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Spatial Analysis of Residual Biomass and Location of Future Storage Centers in the Southwest of Europe

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Abstract: Forests can be exploited for obtaining biomass, which belongs to a bioenergy group with great energy potential that could replace fossil fuels. This article presents a novel procedure to quantify, map and define biomass, which takes into account both environmental and economic issues. With regard to the environment, only the annual growth of tree species is considered, and not the previous stocks. The growth is determined by logarithmic equations through an original procedure supported by a biomass estimator, which represents the amount of biomass generated annually for energy use, and by means of Excel tables, the exploitable biomass values are obtained. Previously, and by using GIS, areas with slopes exceeding 20% are discarded, thus avoiding soil erosion and damage, and in any case that biomass is not extracted for economic reasons. The same procedure is followed, discarding those areas located more than 4 km from forest roads and runways, as transport costs are increased. Finally, those layers with low energy potential are eliminated as well. Therefore, annually selected quantities of biomass can be obtained safely and abundantly by using detailed distribution maps of the resources, and through planning and performing efficient forestry extraction works.

Keywords: biomass estimator; energy resource; geographic information system; residual biomass

1. Introduction

It is necessary to analyze the use of biomass as a renewable energy resource and alternative fuel that nowadays could easily replace fossil fuels in certain territories where it is safe and plentiful.

Given the speed at which the characteristics of forested land are changing, it is difficult to establish the quantity of biomass that can be accessed at a given time. Forest fires, construction of new dams and changes in the use of holdings modify the quantity of forest origin biomass that can be used for energy purposes. Therefore, the use of geographic information systems (GIS), based on regularly updated maps and satellite photos, is particularly useful because it allows a straightforward and fairly reliable quantification of the resources available in the area under study.

There are specific regions in the south-west of Europe with a common ecosystem called "dehesa" [1]. It is a unique space of mountains and plains, well delimited and wooded, frequently used for pastures, and has a great diversity of flora and fauna, where pigs, sheep, cows, bulls and horses, among other animal species are fed. The most important arboreal species are oaks, cork oaks, pines, and above all, holm oaks. These trees are great economic and social importance in the west of the Iberian Peninsula. As this region is affected by extreme changes in temperature, the biomass obtained for energy use can significantly contribute to the production of cold and heat.

The use of GIS for the evaluation and the spatial study of biomass is not recent. As an example, there was a study conducted in Tennessee (USA) in 1996, which consisted of a spatial distribution of forest biomass in several layers and substrates in order to establish the possible placement of thermal plants [2].

GIS has also been used to map the spatial production of biomass and its quantification for various uses, such as wood production, energy, industrial and domestic use, among others [3–5]. There are other studies evaluating regional biomass and their energy potential by using different mechanisms, such as allometric equations, to activate markets and promote thermal use [6–10]. Furthermore, several other studies have used GIS by considering geographical limitations as well as uncertainties associated with biomass, obtaining spatial representations [11]. Therefore, GIS allows a spatial mapping of the crops and their quantification [12–16].

The potential quantity of energy from each crop or species is associated, within the GIS, with the code used in the corresponding municipality and region maps. The addition of the energy values for each crop yield results in a single value of the biomass energy potential by municipality [17–22].

One of the major challenges of biomass management is the optimization of costs regarding its collection and transport, which has prevented it from becoming an important economic activity, slowing down its development. As it will be explained later, GIS techniques are particularly useful in assessing the costs of biomass supply at a regional level, and hence they support decision-making issues in a given area [23,24].

It has worked with several georeferenced databases that make it possible, on the one hand, to handle a large volume of data and perform numerical calculations, and on the other, to map the results by obtaining distribution maps of the different variables studied. The two main variables are the amount of biomass available for energy use and its energy potential. A third significant variable has been introduced for certain analyses, namely energy density [25].

For a particular forestry species, the amount of useful biomass generated annually for energy use is called "residue estimator", and it is a specific parameter that allows the quantification of waste. Therefore, it will vary depending on the forest species under study. An original methodology different from that of other authors was used to obtain the estimators, as discussed below [26,27].

In this article, the process consists essentially of three stages: Firstly, the available area was assessed depending on various technical and environmental conditions, secondly, the annual amount of generated biomass was measured and, finally, its potential was assessed after energetic characterization.

Ćosić et al. (2011) developed a methodology to analyze the energy potential of biomass and to evaluate the cost of biomass considering transport distance, transport costs and the size of power plants. However, they did not identify the most suitable areas for obtaining forest biomass [28].

Velázquez-Martí et al. (2011) quantified the available residual biomass obtained from pruning olive trees in Spain [29]. Gil et al. (2011) used a GIS-based method to assess the geographic distribution of residual forest biomass for bio-energy in a Spanish region through the forest statistics data on the area of each species, considering the fraction of vegetation cover, land slope and protected areas [30].

On the other hand, Viana et al. (2010) assessed the potential quantities of forest biomass residues available in Portugal and examined the feasibility of producing electrical thermal energy [31].

The GIS tool has made it possible to use and combine various data sources such as the Inventario Forestal Nacional (IFN) 2017 [32], the digital terrain model of the Junta de Extremadura (2012) [33], Communications Map and that of municipalities in the province of Badajoz [34], as well as European production and consumption of biomass [35] and the characteristics of forest products in the environment [36].

The aim of this article is to present a novel procedure to quantify, map and define biomass, which takes into account both environmental and economic issues. It also aims to provide a useful tool that is able to plan and manage the energy resources of a region.

2. Materials and Methods

The province of Badajoz in Extremadura, which is located within the most important dehesa area of the Iberian Peninsula, has been taken as a case study. This is an original procedure: the quantification of biomass is carried out using biomass estimators, which follow criteria of environmental sustainability, as in previous cases [37], and have geographical limitations (distances and slopes). Consequently, storage centers to promote local forest biomass markets and encourage their thermal use are established [38].

The groups of forest species considered are included in the National Forest Inventory (IFN3). In the case example (Badajoz), the predominant species, in percentage, are *Quercus ilex*, *Quercus suber*, *Eucalyptus camaldulensis*, and *Pinus* spp., as it is shown in Table 1. Other existing species are less important, with a percentage lower than 0.5%, and globally accounting for less than 1.5%.

Table 1. Distribution of forest species according to the IFN.

Species	%	Species	%
Alnus glutinosa	<0.5	Pinus pinea	2.4
Castanea Sativa	<0.5	Populus C.	<0.5
Cupressus sempervirens	<0.5	Quercus f.	<0.5
Eucalyptus camaldulensis	6.1	Quercus ilex	81.0
Eucalyptus globulus	0.7	Quercus pyrenaica	<0.5
Fraxinus angustifolia	<0.5	Quercus suber	8.0
Pinus halepensis	<0.5	Ulmus minor	<0.5
Pinus pinaster	1.1	Populus nigra	<0.5
Salix spp.	<0.5	Tamarix spp.	<0.5

2.1. Selection of Suitably Exploitable Areas

As indicated above, the methodology to measure the annual amount of residual biomass or residue produced by the forests, and the potential amount of fuel for energy generation, needs previous information:

- Selection of the surface of the stratum that will generate the residue
- Selection of exploitable surface that does not meet certain conditions.

Total exploitable surface biomass was calculated as the difference between the forest area that generates biomass and the generating biomass that does not meet appropriate conditions for extraction. Therefore, it is necessary to previously determine both surfaces. To determine these two surfaces with the support of the GIS, it was necessary to use the information contained in the IFN (files in e00 format), corresponding to the province of Badajoz. All the following methodology is shown in Figure 1.

The surface occupied by stratum is obtained from IFN, eliminating stratum 0, because it is not forest (rivers, towns, roads, etc.). As mentioned above, it is meant to introduce in the study environmental and economic considerations that nowadays limit the energetic exploitation of the forest biomass residues. In this sense, the biomass waste should not be extracted from areas showing high slopes, difficult access or if it is too far from the transport network. Therefore, biomass residues from areas with a slope over 20% were discarded in order to prevent erosion and soil damage. It was proved that the cost difference between harvesting biomass on land with slopes over 20% is much higher than on lower slopes, as, even though it is possible to collect biomass, yields vary considerably. Some authors have determined the increase involved in biomass extraction on slopes greater that 20% [39]. Furthermore, the extraction of biomass from these slopes determines changes in soil erosion and loss thereof, as well as nutrient loss and variation of runoff, which could introduce changes in biomass growth and cause unwanted environmental harm.

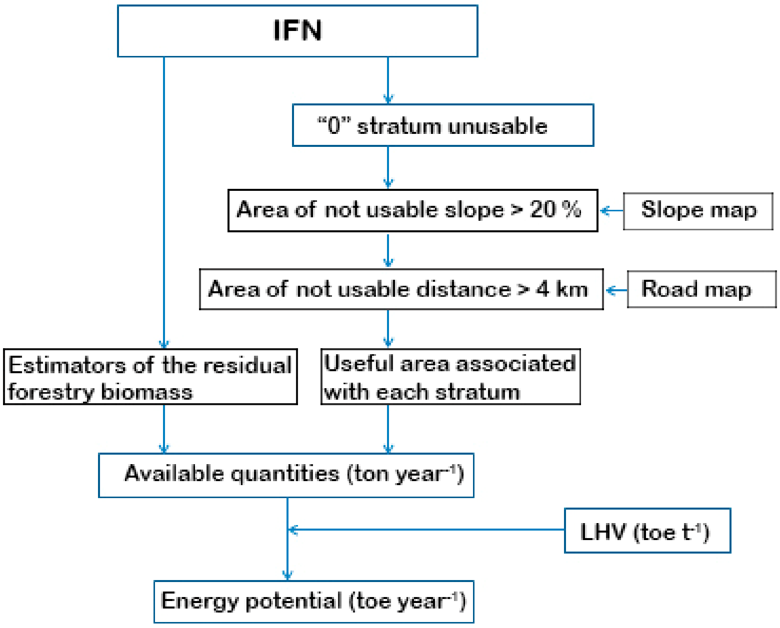

Figure 1. Methodology to estimate the energy potential from forest biomass.

After all, they lack economic feasibility. Here is the procedure we followed, on surfaces in the province of Badajoz, with a slope lower than 20%:

- i Depending on the slope percentage map, areas with a slope under 20% are classified as 1, and those over 20% are classified as 0.
- ii GIS is used to link the grid model and unify all those slope layers under 20%.
- iii A new layer was created with all those new polygons that met the required criteria.
- iv The entire forested area that may produce forest residues (i.e., that from the IFN) was replaced by the layer of exploitable area in the total zone.

An aptitude layer with the preference areas was set in order to ensure that only the forest residues from the areas close to roads and pathways were included. The selected limit distance criterion for financial viability was set at 4 km from any pathways or roads of the transport network. It was estimated that greater than 4 km distance without appropriate forest roads, adds to the costs of biomass extraction substantially. For this, several studies were considered, such as Graham et al. [40], which estimated the average cost of biomass extraction at 53 €/dry ton, and the average cost of €7 per transport km. This means that 4 km transport costs €28 per dry ton, an amount that is more than 50% of the total cost, which determines the unfeasibility of extracting the biomass. The results obtained are shown in Figure 2, were map represents the exploitable area.

The area occupied by protected natural areas belonging to the Red Natura has also been considered. It should be noted, in this regard, that logging and silvicultural treatments are allowed in most of these areas. For these reasons, in a first approximation, the forest biomass of these spaces has been taken into account.

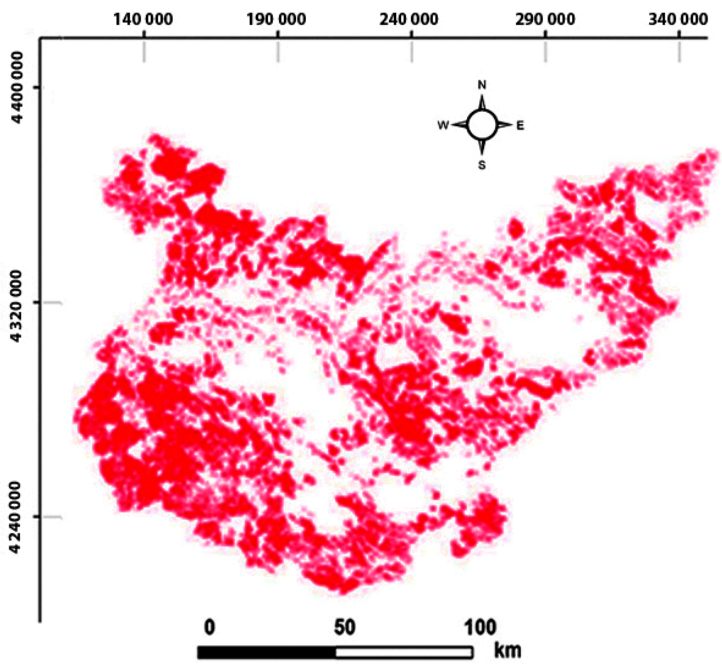

Figure 2. Map of forest exploitable area.

2.2. Determination of Available Forest Biomass

We understand the term forest biomass, in its broadest sense, as the whole forest mass at a given point in time. Stocks and annual increases should be considered. Stocks are defined as the quantity of biomass that exist at the time the forest inventory is made. They are not considered for the calculation of potential due to environmental sustainability issues, as already indicated, so that only annual growth has been included. The purpose of this increase was divided into three different criteria: domestic and industrial use of wood, production of energy and ecological recovery (keeping in mind that woodland is a CO_2 collector and its leaves contribute to soil restoration). Figure 3 shows several forest biomass types.

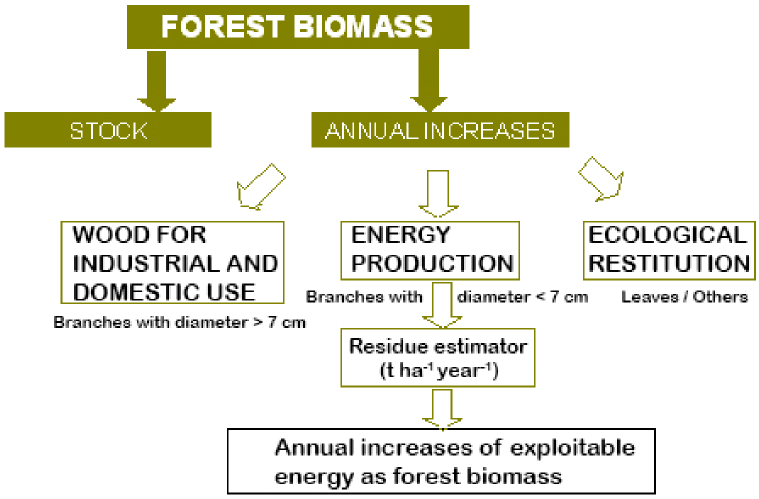

Figure 3. Destinations of forest biomass wastes.

It must be highlighted that in this type of region, the dominant area (around 50%) is the dehesa with medium-density wooded vegetation of around 39% covered surface and substrata mainly consisting of pasture species. The remaining soil (11.27%) consists of forests, mainly *pinus pinaster*, and scrubland [41].

The current legislation prohibits the commercial use of this wood in the timber industry, it is only allowed in forestry/silvicultural activities, and their residues can be used for such purposes.

The fractions of trunks and thick branches are normally used as raw material for the timber industry. On the other hand, the leaves must not be picked up so they can help the ecological restoration of the soil. Considering all this, only the branches with diameter below 7 cm were selected for the quantification of the available biomass for energy use. The only exception was the eucalypt, for which all fractions were quantified because clearcutting is allowed and also there is no other current use for such species in our region.

Therefore, although the biomass fractions established are considered, we referred to aerial biomass because the biomass of the radical part is not used, not only for environmental, but also for financial reasons considering the cost of its extraction. Thus, the following biomass fractions are considered:

Tree bole	
Branches with a diameter greater than 7 cm	R > 7 cm
Branches with diameters between 2 and 7 cm	R 2–7 cm
Branches with a diameter less than 2 cm	R < 2 cm
Leaves	

The methodology was based on calculating the annual increase of forest biomass from branches with a diameter less than 7 cm (including pruning and natural fall), which are what in this article have been defined as estimators of forest biomass. Both calculations and results are grouped by stratum. A stratum characterizes the type of forestry in a given area, depending on the species present, condition of the forestry mass, and the fraction of forest covered. Consequently, it is a statistically homogeneous group, which represents the bulk of biomass generated annually, and is the key variable under study in the work. The mapping information was key to measure the area covered by each species, in order to optimally calculate the biomass it would generate. Each stratum was identified by a number. The geographical distribution of the strata in the province of Badajoz is shown in Figure 4.

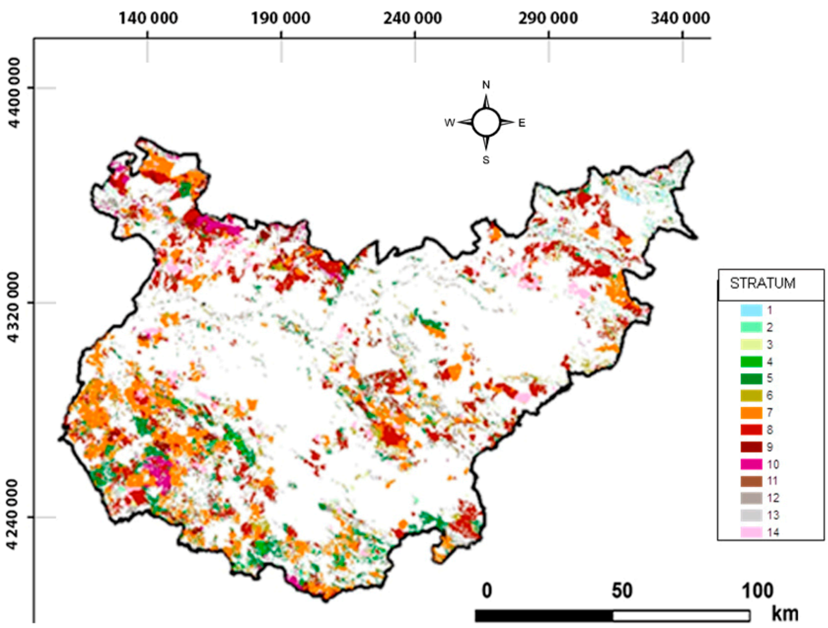

Figure 4. Distribution of strata in the province of Badajoz.

We used a method based on the logarithmic model proposed by Montero et al. [42], which connects the normal tree diameter (diameter of a tree when measured at a distance of 1.3 m over the average ground level, expressed in cm), with the net dry biomass or any of its fractioning. The logarithmic model is used as Equation (1),

$$\text{Ln B} = \text{a} + \text{b Ln } (\text{D}_\text{n}) \quad (1)$$

where D_n is the normal diameter, a and b are two specific regression parameters shown in Table 2, and B is the biomass for each fraction. BT is the total aerial tree biomass, BF is the tree bole biomass, BR_7 and BR_2 are the biomass from branches with a diameter between 2 and 7 cm and less than 2 cm, respectively, BA is the biomass needles, BH is the biomass from leaves and Br is the root biomass. All are expressed in kg of dry matter.

Table 2. Value of parameters a and b for each test species and biomass fraction.

Y	**Species**							
	Pinus pinaster Ait.		**Quercus ilex L.**		**Quercus suber**		**Eucalyptus camal.**	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
BT	−3.00347	2.49641	−2.31596	2.47745	−3.36627	2.60685	−1.33002	2.19404
BF	−3.43957	2.56636	−1.99607	2.01754	−3.01942	2.25213	−2.20421	2.38196
BR_7	−23.0418	6.52359	−5.3470	3.04363	−6.43076	3.21136		
$BR_{2\text{-}7}$	−6.66264	2.63946	−2.52588	2.00304	−3.3924	1.99526	−2.67562	1.87183
BR_2	−4.66658	2.38009	−2.66407	1.97498	−5.33638	2.10315	−2.64825	1.61429
BH	-	-	−4.13268	1.97313	−6.05826	2.14483	−2.05864	1.61762
Br	−3.85184	2.37592	−0.73028	1.7893	−2.81593	2.07774	-	-

With the objective of eliminate the bias added by logarithmic transformation, the results was multiplied by a correction factors (a and b), that was obtained from the standard deviation of the estimate.

By using Equation (2), we obtained the biomass annual increase. The annual biomass weight increase for a given biomass fraction, species and diametric class was defined by the difference between the dry biomass of two consecutive years.

$$\text{IB} = \text{f } (\text{D}_\text{n} + \text{ID}_\text{n}) - \text{f } (\text{D}_\text{n}) \quad (2)$$

where D_n is the normal diameter (cm), ID_n is the annual diameter increase (cm) and IB is the annual biomass increase in kg of dry matter.

The increases in the different fractions of annual biomass measured in kg of dry matter per tree, for each species and diametric class, were obtained through an application of their own, using Equations (1) and (2) [43,44]. This application was perform in Excel Tables, which allowed all kinds of operations and jobs. Once the growth values are obtained using the previous expressions and tables, it is necessary to calculate the average values corresponding to the different fractions for the 14 broadleaf tree species under study.

The final use of the annual increments, i.e., the fractions previously established, are classified according to the traditional purpose of the different fractions, that is to say:

Domestic and industrial use of wood	Tree bole and R > 7 cm.
Energy production	2–7 cm and R < 2 cm.
Ecological recovery	Leaves

With the previous scheme, and based on the above Excel tables, the biomass growths available for each stratum are calculated in accordance with the indicated assigned groups. As an example, Table 1 lists these results for *pinus pinaster.*

The IFN inventory, for the province of Badajoz establishes the amount of trees per hectare (tree/h). Applying the values we collected above (Table 2), we obtained the residual forest biomass estimators (y). This is shown in Table 3 (ton/ha of dry biomass). Therefore, these estimators represent the annual increase of biomass per species and diameter.

Table 3. Annual increases of biomass per species and diametric class (kg/tree).

Diametric Class (cm)	Annual Increase of the Different Fractions of Biomass (kg/Tree)	
	Branches 2.7 cm	Branches < 2 cm
5	0.00	0.07
10	0.44	0.25
15	0.47	0.54
20	0.31	0.82
25	0.43	1.08
30	0.58	1.39
35	0.71	1.63
40	0.92	2.03
45	1.08	2.36
50	1.28	2.67

The estimators also helped to calculate and map the results using the GIS by assigning these estimators to a particular area of influence composed of cells (cell: enclosed unit with some kind of vegetation cover in the inside, different from the surrounding cover. The cell size can vary, with a minimum surface of 2.5 ha).

The area of each cell was used in order to account for just the available forest biomass. In these areas, those zones with a slope over 20% and/or located further than 4 km from roads or forest tracks were excluded.

It is not intended in this research to determine the total cost precisely. So it only took into account the costs of collection and transport, as a measure to improve the utilization of biomass. The annual amount of dry biomass available, once the estimators were calculated, was obtained by Equation (3):

$$Q_{av} = \sum_{n} A_n y_n \tag{3}$$

where A_n is the exploitable area in the cell (ha), y_n is the annual residue estimator (ton/ha) and Q_{av} is the annual amount of available dry biomass in cell n (ton).

Finally, the stages to determine the available biomass, through GIS, were the following: (i) Importation of the estimators (Table 4) to the attribute table of the exploitable area layer. (ii) Calculation of the amounts of biomass from the GIS database [45]. (iii) Graphic representation of the results.

Table 4. Estimators of dry forest biomass residues according to the stratum and dominant species.

Stratum	Dominant Species	y (ton/ha Dry Biomass)
01	Pino pinea and Pinus pinaster	1.035
02	Pino pinea and Pinus pinaster	0.462
03	Quercus ilex and Quercus suber	0.172
04	Quercus ilex with other hardwood species	0.443
05	Quercus ilex	0.235
06	Quercus ilex	0.833
07	Quercus ilex	0.398
08	Quercus ilex	0.165
09	Quercus suber and Quercus ilex	0.517
10	Quercus suber	0.258
11	Eucalyptus camaldulensis	7.453
12	Eucalyptus camaldulensis	4.893
13	Shrubs	0.115
14	Quercus ilex	0.202

It should be noted that the criteria adopted to quantify the annual production of biomass for energy use were set accounting for the sustainability of the resource over time. Final results should therefore be regarded as conservative.

2.3. Calculation of Energy Potential

The biomass potential is defined as the total annual production of energy from the biomass generated by the residues considered in this article. The theoretical biomass potential represents the total amount of waste from forestry operations on the selected species suitable for energy use that is generated in a particular region. This quantity can be regarded as the upper bound of energy that can be actually derived from this kind of residue. The available biomass potential is defined as the amount of energy contained in the biomass that might be technically and economically used for energy purposes. To determine the available forest biomass potential, the following expression was used:

$$P_{av} = Q_{av}\ x\ LHV \quad (4)$$

where LHV is the lower heating value (toe/t), Q_{av} is the annual amount of available dry biomass, P_{av} is the available forest biomass potential (toe) and LHV the lower heating value.

The lower heating values used to determine the energy potential of the different types of biomass are listed in Table 5 [46]. The available potential was estimated according to the lower heating values on a dry basis.

Table 5. Heating values of the residues under study. LHV wb = Lower heating value wet basis. LHV db = Lower heating value dry basis.

Biomass Residues	LHV wb MJ/kg	LHV db MJ/kg
Eucalyptus wastes	14.96	15.97
Pine wastes	9.09	18.60
Cork oak slash	1.60	16.90
Holm oak slash	14.33	17.58
Oak slash	13.10	16.60

3. Results

It is important set the location and features of the generated waste, that is, distance to the exploitation zone and usage. In fact, a large number of authors consider that residues should not travel more 30 km from their origin [39].

Both the geographical data representation and subsequent implementation of spatial analysis were obtained by GIS. This allows one to compute the area where the residues are concentrated and/or the ways it is possible to concentrate them, so that a regional distribution of waste is plotted.

Apart from providing the geographic distribution of the variables under study, biomass and energy potential data, grouped by municipalities, are also provided. The available variables regarding municipalities are:

i Amount expressed in ton/year for a given municipality.
ii Energy potential expressed in toe/year for a given municipality.
iii Energy density for a given municipality (toe/ha year).

The latter variable is defined as the amount of energy per unit area. It provides crucial information, complementary to the energy potential, because it allows the identification of municipalities that achieve higher energy potential regardless of their area. A georeferenced database containing layers with all available and calculated information was generated. Information regarding such a database is described along the following subsections.

3.1. Geographic Distribution of the Variables Under Study

Considering the data obtained from IFN and the exploitable area together, it is possible to map the distribution of the forest species for the area of Badajoz, as shown in Figure 1. By selecting "quantities" as a variable, we obtain the map of the forest biomass geographic distribution for energy use (see Figure 5).

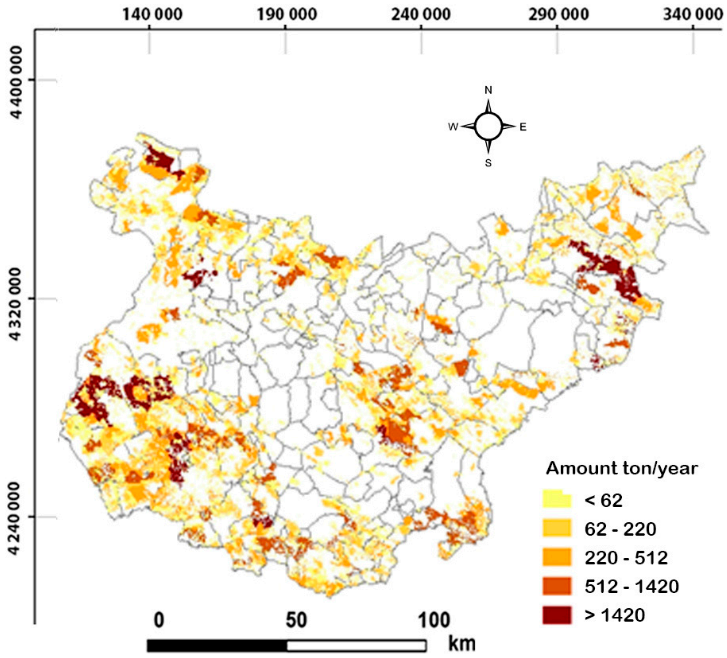

Figure 5. Geographic distribution of the forest biomass for energy use in the province of Badajoz.

Similarly, Figure 6 shows the mapped geographical distribution of the energy potential in the province.

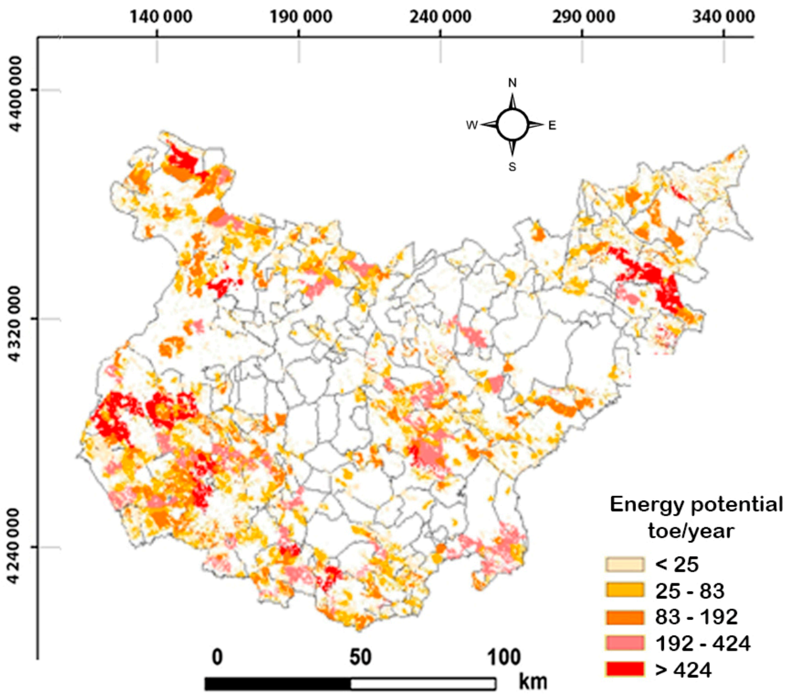

Figure 6. Geographic distribution of the energy potential in the province of Badajoz.

3.2. Municipality Level Data

The amounts of biomass in the province of Badajoz and their energy potential were grouped according to the municipality where they were generated. To that end, the GIS-based management tools and the information contained in the map of municipalities were of particular interest. Thereby, the maps shown in Figure 7 were obtained.

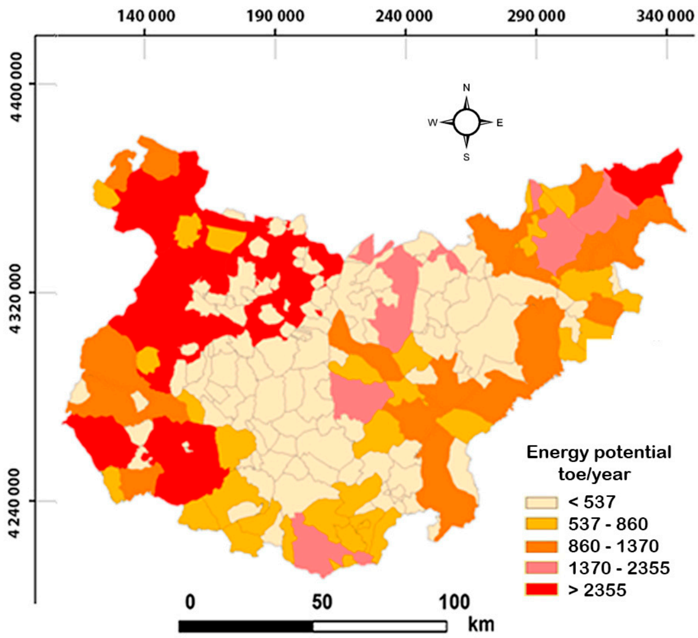

Figure 7. Energy potential per municipality.

Energy density (i.e., the amount of available energy per unit area) is an interesting parameter for the local administrations. The energy density map at the municipality level was arranged as shown in Figure 8.

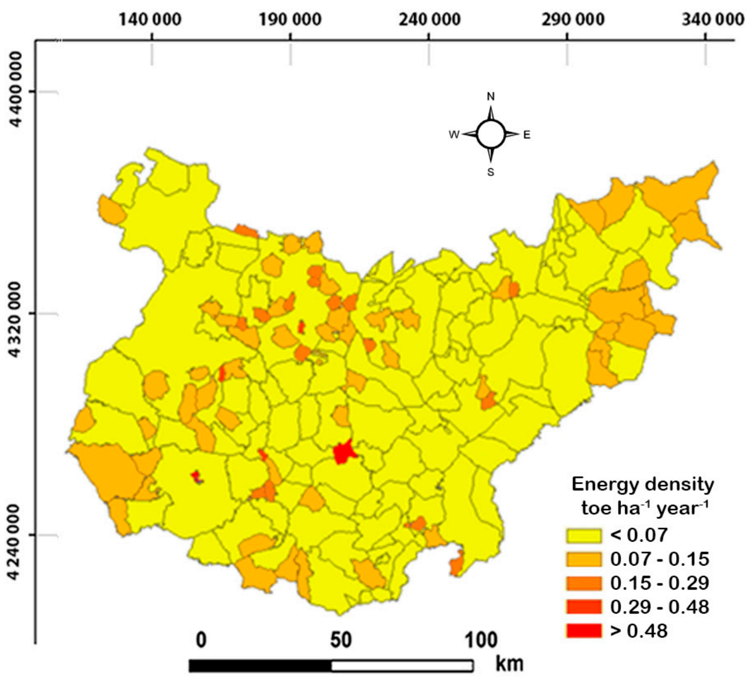

Figure 8. Energy density at municipal level.

3.3. Location of Storage Centers of Forest Biomass

By using the information and methodology described above, the GIS analyzed the optimal location to install forest biomass storage centers (see Figure 9). Neither the areas where the energy potential was low, nor those with some kind of inadequacy, were considered, due to orography, natural protected areas, distance to roads and absence of watercourses.

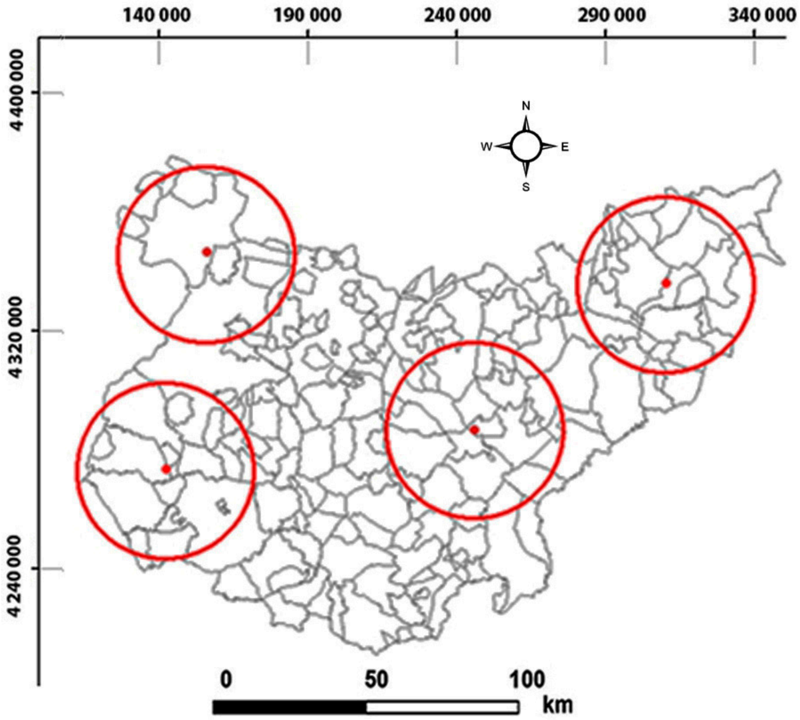

Figure 9. Ideal location of forest biomass storage centers.

We selected those points with a higher concentration of biomass and the surrounding areas were analyzed with GIS. This procedure permitted addition of all the pixels contained in the neighboring areas in a 30 km radius (due to biomass transportation costs). A grid consisting of square pixels (100 m long each) was used to compute the amount of dry biomass per year around the lattice points.

The areas included in the Natura 2000 Network were considered. Using the overlaying procedure, the selected areas were checked not to overlap any protected zone. Municipalities of Table 6 could be considered as optimal for the location of future storage centers of forest biomass. They are close to the main cities in the region and they provide quite good transport of the biomass [47].

Table 6. Location of future storage centers forest biomass.

Municipality	Amount of Biomass Available Ton/Year (30 km Radius)
Alconchel	36.030
Higuera de la Serena	22.169
Alburquerque	29.436
Puebla de Alcocer	36.262

4. Discussion

It is important to take into account environmental and economic issues in order to establish the quantity of biomass available in a certain region. With regard to environmental conditions, an appropriate management of the vegetation in the area must be considered. Therefore, as a first step, a selective tree extraction should be carried out [48]. For this reason, the annual growth of the arboreal species and their extraction is explained, based on pruning, cleaning and silvicultural activities, which in any case should not harm the flora species.

To this end, in this study the biomass obtained was classified into three groups depending on its purpose: tree bole, branches and leaves. Only a limited fraction, corresponding to branches with a diameter of less than 7 cm, was chosen for energy use, thus avoiding indiscriminate felling in forested areas and those with little environmental monitoring.

Those areas occupied by protected natural areas, belonging to Red Natura, were also considered. It should be noted, in this regard, that logging and silvicultural treatments are allowed in most of these zones. For these reasons, as a first estimation, the potential of forest biomass of these spaces was analysed.

From an economic perspective, one of the main disadvantages of biomass is the cost it generates by its collection and transport, which may explain its scarce use. At present, it would be interesting to promote its usage as a renewable energy in order to increase decarbonization of the economic activity [49].

For all the above reasons, in our research, the extraction of biomass in areas with slopes greater than 20% was ruled out, for not being economically profitable. Additionally, problems of soil loss due to erosion and landslides (which could be considered as an added environmental activity) were avoided [50]. As a result, an extraction layer with slopes of less than 20% was generated.

In line with the above, the idea is to extract and use biomass from areas that are well communicated, so we proceeded to generate a layer with an optimal location, depending on their proximity to roads and paths. To this purpose, we selected areas less than 4 km away from communication routes, criterion which reduces transport costs considerably. Eucalypts, which can be cut down and replaced by native species, could be another important source of biomass in the southwest of Spain.

To date there are no plans and/or support from the Public Administration addressing collection and transport of biomass, meaning that it must be transported from other regions to the few thermal power plants that work in the southwest areas [51]. Therefore, this research could help to encourage and improve the economic activity generated out of biomass [52].

Finally, the procedure described here is novel, as a series of original actions have been introduced, including:

(i) Determination of layers of biomass extraction by plant species, excluding those areas "cut" with the GIS, such as those with a slope higher than 20% and those further away from roads and forest roads (over 4 km).
(ii) Creation of specific Excel tables that collect the growths of the fraction of annual biomass in kg of dry matter per tree, and using logarithmic equations, as shown in Table 2.
(iii) Classification of biomass in fractions, so that only diameters between 2 and 7 cm, and diameters smaller than 2 cm are used for energy production.
(iv) Use of residual forest biomass estimators that represent the annual increase of biomass for energy use, which may be the greatest contribution of this procedure.
(v) And finally, optimal location of storage centers, taking into account that biomass supply areas should be restricted to distances less than 30 km from the storage center, due to transportation costs.

5. Conclusions

In the present article, our methodology has focused on mapping and quantifying biomass in southwestern European regions, although it is possible to apply it to any region in the world, as long as there is enough energy potential from the waste of tree species in the area and the growth data are available.

The location of storage centers, will not only be established by the collection center, but also by other circumstances, such as the conditions of the promoters, cost of the land and availability of the labor, among others.

After quantification and subsequent recovery of waste coming from forest biomass, it is possible to obtain the quantities and energy potential of the area under study. For example, in the province of Badajoz, 274,335.36 tons of annually available forest residues could be collected, which could give an energy potential of 112,548 toe.

The above values are only approximate, the actual quantities depend on the frequency of silvicultural treatments that generate them. These are the competency of the Public Administrations, who are responsible for carrying out a forestry plan in order to intensify, as far as possible, the works of clearing and silviculture, thus planning and sorting the forest resources.

Finally, it should be mentioned that, depending on the development of forest harvesting techniques and guarantee of continuous and assured supply in terms of quality, the forest residues considered in this work could replace, at least in part, the fossil fuels that are used today.

In the times when the economy is being decarbonized, by replacing traditional fuels with renewable or biofuels, the planning of forest resources and their management is essential to establish and promote a market of biomass industry, a condition that many European regions could take advantage of.

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