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Spatially explicit assessment of local biomass availability for distributed biogas production via anaerobic co-digestion – Mediterranean case study

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ABSTRACT

Renewable energies, especially energy from biomass, contribute to the sustainable development of the territory. Simultaneously, by using biomass to produce bioenergy, bioreproductive land is devoted to supply energy. As the bioreproductive land area on the European level is decreasing, bioenergy competes against other demands like the production of food, industrial resources or cultural goods and services, among others, thus the correct assessment of the available local potential is important for local and regional planning. Moreover, bioenergy system being a socio-ecological system requires integrated approaches for the evaluation of the factors, components and interactions of such a system, considering that agriculture presents one of the major drivers of the land use change and biodiversity loss. Therefore, this work was focused on the development of the approach for and on the assessment of biogas potentials to provide a support for decision-makers and bioenergy industry at a local scale. The approach exploits the spatial relations among territorial units (i.e., a contiguity analysis), and integrates time series of continuous and discrete data. It is based on the analytic hierarchy process (AHP) combined with GIS-based analysis, and permitted to develop a territorial information system in support for biogas planning, perform analysis of feedstock for biogas from different sources potential and produce plausible scenarios for identification of biogas suitable territorial clusters; the analysis of the tradeoffs between the use of different local sources of the feedstock for biogas production are discussed as well.

1. Introduction

Renewable sources of energies like biogas are considered to be one of the major climate change mitigation options [1]. Enhanced production of the biogas from animal manure and organic municipal waste being a carbon neutral source of energy is also seen in the context of diversion from landfills. In Europe, it is largely encouraged by the new European directive for promotion of renewable energy sources [2] with the obligatory implementation across Member States through the National Action Plans. Moreover, International Energy Agency [3] mentions these sources as those with the one of the highest potentials for GHG mitigation among biofuels, bioliquids and their fossil fuel comparators. In addition, EU Landfill Directive has set the target of reducing the biodegradable municipal waste destined for land fill to 35% of the level produced in 1995 by 2016 [4]. This together with a number of benefits associated with the exploitation of animal manures and slurries for the energy production purposes (i.e. decrease in water, soil and air pollution, additional soil fertilization by digestate, etc.), has encouraged the increasing effort to raise the biogas electricity output of such plants in the European Union, reaching the value of approximately 21,356 GWh in 2008 [5]. Italy was Europe's number four biogas producer in 2009 with 444.3 ktoe, as primary energy production increased by 8.4% over 2008 and electricity production by 8.8%. As it stands there are about 200 installations with combined capacity of about 200 MWe.

Biogas systems in Italy developed from predominantly farm scale plants, using liquid manure and crop residue mixtures for feedstock with a number of centralized plants. The introduction of incentives for increased utilization of renewable resources via the renewable energy certificates system and feed-in tariffs led to proliferation of industrial-scale plants with elaborate logistics. Compared to (for

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Abbreviations

MCA	multi-criteria assessment
MSW	municipal solid waste
AD	anaerobic digestion/digestor
GIS	geographic information system
WMA	waste management authority
AHP	analytic hierarchy process
NYMBY	not-in-my-backyard
RES	renewable energy sources
OFSUW	organic fraction of solid urban waste
AHP-OWA	analytic hierarchy process-ordered weighted averaging
CR	consistency ratio

example) wind and solar energy few articles address issues related to biogas plant planning in Italy, mainly focusing on the overall structure of the biogas market development (i.e. [6]).

As a result of their decentralized nature and the regional investment structure, biogas installations can contribute significantly to sustainable development in rural areas and offer farmers new income opportunities [2]. Furthermore, the use of agricultural material such as manure, slurry and other animal and organic waste for biogas production has, in view of the high potential to reduce greenhouse gas emissions, significant environmental advantages in terms of heat and power production and its use as biofuel. Co-digestion practices are attractive for farmers who in this case have the incentive to treat their own waste together with other organic substrates, obtaining a double advantage of treating waste and selling heat and electricity [7]. Other advantages of such systems for energy planners are the reduction of transmission losses, solution of problems related to congestion in electricity distribution system, while providing appropriate power quality for different types of end-users; they also contribute to the security of supply and to the deferment of transmission lines upgrades and expansions [8]. Longden et al. [9] showed that local scale distributed waste-to-energy plants were the most attractive for the UK's counties by providing greater flexibility in managing changes in residual waste availability and demand for recycling.

In order to address the issue of the wider diffusion of biogas plants, it is also necessary to overcome the so-called Not-In-My-Back-Yard (NYMBY) effect, by which all RES technologies are characterized [10].

The goal of this work is to propose an integrated methodology combining spatial relations, temporal trends and multi-criteria evaluation for the estimation of the biogas through anaerobic co-digestion potential for distributed electricity generation to support the planning at the local scale, aiming at establishment of small and medium anaerobic digester of overall electricity power output of 500–1000 kW. It integrates the numerical and spatially explicit data and contiguity analysis for further introduction of anaerobic digester in the highly agricultural area with the elevated level of tourism, where this type of renewable energy production is absent. This methodology would allow further incorporation of stakeholder preferences and supports the decision-makers.

2. Approaches for biogas potential assessment

The group of multi-criteria analysis tools (MCA) allows the integration of multiple economic, social, environmental objectives and driving factors [11], stakeholder opinion integration, and a detailed analysis at different spatial scales through the link with geographic information systems (GIS). These advantages brought the family of GIS-multi-criteria assessment (MCA) integrated tools to the forefront of the decision-making support. GIS-MCA has been used in a wide array of energy-related problem analysis: i.e. energy-efficient transportation [12], energy planning or agriculture [13,14] or landscape quality evaluation [15]. More specifically, there is a dedicated and recent literature on the estimation of the potential of biomass using GIS multi-criteria modeling techniques in various regions (i.e. [16,17]). In the field of the AD location assessment, Dagnall et al. [18] and Ma et al. [19] have evaluated possible alternative locations based principally on the collected animal manure. Batias et al. [20] developed a GIS-based tool without multiple criteria application for the calculations of available livestock manure for the estimation of the available biogas. While, Bryan et al. [21] have assessed the potential of eucalyptus-based woody biomass in Australia.

It was affirmed that the optimal location of biogas plants is affected by both regulations covering environmental protection and economic considerations [22]. Environmental regulations prevent installation, for example, in nature reserves and water and bird protection areas. Economic considerations are multiple and might include, i.e. infrastructure presence such as road infrastructure, existence of gas networks for bio-methane, and transmission efficiency limitations of district heating grids [19]. Availability of adequate feedstock near the plant location significantly enhances efficiency of operation [22].

In the confirmation of the above-mentioned, Angelis-Dimakis et al. [23] stated that the modeling techniques in the field of estimation of biogas and biomass potentials are mostly used to optimize the management of animal manure. Due to the fact that potential energy available from biogas significantly varies based on the common agricultural practices and the legislation, its assessment should be performed at a local scale. Angelis-Dimakis et al. [23] also state that the new models integrating the manure with other biomasses based on the interaction between geographical and numerical databases are needed. It was also acknowledged that transparent methodologies to evaluate possible interactions of innovative practice, policies and technologies at the community level are required for the correct solutions to be set up in urban environment [24]. A comprehensive review of Calvert [25] concludes that there is a lack of baseline information at the agenda-setting stage of public and private energy planning such as, i.e. spatial distribution of bioenergy sources, technical potential of these sources; this prevents decision-makers from taking bioenergy seriously. Such baseline information needs to be site-specific in order to take seriously the spatial–temporal nuances that are consequential to bioenergy feasibility.

3. Study area

The study area is one of the three waste management authorities (WMA) of Lecce province in the Apulia Region of Italy, instituted in 2002. It is composed of 24 municipalities with the area of 589.7 km^2 and a population of 189,105 inhabitants [26]. The climate of this region is typically Mediterranean, characterized by precipitations in autumn and winter seasons (max of 850 mm/year) and dry summer. In this regards, the landscape is mainly composed of olive orchards (nearly 75% of the area), while autochthonous vegetation is represented by Mediterranean maquis. Agriculture, in particular olives and olive oil production, viticulture, small and medium food plants and tobacco production, and seaside tourism are the most important economic sectors of the area (Fig. 1).

The olive oil industry and the ever increasing amount of tourism pose an additional energy demand in the WMA and increase the production of the urban wastes during the summer season which is

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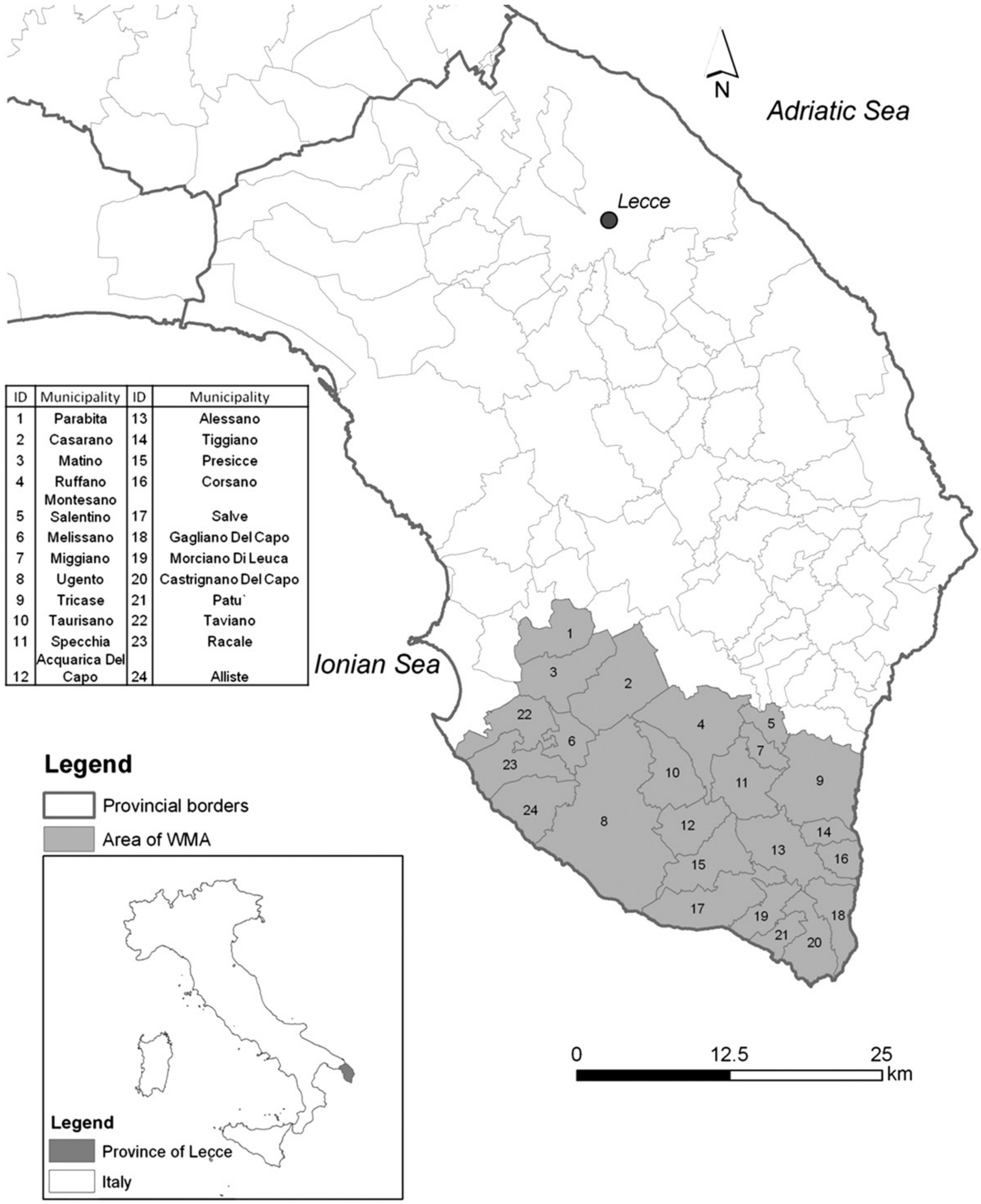

Fig. 1. Study area showing the municipalities examined in this work.

the Southern part of Italy covers the larger part of the year, starting in April and ending in October. Moreover, the implementation of regional waste management plan set the objective of 60% of differentiated wastes by 2015 for this WMA [27].

4. Materials and methods

4.1. Materials for feedstock assessment and evaluation of feedstock potential

In order to maximize the utilization of locally available feedstock for potential production of biogas, the co-digestion practices were chosen for assessment, using the local biomass and organic fraction of solid urban wastes (Table 1). There are several possible combinations of feedstock as sources for biogas production. Their main types are the municipal solid wastes, biomass, fruit and vegetable wastes and manures [28]. It was shown that co-digestion of sewage sludge with municipal urban waste improves the methane production of AD processes [29,30]. The co-digestion of cattle manure with municipal solid waste (MSW) also increases the methane production [31,32]. Moreover, Callaghan et al. [33] showed that co-digestion of cattle slurry with fruit and vegetable wastes gave good co-digestion in terms of methane yield. Several studies have demonstrated the feasibility of valorization of olive

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Table 1
Types of feedstock potential analyzed in the study.

Feedstock	Description	Source
OFSUW (organic fraction of slid urban wastes)	Annual data at municipality level (2007)	[47] with the assumption that organic fraction is 25% of total SUW produced
Agricultural residues	Annual aggregated data olives, grape and grape stalk production (2007)	[26]; CORINE landcover – 2006, 1:5000 [48]
Agro-industrial subproducts	Annual olive oil olives and wine grapes, olive cake, grape marc production (2006–2007)	[26]; CORINE landcover – 2006, 1:5000 [48,49]
Zootechnical sludge	Cattle sludge and manure on the basis of live weights (2006–2007)	National zootechnical database (NZD) for number of cows and buffalos [50] with fixed housing on straw

mill wastes through AD, observing up to 90% increase in methane production when co-digested with alternative residue streams [34,35]. While Palmowski [36] showed the modality for AD of grape marc. Although the specific biogas yields of grape stalk and grape marcs were revealed to be relatively low [37], it might be added in small amounts (due to the lignin content) as a co-digester with the OFSUW or animal slurry [38,39].

In this work we focused on the potential for the production of biogas through the AD with the co-digestion of organic feedstock, the most common for Lecce province being: animal manure and slurry, agricultural residues from viticulture and olive orchards, by-products of wine and olive oil production (such as olive oil cake and grape marc), and organic fraction of solid urban waste (Table 1). Since the agricultural residues and agro-industrial by products of olive grows are available unevenly during the years, the reference years for those was set to 2006–2007, while for the rest of the sources the reference year was 2007. The spatial unit of reference for all datasets was the municipality, which is the lowest jurisdictional level and the finest grain of information available.

Available biogas quantity was estimated according to the coefficients revealed from the literature (Table 2).

4.2. Land availability assessment

The following digital cartographic layers were used for the analysis of the land availability under the exclusive constraints imposed by the landscape and regional law restrictions (Table 3). The procedure involved the Boolean overlay of buffered layers, each layer and the final map together with the biogas data were inserted in the GIS database using ArcGIS 9.3© software and Spatial analyst extension [41] in layers as polygons; they were converted in raster layers for MCA program. The final raster grid was derived with the spatial resolution of 100 per 100 m with the categorical cells of 0 and 1, where under 1 were areas suitable for the biogas plan construction.

Table 2
Biogas conversion factors (compiled after [6,20,37,40]).

Feedstock	Biogas yield factor for 55% of CH_4 (m^3/t)
OFSUW	300
Cattle sludge	32
Cattle (cow and buffalos) manure	70
Grape stalk	110
Grape marc	120
Olive oil cake	125

Table 3
List of constraints.

Exclusive Constraints	Description	Source
Environmental	Regional natural protected areas National natural protected areas Natura 2000 sites	Apulia region administration
Cultural	cultural heritage sites (archeological and architectonic sites, historical monuments)	Lecce province administration
Geological	Caves and valleys	Lecce province administration
Slope inclination	Inclination >20%	Digital Elevation Model [48]
Landscape features	Landscape units	Lecce province administration
Hydrogeology	Basins, channels, waterbodies and coast lagoons	Lecce province administration
Infrastructure	Network of roads, railways, gas pipelines, power lines	Apulia region administration

4.3. MCA analysis – AHP structure (FLOWA)

For the multi-criteria evaluation in the GIS environment an analytic hierarchy process-ordered weighted averaging (AHP-OWA) was used, as provided by the program FLOWA, an ArcGIS 9.3© extension developed by Boroushaki and Malczewski [42]. Fig. 2 represents the hierarchical structure of the problem studied in this article. We identified two main objectives described by specific sets of data (Table 4). The first objective is an economic endpoint (E) integrating distances from sources and sinks of biomass and energy, respectively, with a total of six factors. The distance to major roads, gas pipelines and power lines were selected to minimize the energy transportation costs and environmental impact of new infrastructures and overall traffic reduction; factor of distance to sewage plants was included as the potential for further inclusion of this biogas source in the analysis; while distances to industrial areas and caves would be beneficial to the goal of the reuse, recovery and requalification available degraded areas and minimization of the odor impact of the potential AD. The second objective is resource availability (R) based on amount of feasible biomass derived by agricultural activities and urban wastes with a total of six factors.

FLOWA allows calculating the consistency ratio (CR) as a measure of inconsistency among weight attribution. The ration is computed as (formula (1)):

$$CR = \frac{CI}{RI} \tag{1}$$

where CI is a consistency index and RI is a random index – the consistency index of a randomly generated pairwise comparison

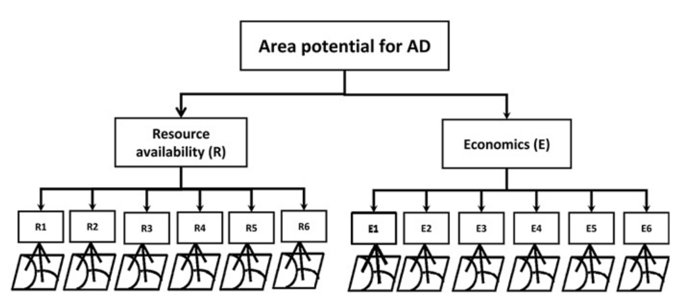

Fig. 2. Hierarchical structure of area potential for biogas plant problem.

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Table 4
GIS criteria and factors used for the analysis.

Criteria	Factors	Sources
Economic	*E*1. Distance to major roads	Own calculation on the basis of data from Lecce province administration
	*E*2. Distance to gas pipelines	Own calculation on the basis of data from Apulia region administration
	*E*3. Distance to power lines	Own calculation on the basis of data from Apulia region administration
	*E*4. Distance to sewage plants	Own calculation on the basis of data from Lecce province administration
	*E*5. Distance to industrial areas	Own calculation on the basis of data from Lecce province administration
	*E*6. Distance to caves	Own calculation on the basis of data from Lecce province administration
Resource availability	*R*1. Biogas potential of organic fraction of solid urban wastes	Own calculation, see Section 4.1
	*R*2. Biogas potential of cattle slurry	Own calculation, see Section 4.1
	*R*3. Biogas potential of organic fraction of animal manure	Own calculation, see Section 4.1
	*R*4. Biogas potential of olive oil cake	Own calculation, see Section 4.1
	*R*5. Biogas potential of grape marc	Own calculation, see Section 4.1
	*R*6. Biogas potential of grape stalk	Own calculation, see Section 4.1

matrix. If CR < 0.1 — the pairwise comparison has a reasonable value of consistency. We applied a pairwise comparison approach developed by Saaty [43], which enables the conversion of verbal comparative weights into numerical scales. In the pairwise comparison matrix the respective weights of criteria were assigned according to the scenarios considered. While the pairwise comparison matrix for the factors of criteria *E* is presented in Table 5.

The standardization for the factors in FLOWA was performed as per formula (2):

$$\mathrm{var}_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \quad (2)$$

Moreover in the application of this program, which integrates the fuzzy linguistic quantifiers between two extreme cases of the *at least one* and *all*, in this work we used *all* as a goal for AHP problem solution. This means that "all" or "at least one" of the important factors/objectives (according to their relative weights) must be satisfied by an acceptable solution. In Boroushaki and Malczewski [42] the full description of the program can be found. For this study the goal "many" was chosen to indicate the areas where the maximum of the chosen criteria would be met.

Table 5
Pairwise comparison of the level of factors in the criteria economic.

	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	Relative importance (weight)	CR
*E*1	1	4	4	8	6	9	0.086	0.089
*E*2	0.25	1	1	5	2	7	0.148	
*E*3	0.25	1	1	5	7	7	0.148	
*E*4	0.125	0.2	0.2	1	0.5	3	0.053	
*E*5	0.166	0.5	0.5	2	1	5	0.086	
*E*6	0.11	0.143	0.143	0.33	0.2	1	0.04	

Table 6
Pairwise comparison on the factors level of criteria resource availability. Scenario 1.

	R1	R3	Relative importance (weight)	CR
*R*1	1	3	0.086	N/A
*R*3	0.33	1	0.75	

Table 7
Pairwise comparison on the factors level of criteria resource availability. Scenario 2.

	*R*1	*R*2	*R*4	*R*5	*R*6	Relative importance (weight)	CR
*R*1	1	2	6	5	5	0.483	0.058
*R*2	0.5	1	6	4	5	0.28	
*R*4	0.167	0.167	1	0.333	0.5	0.061	
*R*5	0.2	0.25	3	1	2	0.097	
*R*6	0.2	0.2	2	0.5	1	0.079	

4.4. Contiguity analysis

A first approximation of the feedstock flows among municipalities has been modeled by incorporating a neighborhood relationship for all spatial units in the study area. A contiguity matrix was compiled by assigning to each cell $x_{i,j}$ of the squared array composed of $N \times N$ elements, where N is the number of spatial units considered, the value of (formula (3)):

$$x_{i,j} = \begin{cases} 0 & \text{if no boundary or road connections} \\ w_{i,j} & \text{if present boundary or road connections} \\ 1 & \text{if } i = j \end{cases} \quad (3)$$

where $w_{i,j}$ is the intensity of the feedstock flow express as the proportion of biomass moving directionally from unit *j* to unit *i*. We assume that two spatial units were neighbors if they share a common administrative boundary and were connected by a major road. The final amount of available resource can be computed by multiplying the rows of the contiguity matrix by a vector of resource among per spatial unit. In our work we simplified the contiguity matrix by considering $w_{i,j}$ to be fixed to 0.5 for all spatial units, thus assuming a symmetric flow among neighbors. Such an approach could be further generalized in two directions: first, by considering a higher order of spatial relations with different contribution weights, like a first and second neighbor with one half and one fourth of contribution; second, by modeling a spatially varying bidirectional flow of available resources. It is important to note that spatial units along the borders of the study area may receive less importance due to their spatial relationships with other units.

4.5. Exploratory scenarios

In order to maximize the biogas yield and considering the reported in literature (see Section 4.1) combinations of feedstock

Table 8
Pairwise comparison on the factors level of criteria resource availability. Scenario 3.

	*R*2	*R*4	*R*5	*R*6	Relative importance (weight)	CR
*R*2	1	8	5	7	0.679	0.041
*R*4	0.125	1	0.333	0.5	0.075	
*R*5	0.2	3	1	1	0.139	
*R*6	1	2	0.143	1	0.107	

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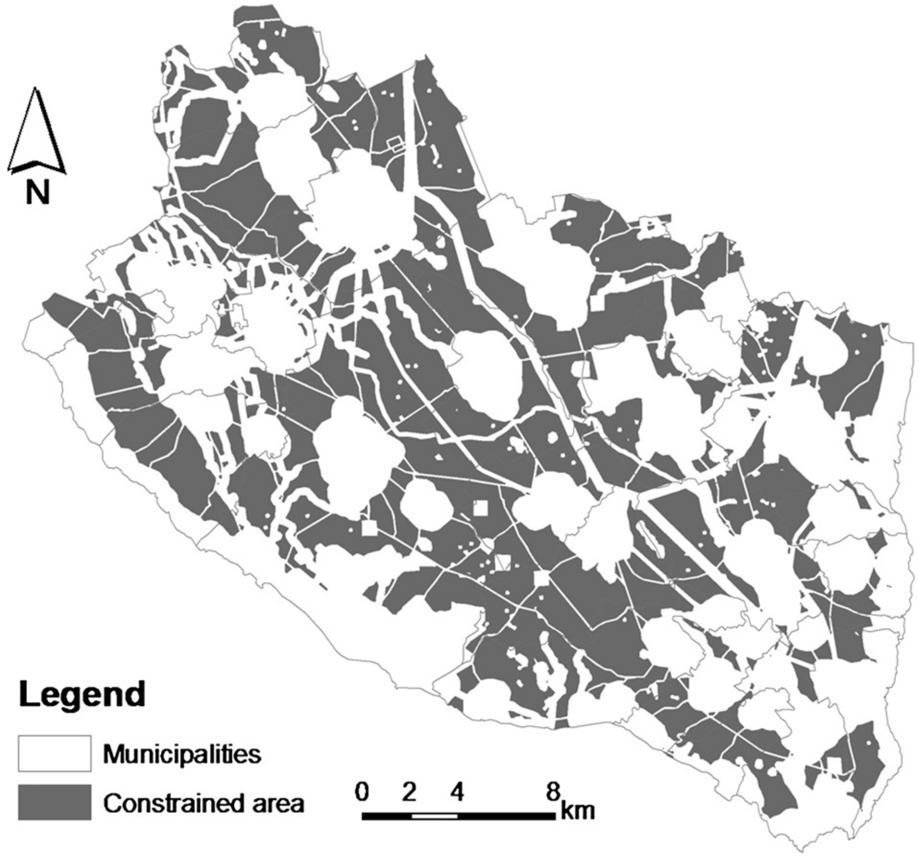

Fig. 3. Potential area for AD after application of environmental, cultural, infrastructural and geological constraints.

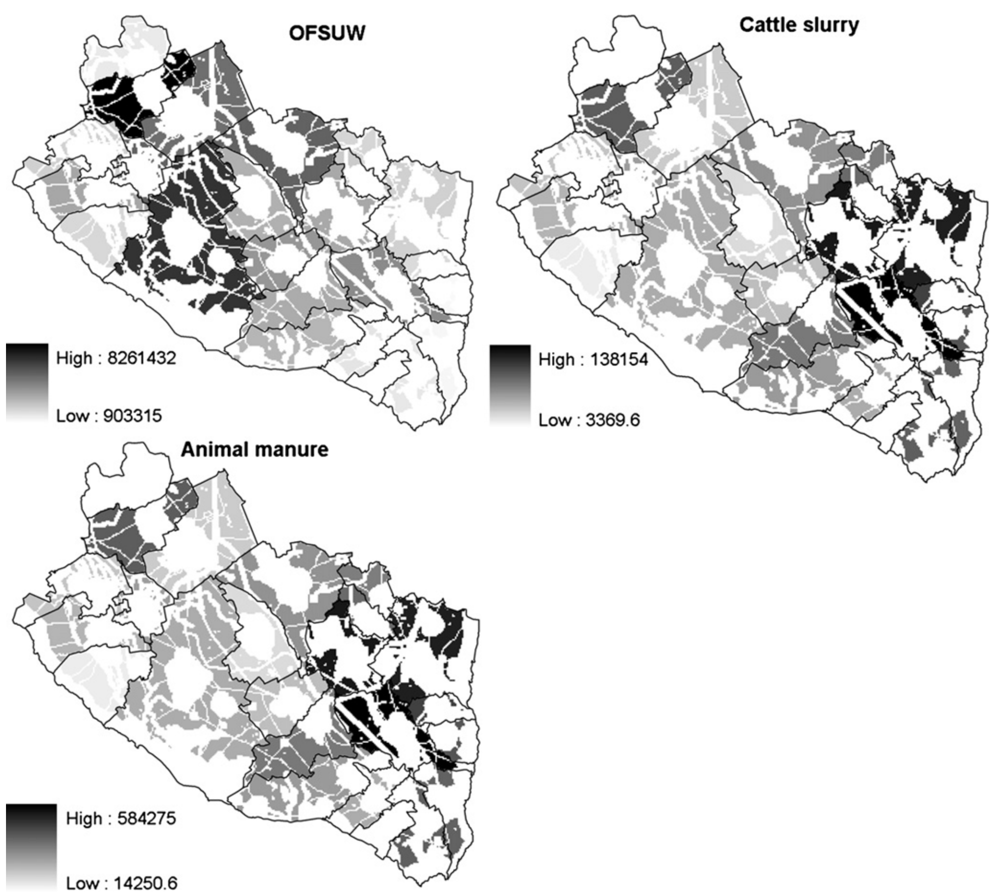

Fig. 4. Spatial distribution of biogas potential from OFSUW, animal manure and cattle slurries in m^3/t.

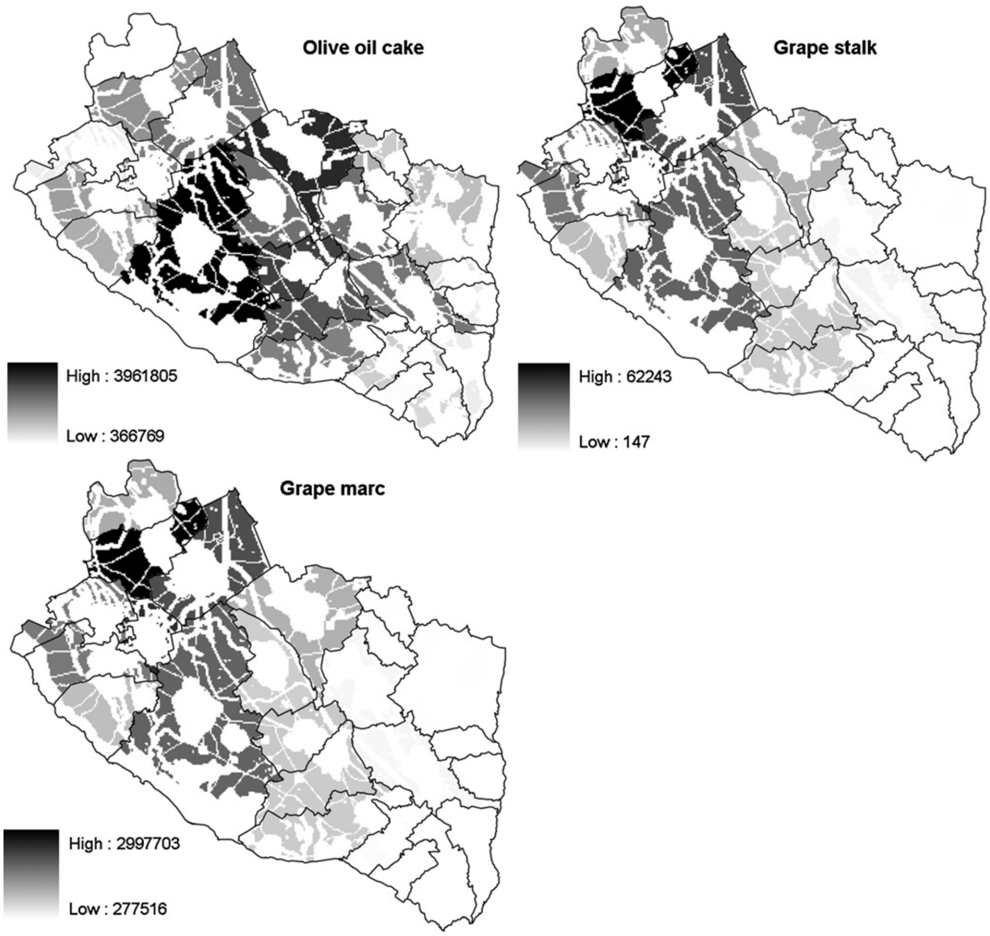

Fig. 5. Spatial distribution of biogas potential from olive oil cake, grape stalk and grape marc in m^3/t.

for co-digestion under anaerobic conditions, in this work three scenarios were tested: (i) combination of OFSUW and animal manure with higher relative importance given to economic criteria; (ii) combination of OFSUW with cattle slurry, olive oil cake, grape marc and grape stalk with higher relative importance assigned to resource availability criteria; (iii) combination OFSUW with grape marc and stalk, with equal importance given to both criteria. The relative importance and weights of factors in the pairwise comparison matrix of the AHP are shown in Tables 6–8.

5. Results

5.1. Landcover characteristics due to constrains

After application of environmental, cultural, geological and other constraints, the resulting potentially available areas are approximately 48% of the territory. High level of fragmentation is observed in the southeastern part due to the presence of several protected areas such as Sites of Community Interest of Natura 2000 network (up to 9% of the area).

Moreover, the coastal areas are uniformly not suitable for the construction projects due to the presence of natural parks both terrestrial and marine and high concentration of cultural amenities (Fig. 3).

5.2. Areas with high theoretical biogas potential under contiguity analysis

According to the multi-criteria GIS model, the highest theoretical potential for AD biogas production among the sources included in the study belongs to olive oil cake, grape marc and OFSUW with clusters of higher availability located in the northern and north-western parts of the area (Figs. 4 and 5).

Following is the biogas potential from animal manure and cattle slurry, clusters of which are found in the eastern part. While the lowest estimated biogas potential is registered for the grape

Table 9
Energetic potential of analyzed feedstock sources[a].

Feedstock	OFSUW		Cattle slurry		Animal manure		Olive oil cake		Grape stalk		Grape marc	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Energetic equivalent (GWh × $year^{-1}$)	17.7	1.93	0.29	0.01	1.25	0.03	8.47	0.78	0.13	0.0003	6.41	0.59

[a] Values obtained assuming the use of biogas for electricity production and considering an electric yield of 35%.

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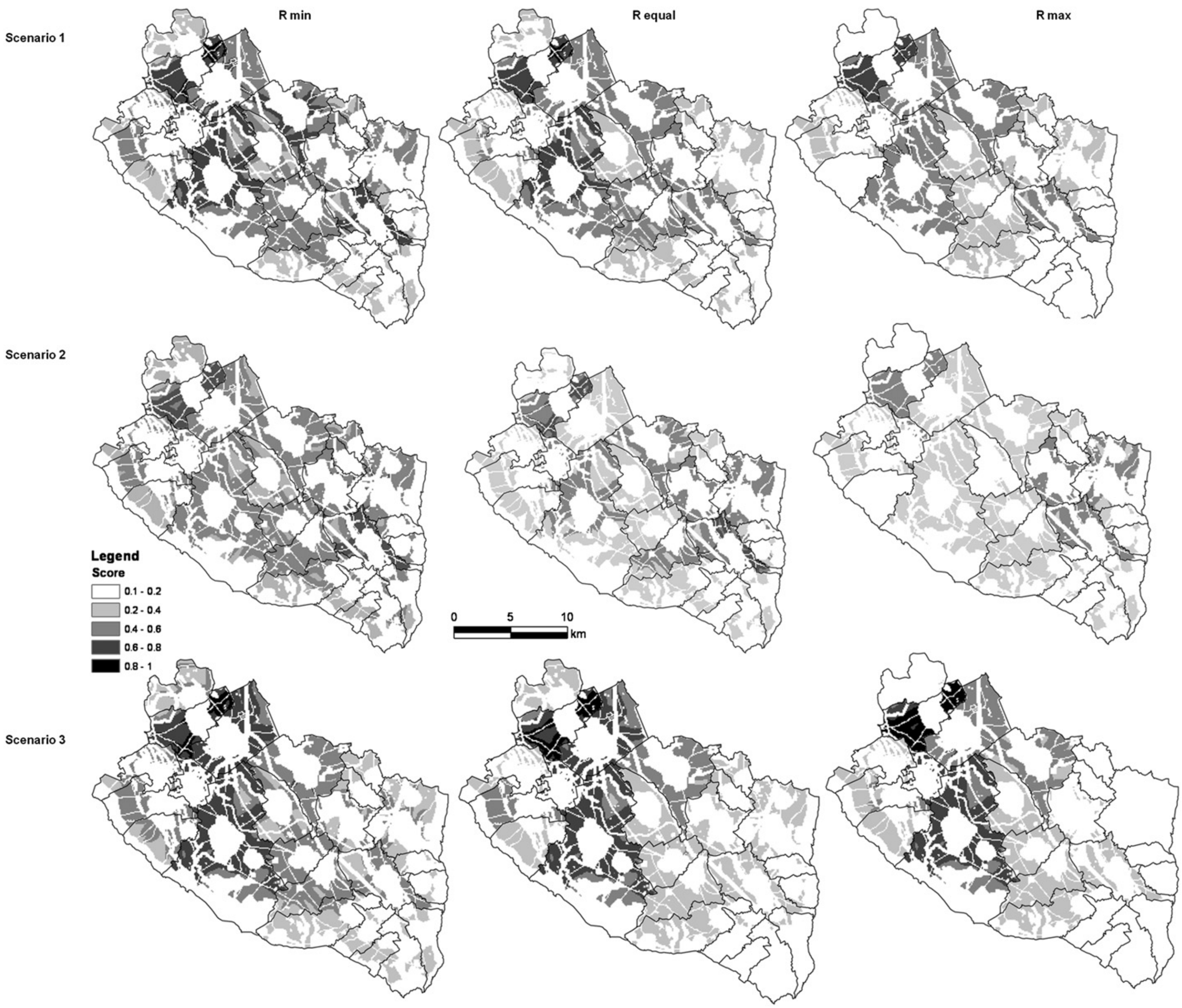

Fig. 6. Scenarios under different importance of criteria and feedstock combinations (R_{min} = low importance of resource availability, R_{eq} = resource availability and economic criteria obtain the same importance; Rmax=resource availability is maximized).

stalk, availability of which follows the pattern of grape marc (Table 9).

The reported costs of the pre-conversion of the feedstock into biogas in the EU25 are on average 30 Euro/MWh for AD without feed-in tariff and 40 Euro/MWh with feed-in [44]. Under these assumptions and the data provided in Table 9, the highest economically viable potential for biogas production among the analyzed feedstock belongs to OFSUW and olive oil cake, following by grape marc and animal manure.

5.3. Exploratory scenarios

The common denominator for all three scenarios is that the areas in the South of WMA have the lowest or 0 potential for AD installations both from the point of view of resource and economic factors availability (Fig. 6). While it results that the ideal areas for AD installations are the northern–eastern parts, repeated cluster of which is observed in all three scenarios. These areas are located in the more densely populated northern part of WMA, so the AD instituted there may provide electricity to some major urban centers.

The combination of the feedstock (OFSUW with grape marc and stalk) in the third scenario results in more areas with higher potential, slightly more clusterized towards the north when the maximum importance is given to resource availability criterion. Small clusters also appear towards the southeastern part when the first scenario is applied with the maximization of the economic criteria importance (Fig. 6).

Overall, second scenario feedstock combination (OFSUW with cattle slurry, olive oil cake, grape marc and grape stalk) and weight attribution result in lowest area availability for biogas production.

6. Discussion and conclusions

The introduction of sustainable technologies is a very long-term and fragile process. New technologies often need to be supported for decades, before sufficient socio-technical momentum emerges. Therefore, the baseline conditions should be carefully evaluated

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before the introduction of such technologies [45]. Biogas production through anaerobic digestion is one of those technologies. The initial introduction of these plants in the area at a farm scale should encourage further development of larger centralized biogas plants as shown by Danish experience [45].

In this work, a rigorous approach for data collection and architecture of the spatially explicit information system is proposed in order to support the strategic planning for the introduction of ADs in the territory in the distributed electricity generation planning. The approach followed a two-step procedure: first the criteria were developed based on the literature research of the key factors influencing the introduction of the ADs in the given area, resulting in two criteria set described by six factors. Secondly, all factors were quantified and integrated in the geographical information system in order to conduct further processing. The contiguity analysis assisted in the understanding of the feedstock flows between the different municipalities, which in the hypothetical planning procedure may encourage the inter-municipal collaboration to sustain the significant investments needed for the biogas plant installations and territorial clusters forming. Moreover, the incorporation of multi-criteria analysis allowed a combination of the multiple factors influencing a decision-makers' choice and a production of several scenarios instrumental when integrated with the land use planning of the area.

It has been revealed that when it comes to the detailed analysis of the land availability at the local scale, application of multiple environmental and cultural constraints may reduce the physical availability of the area by up to a half. While the resource and infrastructure accessibility would further constrain the examined area, leading to the formation of landscape clusters, which indicate the best suitable areas for AD development. The multi-criteria GIS model suggests that the ADs should be located in the northern and northeastern parts of the studied area. These are the areas where the population density is higher and therefore the higher energy demand could be partially addressed. Other isolated patches of high GIS model scores are located in the southern part of WMA, which could be ideal for the small-scale farm based ADs alimented by animal slurry and agricultural residues. The highest potential for electric energy production was estimated for OFSUW and olive oil cake, while the lowest potential is the one for cattle slurry and grape stalk. Giving this was an indication that the latter should be managed always together with the other types of AD feedstock.

The additional value of this approach is that as required by the stream line research multiple sources of feedstock such as organic fraction of solid urban waste, biomass sources and animal production were estimated as to their potential to feed the AD. In this way the best waste management practices could be encouraged for better waste recycling and waste sorting strategies at the municipal level, since in the waste management policy hierarchy, the waste prevention, recycling and energy recovery are located at higher levels than waste disposal [4]. But also for the more sustainable and balanced planning of renewable energies at the municipal and inter-municipal level through integration with the similar analysis for wind and solar energy.

It has been argued that "communicative" planning of renewable energy is crucial for the smooth territorial integration of such projects at the local scale [45,46]. Meaning that participation of different stakeholders during the planning phase is fundamental for the maximization of renewable energy outputs. Therefore, our approach addresses the objective analysis of the area allowing the first screening for the intervention. The refining of the approach would permit the integration of the stakeholder perceptions towards the new technology by assigning the weights based on the public opinion and necessities of the constrained area.

Finally, the approach could be used for the strategic land use planning when integrated with the current land use plans in order to mitigate the consequences of the indirect land use change as a result of energy crop displacement.

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