13

GIS for the Determination of Bioenergy Potential in the Centre Region of Portugal

Tanya C.J. Esteves, Pedro Cabral[1], José Carlos Teixeira[2] and António J.D. Ferreira
Centro de Estudos de Recursos Naturais, Ambiente e Sociedade
Escola Superior Agrária de Coimbra – Instituto Politécnico de Coimbra
Bencanta 3040-316 Coimbra, Portugal
[1]Instituto Superior de Estatística e Gestão de Informação – Universidade Nova de Lisboa, Campus de Campolide, 1070-312 Lisboa, Portugal
[2]Departamento de Engenharia Mecânica – Universidade do Minho
Campus de Azurém, 4800-058 Guimarães, Portugal

Introduction

Every activity performed by mankind is directly or indirectly dependant on the use of energy. Fossil fuels are the main source used nowadays, a presumably limited energy source that may end in the near future (Boyle, 2004). World total annual consumption of all forms of primary energy increased drastically, and in the year 2006 it reached an estimated 10,800 Mtoe (million tons of oil equivalent) (U.S. Energy Information Administration [USEIA], 2009). The annual average energy consumption per person of the world population in 2006 was about 1.65 toe (ton of oil equivalent) (Population Reference Bureau, 2010). In 2010, the consumption of this energy may reach 12,800 Mtoe (USEIA, 2009) and in 2050 it is expected to achieve a range of 14,300 Mtoe to 23,900 Mtoe (International Energy Agency for Bioenergy [IEAB], 2009). We can also assume that it might possibly never end. The current energy crisis is affecting great part of the world population (U.S. Department of Energy, 2009).

The fluctuation of the oil price is causing a severe economic disruption worldwide, where steps must be taken as to guarantee mankind's future. Most fossil fuels must be substituted by other kinds of energy sources to preserve environmental and economic resources. This transformation may lead to a much needed sustainability. Sustainable development is defined as being *the development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (World Commission on Environment and Development, 1990), involving environmental, social and operational management strategies, an equilibrium not easily attained due to their interdependency. Boyle (2004) considers that a sustainable energy source is one that ideally does not deplete substantially by its continuous use, one that does not entail significant pollutant emissions or other environmental problems, or one that does not involve the perpetuation of substantial health hazards and/or social injustices. Renewable energies appear generally more sustainable than fossil fuels, once they are essentially inexhaustible and their use usually entails less green house gases (GHG) and pollutant emissions. By using renewables, a higher level of sustainability may be achieved by modern society (Richardson and Verwijst, 2005).

Portugal is extremely fortunate, as it is rich in bioenergy sources of many sorts. Solar, wind, hydro and tides are just a few of the rich sources that may be harnessed to produce bioenergy in this country. However, this chapter will focus solely on biomass, delineating a GIS-based strategy to comprehend the amount of available bioenergy resources commonly considered as residues. Hence, the aim is to analyze the potential of bioenergy in the Centre Region of Portugal (CRP) for several biomass resources, namely from energetic cultures, forest, agricultural and food residues and the biogas produced as by-product from some human activities. Spatial and non-spatial data are collected and transformed into a comparable energy unit (toe). Another goal is to determine the optimal location for the BCC. This entity encompasses a large range of services before and after bioenergy production, e.g., technical assistance throughout the production process, research, personnel training and product certification. Adequately implementing this infrastructure in the terrain is essential for a flourishing development of bioenergy use in the study area. The two overall outcomes of the developed work will be two maps: one depicting the bioenergy potential for the CRP and another with recommendations for the optimal implementation of the BCC.

Bioenergy in Portugal

This chapter presents the main considerations in the bioenergy study field, defining what bioenergy is, its sources, and the current situation in Portugal.

Bioenergy: What is it?

The renewable energy directive defines biomass as “the biodegradable fraction of products, wastes and residues from biological origin from agriculture (including vegetable and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste" (European Parliament and of the Council [EPC], 2009).

Obtaining a reliable estimate of the total world-wide energy contribution from bioenergy sources is not an easy task. Although the benefits from the use of bioenergy are irrefutable, there are still technical issues that have to be surpassed, e.g., the intermittency of some renewables. Nonetheless, the biggest obstacle has more to do with politics and policy issues than with technical ones. When these renewable technologies are developed in a sensitive way, they have the benefit of being environmentally benign, diverse, secure, locally based and abundant, promoting the involvement of the local communities. Numerous challenges need to be addressed for its untapped potential to be used in a sustainable way (IEAB, 2009). One has to take into account a large number of influencing factors, and not only the environmental aspect. Recently, "new" biomass sources have emerged, being composed of materials that are processed on a large, commercial scale, normally in the more industrialized countries. They are normally purpose-grown energy crops or organic wastes that are capable to create heat or any wide range of solid, liquid or gaseous biofuel (Boyle, 2004).

Bioenergy Sources

Biomass accounts for about a third of total primary energy consumptions in developing countries. Wood plays an indubitable role as an energy source; nevertheless, its patterns of demand and supply, and its associated economic, social and environmental impacts are still poorly understood (Boyle, 2004; Masera, Ghilardi, Drigo and Trossero, 2006). There are many bioenergy sources, from which this chapter will only focus on some of the purpose-grown energy crops (agricultural crops) and wastes.

Farmers in Europe have been discovering the advantages of producing renewable energy and biomaterials. Due to changes in the food production and consumption in Europe, agriculture has shown potential to be a major bioenergy production contributor in the EU27, supporting the efforts to significantly increase the share of renewable energy sources production (European Environment Agency [EEA], 2007). The most widely grown crops for bioenergy purposes are maize, sugar cane, sunflowers, oilseed rape, soya beans, etc. However, future agricultural biomass production should not impose additional economic, social and environmental pressure on farmland biodiversity and environmental resources than is currently the case (EEA, 2007).

A multitude of wastes can be used to produce bioenergy. However, a main question remains: should this material be regarded as a renewable resource? Wood residues that come from thinning plantations and trimming operations generate large volumes of forest residues. It is customary to let these residues rot on site. Although this fact has the environmental merit of retaining nutrients, they may enhance the forest fire risk in many regions. Reusing these residues for energy production is possible. Temperate crop wastes are also able to be used. Surplus in agricultural production often leads to burning in the field, even though air pollution concerns and legislation restrain such practices (Boyle, 2004). Despite animal manure being a major source of important pollutants, particularly methane (CH_4), their use is a viable form of energy production through anaerobic digestion (Ramachandra, 2008). Animal wastes from the confined animal feeding operations lead to new, state-of-the-art waste management systems (anaerobic digestion technology) that make animal operations economically viable and environmentally benign (Cantrell, Ducey, Ro and Hunt, 2008). This leads farmers to reduce their dependency on imported fossil fuels while concurrently improving the soil, water and air quality, and converting the treatment of livestock waste from a liability or cost into a profit centre that can simultaneously generate annual revenues, moderate the impacts of commodity prices and diversify farm income (Cantrell et al., 2008). Municipal solid waste (MSW) is generally considered to include all kind of residues generated from homes, businesses, and the cleaning of public places such as streets, parks, beaches and other recreational areas. They can also be used to produce energy, by recovering landfill gas, incineration, gasification, H_2 production, pyrolysis and anaerobic digestion of the organic fraction (Gómez, Zubizarreta, Rodrigues, Dopazo and Fueyo, 2010). A large proportion of MSW is biological material and its anaerobic digestion reproduces the natural process of degradation of the organic matter in the landfill. This process produces methane, and compost is also an often by-product. The produced gas in landfill biogas plants is increasingly used to generate electricity for local use or for sale and have been amongst the most financially attractive of the existing systems (Boyle, 2004; Gómez et al., 2010).

Bioenergy in Portugal

Countries like Portugal that have low or inexistent access to fossil fuels are subject to the prices of international entities: in 2007, Portugal had an approximate consumption from oil of 54% of the primary energy. However, the country still has a final energy consumption per inhabitant lower than the mean of other EU-25 countries (1.7 toe/inhabitant versus 2.5 toe/inhabitant) (Agência Portuguesa do Ambiente [APA], 2008). But it still represents a constant exit of currency to supplying countries, with a consequent weakening of the economy. This is a very important reason to invest in alternative energies and energetic efficiency, to escape the dependence on the volatility of oil, natural gas and coal prices. The national renewable sector has been strongly developing (Associação das Energias Renováveis [APREN], 2010). The Directive 2001/77/CE of 27 September 2001 stipulated that Portugal would have to produce 39% of electricity from renewable energy sources until 2010

(EPC, 2001). By early 2007, this aim had already been achieved, having altered the stipulated target to an ambitious 45% (Direcção Geral de Energia e Geologia, 2005; European Commission, 2007).

Biomass dedicated power plants are of recognized importance for the global bioenergy balance. Portugal has nine biomass plants working in a cogeneration regime, with a total of 308 MW electric energy generation (APREN, 2010). In what refers to the national production of solid waste, between 1995 and 2008 the increase of these residues accompanied the Gross Domestic Product (GDP) growth, were a respective increase of approximately 32% and 33%. These values translate a production of 5,059 million tones, a total higher than the one perceived in the Portuguese Strategic Plan for Municipal Solid Waste 2007-2016 – 4993 million tones (Ministério do Ambiente e Ordenamento do Território, 2007). In 2008, a mean of 1.3 kg/inhabitant.day was produced (European capitation – 1.4 kg/inhabitant.day) (APA, 2009). Landfills are the main destination for final disposal of municipal solid waste in Portugal. About 65% of the total produced waste is landfilled, followed by incineration with energy valorization (18%), separate collection (9%) and 8% for organic valorization (APA, 2009).

The Centre Region of Portugal

Portugal is a 92,094 km^2 west coast European country, in the Iberian Peninsula. It benefits from its privileged geographic location, between Europe, America and Africa (Agência para o Investimento e Comércio Externo de Portugal [AICEP], 2008). The littoral, generally more flat, is distinguished from the inland sloped areas, where the higher altitudes are in the mountain range located in the Centre Region of the country (AICEP, 2008; Instituto Nacional de Estatística [INE], 2009). As for the territorial units for statistics (Nomenclature of Territorial Units for Statistics – NUTS), the country is at NUTS I level, divided into seven NUTS II territories (Regions), in which the CRP is included. This region is divided into 12 NUTS III areas (Fig. 1). It occupies 28,200 km^2, comprising a total of 100 municipalities (AICEP, 2008). As for the protected areas, there are 4,560.31 km^2 classified in the Natura 2000 network, as well as 1,981.67 km^2 of various types of protected areas (INE, 2009). The 2001 Census states that this region has 2,371,700 inhabitants (AICEP, 2008), which in 2006 produced 1,060,968 t of municipal urban waste (71,466 t from selective collection) (INE, 2009). The CRP is one of the richest, in terms of forest stands. Olive groves, pine and eucalyptus forest stands are prominent (AICEP, 2008). A massive yearly problem are forest fires: in 2007 and 2008, a total of 4,482 wildfires occurred, burning 77.88 km^2 of land (INE, 2009). In agriculture, there was a variety of crops planted (e.g., wheat, rice, cherries). Potato crops produced a total of 28,470 t in 2008, although the planted area was only of 152.08 km^2. Maize was the crop with most planted area (342.04 km^2), although the total production was 174,015 t.

Wine and olive oil production are also common in this region. In 2008, 1,507,444 hl of wine were produced, as well as 144,743 hl of olive oil, from 309 olive oil mills (INE, 2009).

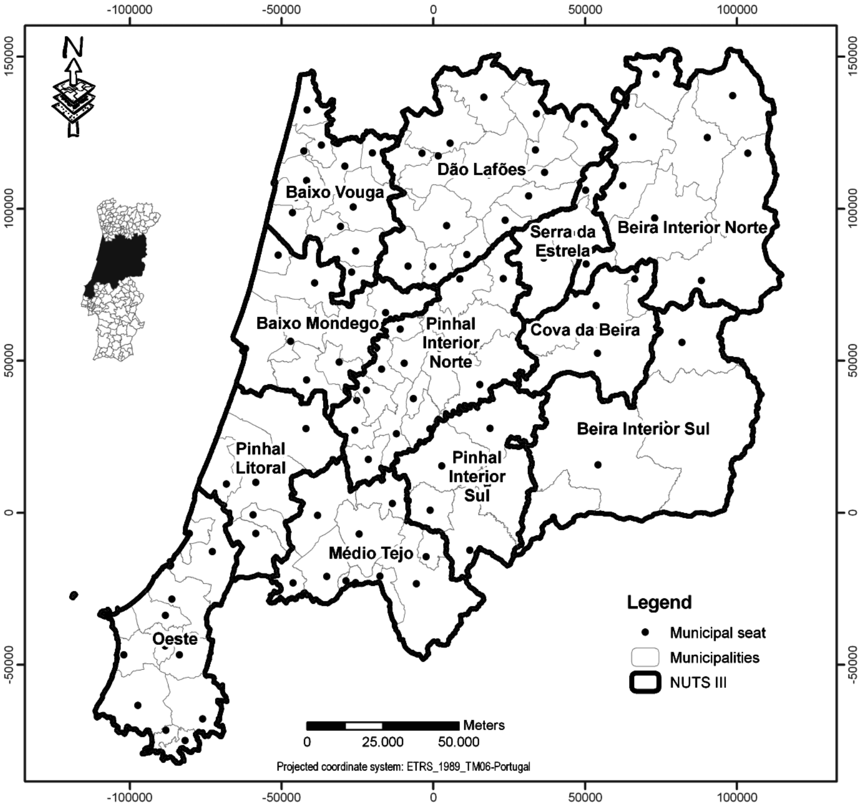

Figure 1. NUTS levels of the CRP.

Regional energy consumption can be categorized in *domestic*, *non-domestic*, *industrial*, *agriculture*, *lighting of public roads*, *inner lighting of State/public buildings* and *others*. In 2007, the *industrial* sector used most energy (547,085.76 toe), in contrast with the *others* sector (12,157.36 toe). The *domestic* and *agriculture* sector spent 256,006.69 toe and 25,946.79 toe, respectively. The consumption of electric energy per inhabitant was of 0.107 toe, as opposed to the national average of 0.112 toe. As expected, the *industrial* sector spends most energy per consumer (15.239 toe), whilst the *agriculture* sector spends 0.201 toe and the *domestic* uses 0.361 toe (INE, 2009). Gross production of electricity was of 1,387,955.62 toe, having 176,528.05 toe come from wind power, 123,427.47 toe from hydropower and 1.332 toe from photovoltaics. Thermal power was also produced (1,087,998.77 toe), from which 182,571.88 toe came from central cogeneration (INE, 2009).

The Bioenergy Potential Map for the Centre Region of Portugal

The bioenergy map for the CRP is one of the two results of the present study that may help us attain a general overview of the amount of available biomass and to understand how that biomass is distributed throughout the region. To aid in this study, a multicriteria decision analysis will be used as to obtain a final result.

Input Resource Collection and Treatment

The collection and treatment of the information presented a difficult task: the size of the study area, the dispersion and availability of data were real concerns to deal with upon this stage. Only freely available data was used to create this map. One of the main struggles faced was that recent data was seldom available (the 1999 information for the agricultural sector is used). Information from several sectors was collected, namely: forest residue biomass, agricultural residue biomass, energetic cultures, animal husbandry residues, municipal solid waste, used vegetable oils, agricultural and food industries. In what refers to geographical data, only the 2010 Official Administrative Map of Portugal was used (Instituto Geográfico Português [IGP], 2009).

The analysis scale is at the municipality level. A municipality is a political unit that has an incorporated local self-government. It was the level considered adequate to perform an analysis of the bioenergy potential, that at a larger scale (e.g., parish), too many details would have to be taken into consideration, not being compatible with the aim of the present study. Depending on the subsequent results, a more detailed analysis on a larger scale that is based on the results could be produced for some territorial clusters. On the contrary, a larger scale (e.g., district, NUTS III) would omit too much information, something not desirable at this point.

In general, bioenergy potential for each source was obtained by knowing the area occupied by the source in each municipality of the study region, the annual production of residues for each source and their Low Heat Value (LHV). Multiplying these values and transforming them into a unique unit (toe), bioenergy results appear for forest (maritime pine, cork oak, eucalyptus, holm oak, stone pine, Portuguese oak, sweet chestnut, other hardwood trees, other softwood trees); burned areas; shrublands; agriculture (fresh fruit, citron, nut, vineyard and olive grove permanent drops and maize, wheat, barley, rye, sorghum, oat and rice temporary crops); and energy crops (maize, wheat, barley, rye, sorghum, potato and sugar beet amylaceous crops and sunflower oleaginous crops). For this last production, two details differed from the previous: first, as to not compete with food production, only agricultural areas that have been abandoned throughout the last 20 years were used for these crops; secondly, instead of using LHV values, an energy conversion index (l/t) was used and then the result was transformed into toe. For the energy potential from animal husbandry effluents, bovine, swine and bovine intensive farming are considered. Each animal has different physiology, producing a different daily amount of biogas. Determining this value for each animal and knowing how many are available, the yearly production of biogas is known. This value was then multiplied by the biogas LHV and the potential bioenergy for animal husbandry effluents is known.

For this study, a theoretical value for biogas generated from one ton of MSW in landfills was considered. Knowing the yearly amount of material deposited at a landfill site, the amount of biogas produced annually per municipality was obtained. This value is multiplied by the biogas' LHV and the bioenergy potential (toe) is estimated. Organic valorization is foreseen for most of the region in the near future. Knowing the average municipal production of organic residues, it was multiplied with the amount of biogas that a ton of residue produces. This result was then multiplied by the biogas LHV value, obtaining the final result for bioenergy potential (toe) for organic valorization. Some residues in MSW aren't anaerobically digested, where direct combustion of the inorganic part of the MSW may be a solution. Knowing the typical composition of the MSW in Portugal, the average amount of paper/cardboard, plastic, textile, fine matter and other materials were determined. Multiplying their percentage amount with the total values deposited in the landfill, the total amount of different inorganic material was known. Also having the LHV for each type of material, the energy potential (toe) resulting from this combustion was calculated. To calculate the amount of used vegetable oils (UVO) produced per municipality, the yearly average capita value in Portugal was used. By multiplying this value with the population in each municipality, the consumption/inhabitant.year was known. From the total amount of produced UVO, only 45% is actually considered as waste, and only 60-70% of that amount is the one that actually suffers transesterification. Thus, the amount of biodiesel produced per municipality per year was calculated. By transforming the obtained values in toe with the LHV value, the amount of potential bioenergy was calculated. As for energy obtained from the agricultural and food industries, the olive press cake residue is reused for bioenergy production by combustion. By knowing the amount of produced olives, the residue amount was also known and multiplying this value by the LHV value, the potential bioenergy was obtained for this residue. Similarly for wine production, there is also a residue composed of grape stems, where, by knowing the amount of wine production, we could calculate the amount of produced residue for combustion. Knowing the LHV value, the amount of potential bioenergy to be retrieved from this waste was obtained.

Using GIS for the Multicriteria Decision Analysis for Bioenergy Potential

This study used the ArcInfo 9.3 software, produced by ESRI, to perform the multicriteria decision analysis. Most of the data used by managers and decision makers is somehow related to a geographical level. Data that is undigested, unorganized or unevaluated may be processed to obtain information in order to have some kind of significance. Doing so adds extra value to the original data, proving useful to decision makers to produce quality decisions (Malczewski, 1999). Typically, spatial decision problems involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria, while some are of the qualitative and other of the quantitative nature (Malczewski, 1999, 2006a, b). Multicriteria decision analysis is a useful tool to help solve this type of problems. It uses two types of criteria: *constraints* and *factors*. The former are based on boolean criteria restricting the analyses to specific regions while the latter define a degree of suitability for the whole geographical space, specifying areas or alternatives according to a continuous measure of suitability (Hansen, 2005). The decision making process involves the aggregation of selected criteria that need to be standardized to a common scale (Hansen, 2005). A boolean overlay approach involves the application of operators such as intersection (AND) or union (OR) resulting in binary maps where only the suitable (TRUE) and non-suitable (FALSE) locations are present. An alternative method is the *weighted linear combination* that weighs and combines the factor maps to evaluate the suitability of each cell (Jiang and Eastman, 2000). The suitability s at the k^{th} pixel may be determined by a weighted linear combination (Hansen. 2005):

$$s^k = \Sigma\, w_i x_i^k \tag{1}$$

where w_i is the weight and x_i^k is the value of criteria i in the k^{th} pixel. The weights $w_1, \ldots, w_n$ show each criteria's relative importance and their sum should not exceed 1.0 (Hansen. 2005). Here, a combination of the *boolean overlay* and the *weighted linear combination* was used.

The data described in Section 4.1 was introduced into a geographic database and, with the aid of the *ModelBuider* tool, input data turned into information. This functionality created the model to process the input data, allowing to chain together sequences of tools, feeding the output of one tool into another (Environmental Systems Research Institute [ESRI], 2010). Used functions in this model were merge, dissolve, feature to raster, weighted sum and divide tools. No personalized formulas were used in this particular model, only the standardized ones available by the ArcInfo 9.3 tools.

The merge tool merged the polygon data (municipalities with the bioenergy information) of the different input residue feature classes, and the dissolve tool aggregated the potential bioenergy field for each municipality feature class. The feature to raster tool transformed the vector data into raster so that the weighted overlay tool could be used, overlaying the rasters, using a common scale and weights and outputting the final result of the model (ESRI, 2010).

Results

Currently, there is no method to fully yield 100% of the potential that is available by each and every considered residue. Due to technology constantly progressing and presenting new solutions, these are frequently surpassing existing boundaries, so, whatever considered yield for bioenergy production in this study would rapidly be outdated. The outputted map can be found in Fig. 2. We find that the most promising area in terms of bioenergy production is the northern inland area, Beira Interior Norte, achieving a maximum of 98,912.40 toe in the Sabugal municipality. This fact may be due to the combination of climatic factors with the high amount of agricultural and forest areas, leading to higher biomass yield. The littoral part of the CRP has a much lower potential, where the lowest production is of 1,848.54 toe (Entroncamento). The general middle region of the study area and the Oeste NUTSIII are not appropriate for bioenergy production from biomass.

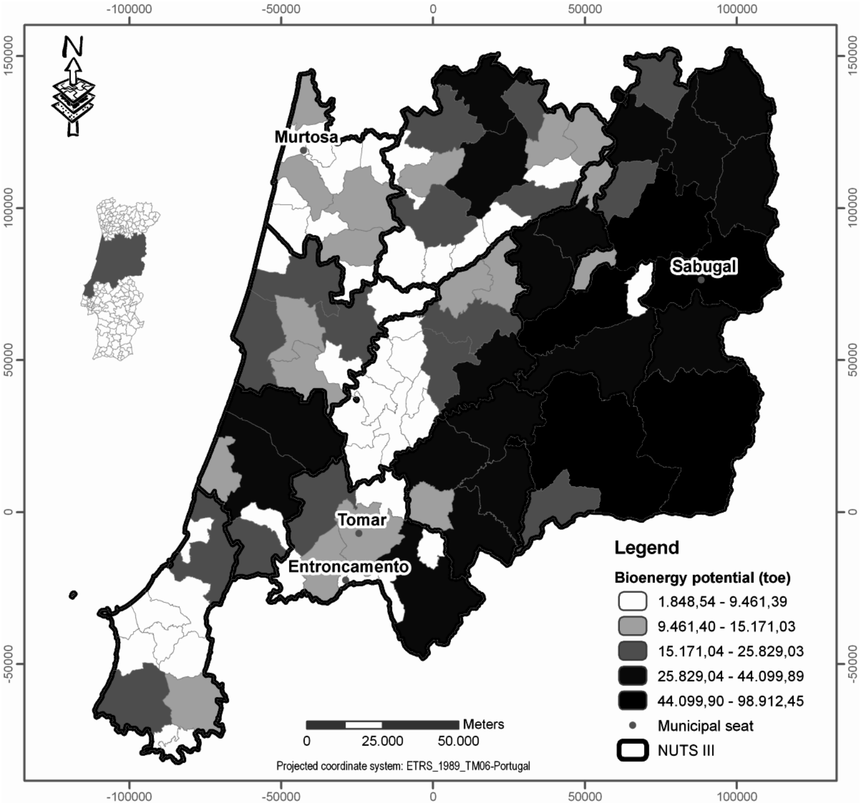

Figure 2. Bioenergy potential for the CRP.

The component that most influences this final map is the forest waste biomass. The source's produced amount is overtaking the remaining sources, mainly due to shrubland contribution.

Information confidentiality for some municipalities is a factor hampering the true potential analysis. For various waste sources, many municipalities (around 5%) had confidential data in the consulted bibliography. This fact may certainly alter the presented results drastically, once that the municipalities can produce enough waste to make a great difference in the final value for those municipalities, making the presented results rapidly obsolete.

Location of the Bioenergy Competency Centre

The BCC will not produce energy itself. Rather, it will have several critical functions for the further development of bioenergy production. In general, it is thought to constantly manage and update information produced in the first section of this work and study the costs of production/collection and processing of the materials needed for the production of bioenergy, as well as the definition of the threshold of economic viability. Its tasks include product certification, research, development and innovation, consultancy, training and trials. It will integrate the main stakeholders in the CRP, as to maximize the profitability of the various laboratorial, management and economical infrastructures and available knowledge. Information flow will be key in this organization's work processes. Taking these important functions into consideration, the implementation of the BCC is of utmost importance. Acknowledging this fact, it should be located in a place of easy access to all stakeholders.

Input Resource Collection and Treatment

For the implementation of the BCC, several suppositions had to be considered. As before, all information is freely available to the general public. The national network of the protected areas was used to determine the existing natural protected areas; the Corine Land Cover 2006 for Portugal (IGP, 2009) was used to determine land use; the itinerary map for Portugal (Instituto Geográfico do Exército, 2009) was used for road information; Shuttle Radar Topography Mission (SRTM) digital elevation data (Consultative Group on International Agricultural Research, 2008) was used to obtain slope information; the location of existing and future biomass power plants in the CRP was also used. Other information can be used, such as sight-seeing and recreation areas, as to exclude them from the final result (one does not want to implement the BCC in these areas). To the author's knowledge, there is no information of the sort available for the study region. What can be done is, when selecting the location from the final map, to compare this information with the Municipal Master Plan, once this document contains the previously stated information. If the map were done at a single municipal level, the information would certainly be easier to incorporate in the created model.

Using GIS for the Multicriteria Decision Analysis for the BCC Implementation

The *ArcInfo 9.3 ModelBuilder* functionality was again a valued tool to locate the BCC. In general, all the information is classified into five different classes, being 1 the least favourable condition and 5 the most preferable one. Three approaches for using the roads were used: the first one expressed the importance of the existing types of roads, making sure that the BCC is easily accessible to all stakeholders; the second approach considered the distance to roads, preferably locating the BCC closer to the roads; and, finally, the use of service areas (with the *Network Analyst* extension) to know the time (hours) it takes the main stakeholders to access the BCC. The resulting map from bioenergy potential analysis is also used as input, so that the BCC can be located preferably in areas with higher production of biomass.

Some restricting conditions also influence the final map results. The protected areas information was used to exclude these areas, once it is illegal to build in such areas. In what refers to the land use, some features were excluded from this feature class once that a construction such as the BCC could not be located in the areas: continuous urban fabric; discontinuous urban fabric; wetlands; and airports. Having considered the aforementioned restrictions, these were merged and transformed into a raster information layer reclassified from 1 to 5. The restricted areas were excluded from the analysis (NoData).

Slope plays a major financial role in building an infrastructure. The steeper a terrain is, the higher will be the construction costs. It also influences travelling: steeper slopes bring more difficulties in transportation (with more fuel consumption). After reclassifying all the inputs in a 1 to 5 scale, a weighted overlay carried out using all the rasters. Table 1 shows four different scenarios for the inputs. Scenario 1 translates the fact that both stakeholders (biomass plants and waste producers) represent an important role for the BCC (higher weights, both with 25%). *Slope* and *restrictions* parameters were constant in all scenarios.

Table 1. Weighting of different inputs for determination of the location of the BCC

Inputs	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Restrictions	5	5	5	5
Slope	10	10	10	10
Road differentiation	15	20	15	20
Distance to roads	20	15	20	15
Network analysis from biomass plants	25	25	30	30
Bioenergy potential	25	25	20	20

In Scenario 2, all parameters had the same weight as the first, besides the *road differentiation* and *distance to roads* ones (more emphasis for the first – 20% – than the second – 15%), as to verify the influence of both aspects on the final result, by comparison with Scenario 1. Scenario 3 considered the same weights as in Scenario 1, except for *network analysis from the biomass plants* and the *bioenergy potential*. In this case, business success is important for biomass plants (as opposed to farmers and other producer stakeholders, that face this more as a secondary business by selling their residues), so they may be more reliant on the services that the BCC may offer than the remaining stakeholders, thus having a higher percentage value (30%) than the bioenergy potential (20%). In the last scenario (4), all weights were changed in respect to Scenario 1. Basically, the *network analysis from the biomass plants* and the *potential bioenergy* were the same as Scenario 3 and the *road differentiation* and *distance to roads* were equal to Scenario 2. From the resulting information, areas with values 4 and 5, and with an area larger than 22,500 m^2 were chosen (projected area necessary for the BCC was 150 m × 150 m).

GIS tools such as buffers, merge, reclassify, weighted overlay, conditional and network analysis were used to materialize this model.

Results

The proper implementation of the BCC will allow stakeholders to have easier access to the provided services. Road types, road distance, travel time, bioenergy potential and slope were the factors considered. The weighing process proved itself difficult, due to the high amount of inputs. One cannot make large differentiations between two comparing values once the remaining parameters would suffer a large reduction, influencing the final result. In Fig. 3, we can verify that different scenario results are very similar between them. Most of the suggested locations in the different scenarios are coincident, although with visible changes in the area amount for each scenario. Another factor that is clearly visible is that there are more areas to implement the BCC with a classification of 4 than there are with a classification of 5 (Table 2). Scenario 2 is the most limitative one, once less area with classification 5 is usable. Scenario 3 is the broadest of them, where more area is available, although the one with classification 5 is higher in Scenario 1. If it were preferable to use only locations with this classification, the solution would be almost the same in all scenarios. Generally, preferable locations would be situated in the Viseu, Covilhã, Guarda, Sabugal, Fundão, Castelo Branco, Sertã, Cantanhede, Coimbra, Pombal and Leiria municipalities. Note that, after a selection of the final area, the results should be confronted with the municipality's Municipal Master Plan.

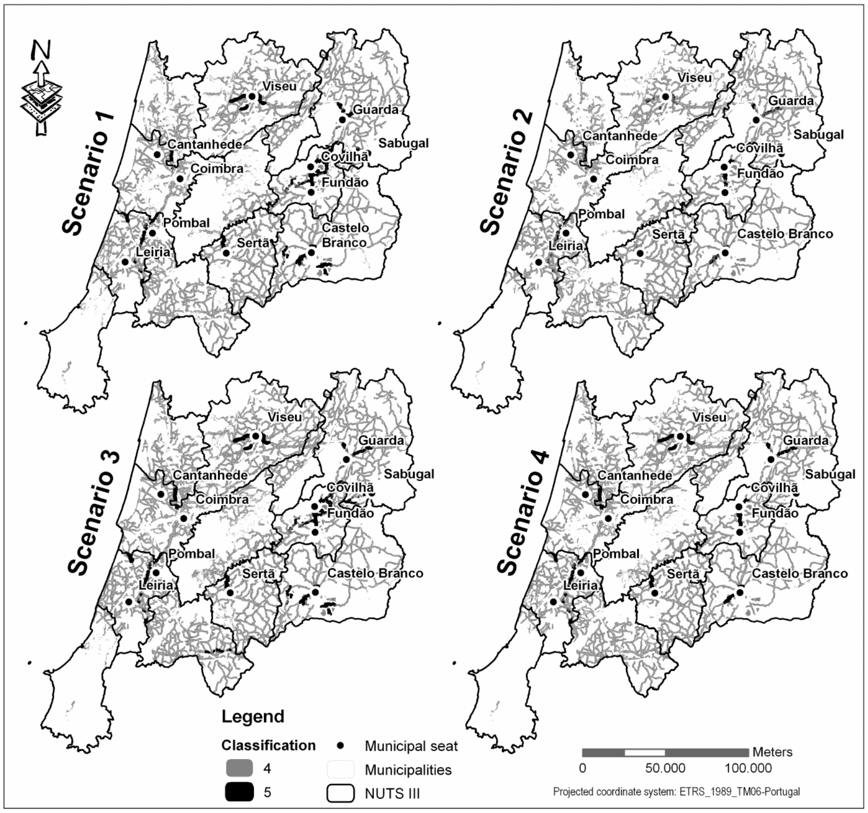

Figure 3. The four scenarios for the implementation of the Bioenergy Competency Centre.

Table 2. Summary of areas with classification 4 and 5

Scenarios	*Total area*	*Areas with classification 4*		*Areas with classification 5*	
	(ha)	*Ha*	*%*	*ha*	*%*
Scenario 1	578,021.15	567,981.87	98.26	10,039.28	1.77
Scenario 2	512,315.38	508,802.14	99.31	3,513.24	0.69
Scenario 3	645,172.95	635,514.89	98.50	9,658.06	1.50
Scenario 4	593,636.41	586,909.87	98.87	6,726.55	1.15

Choosing a determinate location depends on a variety of opinions. GIS and its results are socially constructed via negotiations between various social groups such as developers, practitioners, planners, decision-makers, special interest groups, citizens and others who may have interest in the planning and policy making process (Malczewski, 2004). Many of these issues have to be pondered by the key actors of the future BCC. An appealing option would be locating the BCC in the inland area of the country (Viseu, Guarda, Covilhã, Belmonte, Sabugal, Fundão, Castelo Branco and Sertã). The aim is to confer some dynamism to the area, once this population is increasingly fleeing to the littoral, looking for better life conditions. This may lead to local employment, as well as the possibility of awakening the surrounding population to this new business and delay (or even mitigate) land abandonment.

Future Research Directions

The complexity of the environmental sector depends on a wide variety of composite and comprehensive tools, in which GIS are included, to help solve problems and create new and innovative solutions for the environment. Being conventional energy a source of economic losses for countries, a strong challenge is imposed upon them to produce their own energy sources, mainly through green energies. Bioenergy use may be a sturdy step in that direction, guaranteeing the safeguard of environmental and economical resources of the countries. This study offers a step in this direction. Understanding what resources are in a given territory and using them to an economic and environmental advantage is one of the goals to achieve.

Although the presented results are valid, they could be enhanced. More recent information would bring authenticity to the results to represent today's reality, where certainly much has changed since then. It would be interesting to see how final results differ by using recent data.

By inserting transformation rates into the final results, these would give a realistic view of the bioenergy potential in the territory. Saying, e.g., that a given area has a bioenergy potential of 1500 toe doesn't really ring true; transformation yields for different technologies have to be taken into consideration to determine the actual potential for bioenergy.

Many waste typologies were not considered, being able to present a viable source for bioenergy, e.g. biogas from sludge treatment from wastewater treatment plants and industrial sources (residues from industries that use material such as bark, leather, wood, tyre fluff, etc.). The insertion of this data into the present study would be of great benefit.

An important step to validate the described study would be to make a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. It would verify its feasibility, using different types of biomass to make a well-founded decision. This aspect is of extreme importance, once we desire our energy production to have a positive energy balance, as well as to be profitable. This type of study may promote the full use of bioenergy production in the CRP.

Conclusion

New energy sources are necessary to ensure the sustainability of mankind's future. One of possible solutions is to use bioenergy waste from various sources as to yield energy from them. This was the base premise of this study. The use of this material may contribute to decrease the amount of imported fossil fuels, with economic advantages and to partially replace a pollutant energy source by a greener one.

A large amount of resources are present in the CRP, particularly forest waste, being a main contributor for the amount of bioenergy that may be produced. When compared to the other resources, it is the one present in higher amount. Using this material in particular has a double function: production of bioenergy and aid in the prevention of forest fires, saving lives, material goods, ecosystems and, ultimately, money. Yet other unconventional bioenergy sources exist that are of great interest for the future, such as agricultural residues, MSW, animal husbandry effluents, agricultural and food industries waste and energy crops. As analyzed in the final results, the inland region of the study area promotes higher bioenergy potential yield. This fact may bring positive consequences to these areas, in which local richness may be enhanced. With the yield of available biomass, local population will be employed, giving them better life conditions. This is important, once these areas have been seeing an increasing desertification to littoral urban centres. Reactivating these rural areas and providing a sustainable income would greatly help the local population's overall conditions. However, an important aspect has to be taken into consideration when producing bioenergy: the amount of energy used to produce, treat and transform the residues might not compensate their use. In this study, this refers to the use of energy crops. Perhaps the low value obtained for these crops is related to how the model was created. But still, maybe, and simply enough, energy crops are not a viable source for the CRP.

The location of the BCC was a second main result for this study. A correct implementation will help all interested parts in easily reaching this Centre. Results point to more adequate areas in the inland region, being this result highly desirable. Varying the weights of the different parameters had no great influence in the actual location of the BCC. In general, favourable results landed pretty much in the same municipalities for all four scenarios. Scaling issues should be taken into consideration. The used local data may have different interpretations, depending on the scale analysis. At a local scale, one would say that a given municipality has not enough production for bioenergy from a determinate source. But when considering the bordering municipalities, this municipality may be a contributor for production to be cost-effective and successful. Looking at the information with a regional perspective, several key issues may be tackled: environment (CO_2 emission reduction, less wildfires, etc.), economic, society (employment, local development) and politics (more subsidies to promote bioenergy production from biomass).

References

Agência para o Investimento e Comércio Externo de Portugal (2008). Portugal - Perfil país. AICEP Portugal Global, Lisboa.

Agência Portuguesa do Ambiente (2008). Relatório do Estado do Ambiente 2007. Agência Portuguesa do Ambiente, Amadora.

Agência Portuguesa do Ambiente (2009). Relatório do Estado do Ambiente 2009. Agência Portuguesa do Ambiente, Amadora:.

Associação das Energias Renováveis (2010). Roteiro Nacional das Energias Renováveis - Aplicação da Directiva 2009/28/CE. Associação de Energias Renováveis, Lisboa.

Boyle, G. (2004). Renewable energy: power for a sustainable future (2 ed.). Oxford University Press, United Kingdom.

Cantrell, K.B., Ducey, T., Ro, K.S. and Hunt, P.G. (2008). Livestock waste-to-bioenergy generation opportunities. *Bioresource Technology*, **99**, 7941–7953.

Consultative Group on International Agricultural Research (2008). CGIAR – Consortium for Spatial Information. Retrieved August 19, 2008, from http://srtm.csi.cgiar.org/

Direcção Geral de Energia e Geologia (2005). Direcção Geral de Energia e Geologia Homepage. Retrieved November 5, 2010, from http://www.dgge.pt/

Environmental Systems Research Institute (2010). ArcGis 9.3 Desktop Help. ESRI, USA.

European Commission (2007). Evaluation report on the implementation in Portugal of the European sustainable development strategy – June (No. Tech. Rep. SG/743/07-EN). European Commission, Brussels.

European Environment Agency (2007). Estimating the environmentally compatible bioenergy potential from agriculture (No. Tech. Rep. 12/2007). European Environment Agency, Copenhagen.

European Parliament and of the Council (2007). Directive 2001/77/EC. Promotion of electricity produced from renewable energy sources in the internal electricity market. *Official Journal of the European Communities*, Brussels.

European Parliament and of the Council (2009). Directive 2009/28/CE. Promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Communities*, Brussels.

Gómez, A., Zubizarreta, J., Rodrigues, M., Dopazo, C. and Fueyo, N. (2010). Potential and cost of electricity generation from human and animal waste in Spain. *Renewable Energy*, **35**, 495–505.

Hansen, H.S. (2005). GIS-based Multi-Criteria Analysis of Wind Farm Development. Paper presented at the ScanGis 2005 – 10th Scandinavian Research Conference on Geographical Information Science, Stockholm, Sweden.

Instituto Geográfico do Exército (2010). Instituto Geográfico do Exército. Retrieved October 7, 2010, from http://www.igeoe.pt

Instituto Geográfico Português (2009). Instituto Geográfico Português. Grupo de Detecção Remota. Retrieved September 12, 2009, from http://www.igeo.pt/gdr/

Instituto Nacional de Estatística (2009). Estatísticas Agrícolas 2008. Instituto Nacional de Estatística. I.P., Lisboa.

International Energy Agency for Bioenergy (2009). Bioenergy – A sustainable and reliable energy Source (No. Main Report). s.l.: IEA Bioenergy.

Jiang, H.E., J.R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science*, **14(2)**, 173–184.

Malczewski, J. (1999). GIS and multicriteria decision analysis. John Wiley and Sons, Inc., USA.

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning*, **62**, 3–65.

Malczewski, J. (2006a). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, **20(7)**, 703–726.

Malczewski, J. (2006b). Integrating multicriteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach. *International Journal of Environmental Technology and Management*, **6(1/2)**, 7–19.

Masera, O.G., A., Drigo, R. and Trossero, M.A. (2006). WISDOM: A GIS-based supply demand mapping tool for woodfuel management. *Biomass and Bioenergy*, **30**, 618–637.

Ministério do Ambiente e Ordenamento do Território. (2007). Plano Estratégico para os Resíduos Sólidos Urbanos 2007–2016. Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa.

Population Reference Bureau (2010). 2006 World Population Data Sheet. Population Reference Bureau, Washington.

Ramachandra, T.V. (2008). Geographical information system approach for regional biogas potential assessment. *Research Journal of Environmental Sciences*, **3(2)**, 170–184.

Richardson, J. a. V., T. (2005). Sustainable bioenergy production systems: environmental, operational and social implications. *Biomass and Bioenergy*, **28**(Preface), 95–96.

U.S. Department of Energy (2009). Department of Energy. Retrieved June 23, 2009, from http://tonto.eia.doe.gov/oog/info/twip/twipcrvwall.xls#'Data 2'!A1

U.S. Energy Information Administration (2009). World Total Primary Energy Consumption by Region. Reference Case, 1990-2030. Energy Information Administration/International Energy Outlook. Retrieved July 27, 2010, from http://www.eia.doe.gov/oiaf/ieo/pdf/ieoreftab_1.pdf

World Commission on Environment and Development (1990). Our common future. Oxford University Press, USA.