken in plants already working in the Basilicata region (Southern Italy). This data is in agreement with what is reported by Fiala (2012), where the mean price is estimated to €55–60/t untreated, for good quality wood chips.

However, among benefit items the possible revenues generated in the form of white certificates that would lead to extra economic profits were not considered (Romano et al., 2013b; Cozzi et al., 2014).

Fertigation system costs include the installed water conveyance pipe from the WWTP to the SRF areas, the storage tank, as well as the pumps and filters required for the distribution and pre-treatment of water. The cost items (AA.VV., 2012) are shown in Table 5.

Since the alternative treatment of wastewater through vegetation filter systems results in an economic advantage for the companies in charge of water treatment, a further increase of vegetation filter productivity for farmers could derive from the economic compensation they would have when accepting that water in their soils. A study conducted in Ireland has demonstrated that this compensation may amount to 788–2004 GBP/ha year (Rosenqvist and Dawson, 2005b). The exact amount of the compensation is difficult to define or predict, as it depends on the agreements between wastewater treatment plant operators and the farmers concerned, on the water volumes and the costs of other treatment methods. In the specific case study, following estimates carried out after wastewater treatment by the conventional activated sludge process (see Section 1), the amount of compensation is considered to be 0.19 €/m^3 of water used in fertigation.

4. Results

The multicriteria analysis model has resulted in the suitability maps of SRF for willows and poplars (Fig. 3). Based on the distribution of suitability values, poplar seems to be the species with the highest suitability for SRF in the region (Romano et al., 2013a). This confirms the findings of recent studies showing that willow is a more suitable species under the typical site-specific conditions of north-Europe countries (Dimitriou and Rosenqvist, 2011; IEA Bioenergy, 2011).

To facilitate the reading of the results obtained using the OWA model, the values achieved have been discretized using Chen

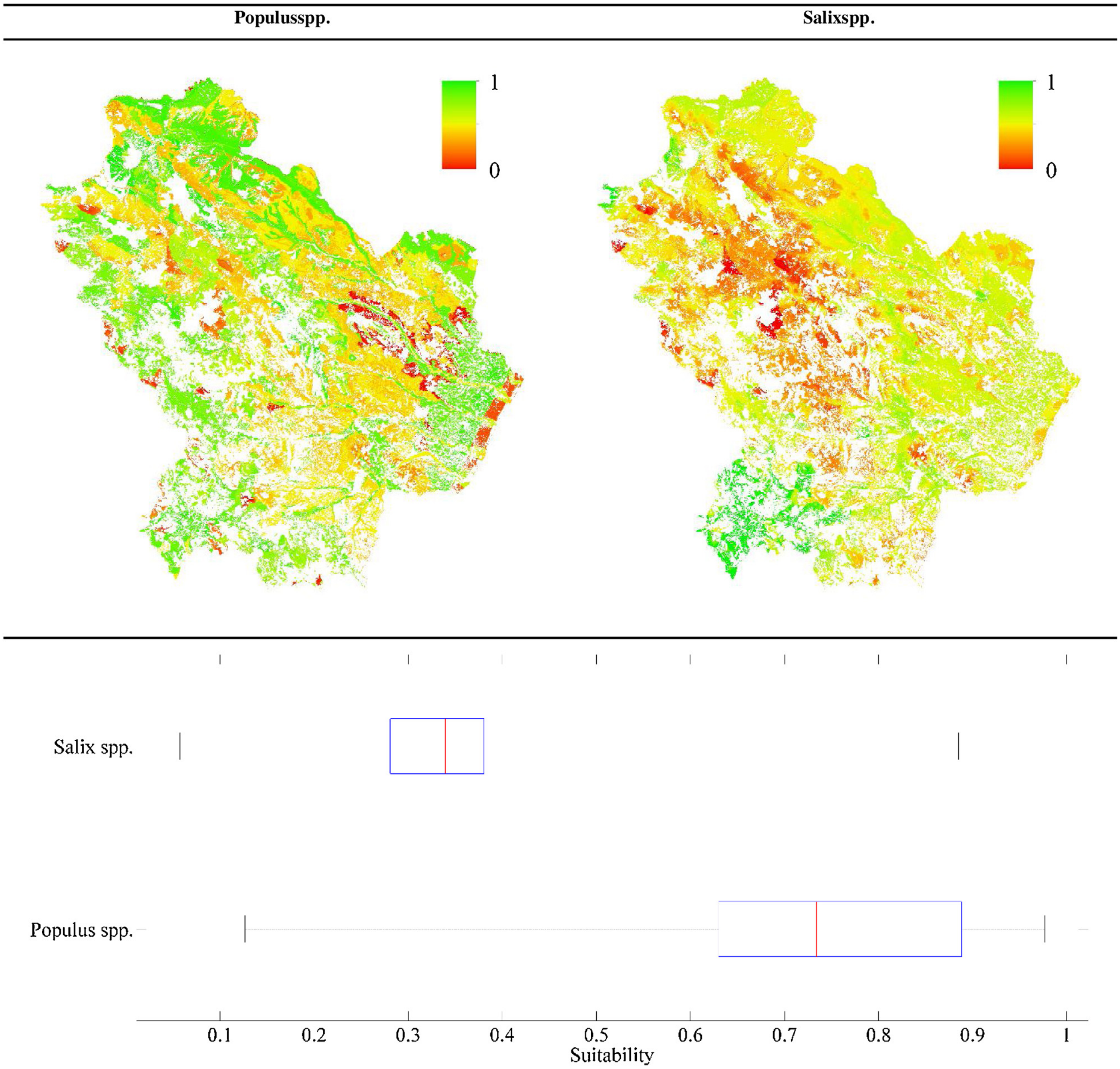

Fig. 3. Land suitability map and box-plot of suitability values.

Fig. 4. Payback period for a SRF plantation sited at 100 m from the WWTP.

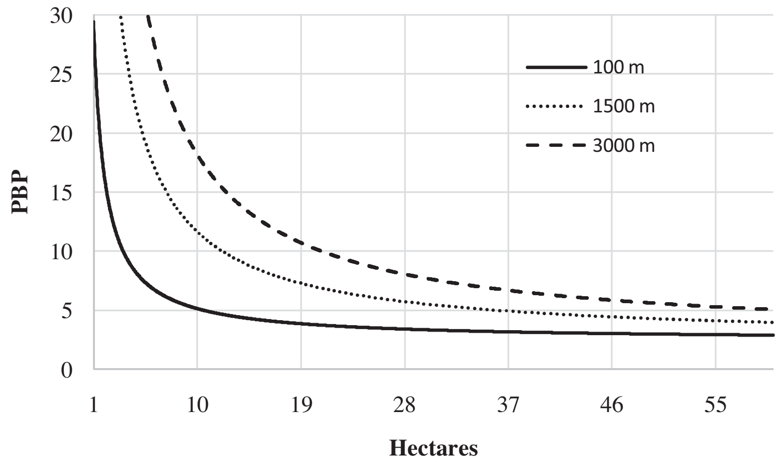

Fig. 5. Payback period calculated for an SRF plantation sited at distances of 100 m, 1500 m, 3000 m.

Table 6
Sum-up table of cost effectiveness indicators for Short Rotation Forestry areas with positive Net Present Value, identified for each wastewater treatment plants.

WWTP[a] Id[a]	Potential irrigable service area ha[a]	SRF[a] Area Id	SRF surface ha	Distance m[a]	Irrigated surface ha	NPV[a] €	NPV €/ha	PBP[a] years
7	13	379	113	2773	13	33800.73	2600.06	10
	13	400	66	383	13	511790.62	39368.51	5
	13	402	3454	1141	13	367431.91	28263.99	6
	13	415	131	441	13	500074.89	38467.30	5
	13	416	6	283	6	161135.69	26855.95	6
15	43	357	152	10083	43	81810.07	1902.56	10
	43	464	90	8457	43	371906.87	8649	9
	43	479	168	3638	43	1370682.89	31876.35	6
	43	486	15	3080	15	50896.39	3393.09	10
16	13	716	18	100	13	511752.00	39365.54	4
22	11	468	5	566	5	43773.37	8754.67	9
31	19	1672	10	566	10	167802.52	16780.25	7
39	11	1129	57	141	11	407720.57	37065.51	5
	11	1148	6	941	6	4082.00	680.33	10
45	16	304	904	1190	16	502090.41	31380.65	6
	16	346	270	2924	16	155227.52	9701.72	9
47	12	1542	507	1041	12	217390.40	18115.87	7
	12	1557	8	200	8	210449.79	26306.22	6
59	17	1535	15	100	15	500207.39	33347.16	5
	17	1544	169	2704	17	59613.57	3506.68	10
	17	1549	29	2890	17	22456.38	1320.96	10
65	58	1622	74	4090	58	1438251.45	24797.44	6
	58	1623	104	1500	58	1956241.33	33728.30	5
	58	1632	41	100	41	1545618.87	37698.02	4
	58	1635	107	1990	58	1849874.00	31894.38	5
	58	1639	15	1207	15	267951.40	17863.43	7
68	10	1569	232	1290	10	47713.10	4771.31	10
	10	1605	43	241	10	257418.75	25741.88	6
	10	1621	44	1500	10	5703.02	570.30	10
70	17	1577	99	1166	17	336875.53	19816.21	7
	17	1598	11	200	11	293537.57	26685.23	6
	17	1600	4	100	4	37650.03	9412.51	9
74	38	1637	25	3556	25	213118.84	8524.75	9
	38	1659	9	724	9	123875.69	13763.97	8
	38	1670	84	2563	38	944305.31	24850.14	6
	38	1681	37	6657	37	84512.85	2284.13	10
77	65	606	25	100	25	1271910.78	50876.43	3
	65	645	21	1490	21	771215.15	36724.53	5
78	36	621	134	3000	36	1295438.01	35984.39	5
	36	677	22	3446	22	430317.40	19559.88	7
	36	707	32	3221	32	1029458.55	32170.58	6
	36	762	20	4556	20	97449.74	4872.49	9
79	17	782	8	1231	8	92704.87	11588.11	8
	17	789	51	3780	17	76850.67	4520.63	9
	17	804	100	3111	17	224946.40	13232.14	8
81	38	40	72	7541	38	303690.84	7991.86	9
	38	41	987	6043	38	606159.97	15951.58	8

Table 6 (*Continued*)

WWTP[a] Id[a]	Potential irrigable service area ha[a]	SRF[a] Area Id	SRF surface ha	Distance m[a]	Irrigated surface ha	NPV[a] €	NPV €/ha	PBP[a] years
	38	45	217	6607	38	490553.84	12909.31	8
	38	46	488	5249	38	762269.46	20059.72	7
	38	91	25	5080	25	141898.53	5675.94	9
	38	101	27	3407	27	577087.30	21373.60	7
	38	105	306	8083	38	198119.72	5213.68	9
	38	115	59	5038	38	804279.59	21165.25	7
	38	116	144	141	38	1783690.81	46939.23	3
	38	127	240	6787	38	454573.96	11962.47	8
	38	130	72	4321	38	947711.02	24939.76	6
101	11	145	26	2156	11	54794.15	4981.29	9
	11	163	505	200	11	445921.15	40538.29	4
	11	169	1145	541	11	377636.87	34330.62	5
104	23	713	33	2080	23	562607.05	24461.18	6
	23	771	104	100	23	958586.89	41677.69	4
	23	810	21	2373	21	410238.29	19535.16	7
112	302	597	95	10464	95	2518874.05	26514.46	6
	302	614	135	11015	135	4392439.09	32536.59	5
	302	639	85	13460	85	1423743.20	16749.92	8
	302	644	141	11214	141	4650260.93	32980.57	5
	302	674	50	11849	50	10118.65	202.37	10
	302	675	783	18900	302	11619411.58	38474.87	5
	302	715	81	100	81	3943154.23	48680.92	3
	302	867	205	19227	205	6576721.67	32081.57	6
116	21	158	55	3707	21	218053.93	10383.52	9
	21	164	23	4577	21	44084.12	2099.24	10
	21	175	169	2690	21	421485.37	20070.73	7
	21	183	17	2531	17	251396.28	14788.02	8
	21	213	22	3600	21	239475.25	11403.58	8
	21	218	12	1383	12	228845.86	19070.49	7
	21	219	29	4000	21	159475.25	7594.06	9
	21	225	16	1800	16	347219.24	21701.20	7
	21	229	3711	100	21	974483.48	46403.98	4
	21	248	25	4138	21	131779.75	6275.23	9
119	38	1673	11	1466	11	27613.61	2510.33	10
146	11	1052	68	2338	11	45107.97	4100.72	9
157	13	1486	3	283	3	10870.18	3623.39	10
	13	1487	3	100	3	47438.73	15812.91	8
163	11	855	82	100	11	392962.88	35723.90	5

[a] WWTP = wastewater treatment plants; SRF = Short Rotation Forestry; NPV = Net Present Value; PBP = Payback Period; Id = identification number; ha = hectare; m = meter.

method (Chen and Hwang, 1992). This method is a sound and well-established tool to convert cardinal values to quality attributes, as it provides the mathematical representation of a linguistic term. Assuming a moderate risk-averse behaviour of professionals, as it results from a direct survey, we have considered the areas with values within the 0–0.77 range as unsuitable and those within the 0.77–1 range as suitable.

The reclassification of maps has led to identify only suitable soils with surface areas of 258,512 ha and 394 ha, respectively, for poplar and willow. Given the small area regarding willow, only the poplar suitability map was included in the spatial analysis model.

According to the calculation of the IWR of that crop, it emerged that large volumes of wastewater were required to meet irrigation requirements, up to even 19,000 m^3/ha for the second growing season. The Italian legislation on wastewater reuse does not impose any limitation on the volumes that may be supplied to crops, provided that crop irrigation requirements are not exceeded. Considering that for a vegetation filter system implemented in Sweden, up to 4000 mm/ha equal to 40,000 m^3/ha (Dimitriou and Aronsson, 2007) have been applied for the growing season, it results that the water volumes estimated in this study may be considered as being acceptable to meet the high evapotranspiration rates estimated for the crop. It was decided, however, to exclude from the analysis the soils falling within nitrate-vulnerable zones, for which more detailed analyses would be required. It results that the soils potentially suitable for vegetation filter systems are further reduced to 158,884 ha.

The determination of the potential irrigable service area has led to some considerations on WWTPs. In the region there are mostly small and medium-sized plants, with monthly average flow rates of about 25,700 m^3. Looking at the curve of PBP (Fig. 4) calculated for a theoretical SRF plantation considering a 100 m distance (optimal siting) from the WWTP and regional mean values for IWR, the productivity and the land benefit derived from the crop concerned, it is deduced that to have an average payback time less than half of the plant lifetime (<6 years), the area planted with SRF should cover at least 10 ha.

The distance of the vegetation filter from the WWTP is the most influential factor on the economic feasibility of these systems, given the high investment cost of the water conveyance pipe. With greater distances, increasing surface areas are necessary to have an economic return in the short period. As is shown in the Fig. 5, shifting from a distance of 100 to 3000 m, areas should be five times greater to have a payback period less than 6 years.

In the spatial analysis, he plants with an potential irrigable service area lower than 10 ha were excluded, so that only 37 treatment facilities potentially useful for fertigation were identified. Based on these plants, the raster of areas of influence and distances was built. This was useful to identify the SRF soils sited downstream of WWTPs that covered 34,282 ha and were grouped by contiguity criterion through the function group (see Table 3).

Based on the final result of the spatial analysis model, which has supplied for each SRF soil information on the associated treatment facility, its distance from it and the mean values of productivity

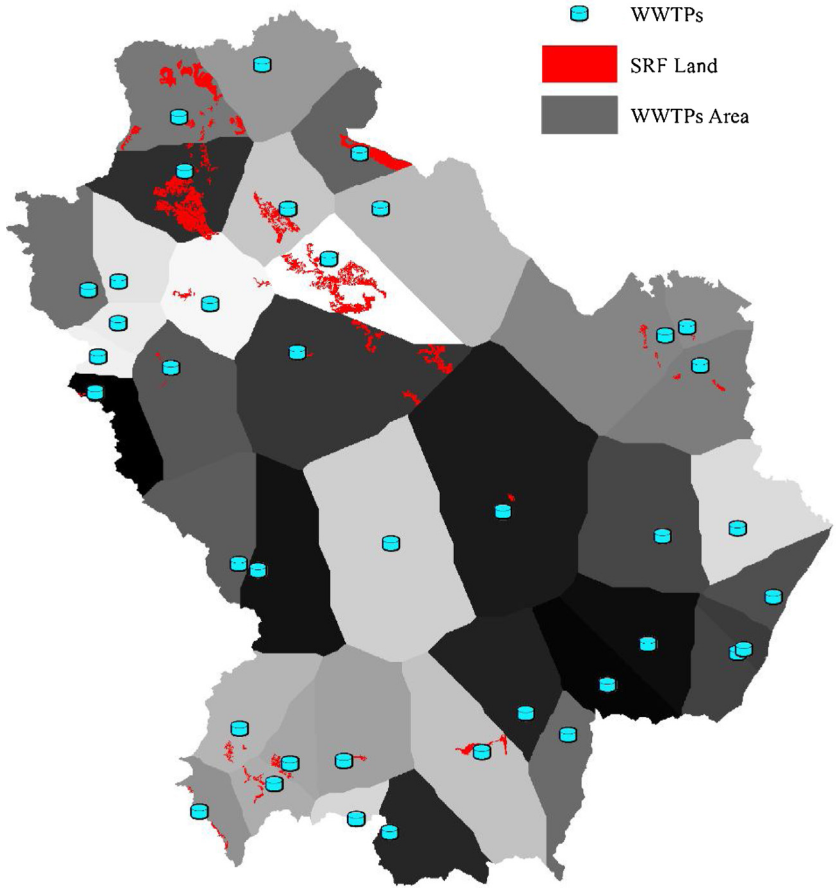

Fig. 6. Geographical location of SRF areas with positive NPV.

and land benefit, cost effectiveness indicators were calculated (see Section 3.4).

In many cases, the SRF areas identified for each treatment plant for the supply of fertigation water, were greater than the actual potential irrigable service areaof the treatment plant.

In case of areas exceeding the potential irrigable service area of WWTPs, the analysis was conducted only on the hectares that may be actually fertigated (e.g., on an area of 150 ha suitable for SRF the analysis was limited only to the 70 ha of potential irrigable service area of the WWTP, namely those with the highest cost effectiveness of the investment).

Results indicate 85 SRF areas with positive NPV falling within the areas of 25 treatment plants (Table 6). As a consequence, about 60 SRF areas are excluded, based on cost effectiveness criteria.

The choice of the areas where to direct investments depends both on NPV and on the needs of investors and their willingness to accept a longer payback period of the investment in order to have a higher economic benefit.

According to these choices, the spatial analysis model allows for quick identification of the areas that may be chosen for the investment, since they are geo-referenced (Fig. 6).

5. Conclusion

The use of endogenous resources looks more and more as a crucial process in the energy strategy of countries. This is even more important for those countries, including Italy, largely dependent on foreign countries for their energy requirements.

The recent orientations in development programs at the national and European level indicate well-defined strategic objectives, targeted both to fulfill the obligations undertaken in compliance with Kyoto Protocol and to ensure a greater geopolitical security, thus reducing progressively the dependence on imports. This would result in social and ecological advantages, through the reduction of harmful gas emissions, as well as economic benefits, by increasing the share of national energy needs met by the domestic production and favouring the setting up of local micro-districts that involve business growth and employment in rural areas. On the latter, it is noteworthy to consider that Italy's energy imports that account for 94% of its consumption cost as a whole about 62 billion euros per year (Ministero Sviluppo Economico, 2013). On these bases, the National Energy Strategy identifies four key objectives, namely (a) the reduction of differences in energy cost compared to the rest of Europe; (b) the achievement of environmental and decarbonization objectives set out by the EU through the 2020 climate and energy package; (c) greater food security associated with a progressive reduction of foreign dependence and (d) favouring the economic sectors connected with renewable energies.

Renewable energies are the tool to reduce harmful gas emissions, on one hand, and get economic benefits, on the other. The unique condition emerging in the implementation of a renewable strategy is that development should be widespread across the territory, as renewables are low energy sources.

The production of energy biomass on agricultural soils (SRF) provides undeniable environmental and economic benefits for society and farmers and is therefore encouraged by governments. There are, however, limitations related to the climate (notably to the precipitation trend), that influence the production significantly. The use of adequately treated wastewater is a valuable tool to increase SRF production values and ensure at the same time the uptake of part of the nitrates contained in wastewater, thus reducing treatment costs.

Despite the many experimentations conducted in central and northern Europe, which prove the huge economic and environmental benefits derived from vegetation filter systems, in Italy their use is limited. It is necessary to arrange for tools aimed to facilitate and promote their implementation. A spatial analysis model using GIS is an appropriate means to explore the ex-ante feasibility of these systems and assess their economic and financial implications and the payback time of the investment, as well as evaluating exactly their geographical location.

Based on the above considerations, the work has proposed a spatial analysis model that has enabled to assess the agronomic and economic feasibility of multifunctional SRF plantations in Mediterranean environments and, more specifically, in the Basilicata region, Italy. Through the applied model a land use suitability analysis was carried out for SRF plantations with poplars and willows, and, based on the existing WWTPs in the region, the most suitable areas for fertigation were identified. Moreover, in the geographical assessment process a further selection criterion has also been included, which concerns professionals' risk propensity. Selected areas include only those highly suitable for the above species, and thus, likely to be successful (with values ranging between 0.77 and 1), thus reducing greatly the uncertainty of the investment.

According to the geographical location and the volume of treated wastewater of the existing WWTPs in the region, it results that the distance of soils from WWTPs is the discrimination factor for feasibility. Out of the 163 existing WWTPs at least 25 can fertigate 864 ha of SRF. This proves that the region has high bioenergy development potentials with undeniable economic advantages, including a large availability of sites with net benefits up to 50,876.43 €/ha and payback periods between 3 and 10 years.

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