Energy potential of native shrub species in northern Spain

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1. Introduction

Spain is a country with a low rate of energy self-sufficiency. In the mid-1990s, the state energy policy encouraged the use of renewable energy, including a reward system. In the field of renewable energy, biomass is an important option.

Cantabria (on the northern coast of Spain) is located at latitude 43º 28'N and longitude 3º 48'W. In this region, more than 27% (Table 1) of the forest-use surface is not occupied by trees but by shrub species of no economic value. The shrub is composed of multiple species distributed heterogeneously over the terrain (land surface), although in each area, one particular species tends to predominate over the others because of soil parameters [1] (e.g., organic matter, depth of bedrock, pH, chemical composition, texture). The shrub species adapt well to the environment (reduced water consumption, low fertility requirements, and low soil pH) with acceptable productivity and good calorific value [2]. The search for new sustainable energy sources to help alleviate the dependence on fossil fuels makes waste shrub an attractive target.

Table 1. Forest surface of Cantabria [1]

Use	Hectares (ha)	%
Forest covered by trees	209,611	39.4
Forest covered by scrub	145,201	27.3
Total forested	359,458	67.5
Total region	532,139	100

Several studies related to the energy characterisation of biomass from forest and herbaceous species have been published in the scientific literature [3-11]. This study examines a type of biomass consisting of shrubs that are native species of northern Spain. The shrub species grow in degraded soils of low fertility, where short rotation forestry productivity is low or zero. In this study, the shrub was evaluated with respect to energy and productivity with the goal of using it as a fuel to generate electricity. Productivity was estimated in tonnes per ha per year (t ha^{-1} yr^{-1}) for the most representative shrub species in the region, and the most significant variables with respect to energy were determined, i.e., the gross calorific value (*GCV)* (applicable when the water generated in the combustion was in a liquid state), the net calorific value (*NCV)* (applicable when the water generated in the combustion was in a gaseous state), density, elementary chemical analysis, weight percentage of ash after combustion and fuel value index (*FVI*). These values were determined for three values of moisture (high, medium and low). The ash content generated in combustion and the effect on the *FVI* influences the design of boilers because of, for instance, corrosion, adherence of dirt and heat transfer [12, 13]. The *FVI* is an important characteristic for screening desirable fuel species [14].

2. Material and Methods

The species analysed in this work were *Rhamus alaternus, Ulex europaeus, Prunus spinosa, Smilax aspera, Erica cinerea, Rubus ulmifolius* and *Pteridium aquilinum*. These species represent the shrubs of Cantabria in different proportions, depending on the region. *Rhamus alaternus, Ulex europaeus* and *Prunus spinosa* are all bushes; thus, the native shrub was divided into twigs (leaves + branches less than 6 mm in diameter) and wood. Both twigs and wood were weighed to determine their relative contribution. The other species are herbaceous; therefore, stems and leaves were crushed to analyse them. To quantify the amount of biomass of each species analysed, areas occupied by shrub were cleared and weighed, and the amount of biomass per ha per year was subsequently estimated. To conclude, an economic analysis of the recovery of this shrub in terms of power plant fuel was performed.

For a study of this type to be useful, the results must be representative, which depends on the sampling process. To estimate the productivity, each species was selected and sampled in two different places in the region where that species was dominant. The areas of the plots range from 2 to 5 hectares. Within each plot, 5 cuttings were taken with areas of 10 m^2 each at approximately 5 cm in height. Next, the shrub was weighed to determine the weight per unit of area cut. *Rhamus alaternus, Ulex europaeus* and *Prunus spinosa* were divided into twigs and wood (including bark), weighing each fraction wet in the field.

Simultaneously, samples were collected to analyse moisture at the time of cutting. These samples were transported in sealed polyethylene bags to prevent moisture loss. Dry weight values were thus obtained from the moisture of the green samples.

Once in the laboratory, the moisture was analysed (high humidity) from five sub-portions of each sample, and the *GCV* was determined from another five sub-portions. The remaining ashes were weighed, and the density was calculated from another five sub-portions using the volume of displaced liquid method [15]. The remainder of the sample was allowed to dry naturally for 2 months. During this time, the same analyses were repeated for medium and low moisture. The moisture ranges were 65%-40%, 35%-20% and 10%-2% for high, medium and low moisture, respectively.

The *NCV* is determined from the *GCV* according to the following equation [16]:

$$\mathrm{NCV} = \mathrm{GCV} - 2{,}442 * 0.01 * (\mathrm{H_b} + \mathrm{H_a}) - 2{,}442 * 0.01 * 9 * \mathrm{H_d} \quad , \qquad (1)$$

where H_d is percent of hydrogen in the dry sample, H_b is percent moisture in the sample and H_a is percent humidity in the air during the combustion.

To compare the fuel quality characteristics of the species studied, the FVI was calculated for different degrees of moisture using equation (2) as follows [15]:

$$\mathrm{FVI} = \frac{\mathrm{GCV\ (kJ\ g^{-1})\ x\ Density\ \ (g\ cm^{-3})}}{\mathrm{Ash\ content\ \ (g\ g^{-1})\ x\ Moisture\ content\ \ (g\ g^{-1})}} \,, \qquad (2)$$

where $g\ g^{-1}$ indicates that the weight is divided by the total weight.

The FVI calculation of *Ulex europaeus, Prunus spinosa* and *Rhamus alaternus* was performed using the combined weight percentages of wood and twigs.

The elementary chemical analysis (Carlo Erba1108) was provided by an external laboratory. In the field, to weigh the amount of biomass required, a hanging scale, PCE-CS model 1000, with a sensitivity of 0.1 kg, was employed.

In the laboratory, weighing was performed on an electronic balance, model Sartorius BP 121S, moisture analysis was performed with an analyser, model Sartorius MA145, and *GCV* determination was performed in a calibrated calorimeter, model IKA C 5000. The characteristics of these devices are described elsewhere [16].

Finally, a brief economic analysis was conducted of the impact generated by the use of 40% of the shrubs that cover the forest area in the region. This analysis focused on the revenue that would be generated by the exploitation of this resource, i.e., the analysis does not take into account the costs associated with harvesting and transporting the fuel to the power plant.

3. Results and Discussion

Table 2 shows the standard climatic characterisation of the areas where samples were taken. These values have an influence on vegetative growth and therefore on production, as well.

Table 2. Average climatic parameters for the sampling areas [17]

Climatic parameters	**Value**
Annual average temperature	14.0 °C
Annual average maximum temperature	18.3 °C
Annual average minimum temperature	10.0 °C
Annual average relative humidity in air	74.90%
Total accumulated rainfall per year	855.26 mm
Annual average wind speed	11.4 km/h
Hydric deficiency	99
Mediterraneanity index	2.4

The site is characterised by a climate with moderate temperature variation and regular rainfall. Long-term values for the mean air temperature and the annual rainfall are 14ºC and 855 mm, respectively. The Mediterraneanity index is 2.4 [18], indicating a small Mediterranean influence, primarily in the summer months, resulting in reduced growth from a lack of water. Table 3 shows the average weight percentage of twigs and wood in the shrub species found in the field trials.

Table 3. Average weight percentage of the wood and twigs in three species

Shrub species	Twigs (%)	Wood (%)
Ulex europaeus	27.22	72.8
Rhamus alaternus	28.75	71.3
Prunus spinosa	25.8	74.2

Table 4 shows the average *GCV*, the average *NCV*, the density and the percentage of ash from the combustion of shrub from each species at varying degrees of moisture. There is a strong influence of moisture content in the calorific value for all species. The most remarkable value is found in *Pteridium aquilinum*, in which the ratio between $NCV_{moisturemín}$ and $NCV_{moisturemáx}$ is greater than three. For the biomass from other species, this ratio is greater than two. This finding indicates the importance for this biomass to be dried in the field because it will reduce the cost of transportation to the power plant per ton of dry shrub. Table 4 shows that the genera *Erica cinerea* and *Prunus spinosa* have higher *NCV* values at low moisture, 17.5 MJ kg^{-1} and 17 MJ kg^{-1}, respectively. In addition to the calculation of the total shrub *NCV* of *Prunus spinosa*, the percentage in weight of the different parts (twigs and wood) and their respective *NCV* have also been calculated.

An ANOVA calculation was performed for one factor (species). This analysis revealed significant differences for the *NCV* (p-value < 0.05) between species. Using multiple comparison techniques (Newman-Keuls), two groups of *NCV* values appeared: a first group with a 16.79 MJ kg^{-1} *NCV* average (*Ulex europaeus, Rhamus alaternus, Prunus spinosa, Erica cinerea, Smilax aspera and Rubus ulmifolius*) and a second group (*Pteridium aquilinum*) with a 14.5 MJ kg^{-1}*NCV* average.
Shrub density drops as the moisture content of the samples decreases. The densities at low moisture vary from a maximum of 804 kg m^{-3} for *Ulex europaeus* to a minimum of 297 kg m^{-3} for *Pteridium aquilinum*.

For shrub species, the wood has greater density than the twigs. With respect to the ash content, twigs generate more ash. The twigs of *Rhamus alaternus* left more than 6.4% ash at low moisture. If the total ash is weighed, *Rhamus alaternus* left 3.4% at low moisture, which is lower than the amount of ash that *Rubus ulmifolius* produces, which was greater than 3.7%. High ash content is detrimental to the quality of the shrub as fuel. Moreover, this ash content provides an idea regarding the amount of nutrients extracted from the ground with the removal of the species. The ash content is generated in greater proportion in bark and leaves than in wood [16, 19]. The elementary composition is presented in Table 5.

Table 4. Average *GCV, NCV*, ash percentage and density of the species studied

Shrub species	Moisture	GCV (MJ kg−1)	NCV (MJ kg−1)	Ashes (%)	Density (kg m−3)

Ulex europaeus					
Thin branches	max	10.1 ± 0.2	7.4 ± 0.6	1.7	879
	med	17.7 ± 0.1	16.0 ± 0.9	2.9	638
	min	18.7 ± 0.09	17.1 ± 0.1	2.95	663
Wood	max	11.3 ± 0.2	8.9 ± 0.2	0.43	1022
	med	16.3 ± 0.1	14.5 ± 0.9	0.49	923
	min	18.2 ± 0.2	16.6 ± 0.8	1.32	802
Rhamus alaternus					
Thin branches	max	8.6 ± 0.1	5.7 ± 0.7	6.53	952
	med	13.8 ± 0.3	11.6 ± 0.9	5.81	728
	min	18.2 ± 0.2	16.6 ± 0.2	6.47	526
Wood	max	11.9 ± 0.1	9.6 ± 0.05	0.32	986
	med	15.7 ± 0.2	14.0 ± 0.3	1.15	859
	min	18.0 ± 0.1	16.5 ± 0.6	2.19	781
Prunus spinosa					
Thin branches	max	7.9 ± 0.1	5.0 ± 0.2	7.7	681
	med	15.8 ± 0.3	13.8 ± 0.1	5.6	492
	min	18.9 ± 0.08	17.3 ± 0.1	2.8	428
Wood	max	11.3 ± 0.05	8.8 ± 0.2	0.61	997
	med	13.5 ± 0.09	11.5 ± 0.1	0.48	887
	min	18.6 ± 0.2	17.0 ± 0.1	1.83	789
Erica cinerea					
	max	16.1 ± 0.1	13.8 ± 0.1	0.66	1018
	med	17.7 ± 1.3	15.8 ± 0.1	1.26	851
	min	19.1 ± 0.06	17.5 ± 0.1	1.24	658
Smilax aspera					
	max	9.1 ± 0.2	6.5 ± 0.1	1.79	541
	med	12.7 ± 0.08	10.3 ± 0.3	3.74	421
	min	18.5 ± 0.09	16.9 ± 0.3	2.95	313

Rubus ulmifolius					
	max	9.4 ± 0.07	6.7 ± 0.5	3.89	689
	med	16.2 ± 0.1	14.4 ± 0.1	3.59	475
	min	17.7 ± 0.1	16.2 ± 0.1	3.74	440
Pteridium aquilinum					
	max	7.9 ± 0.2	4.8 ± 0.6	6.49	502
	med	13.0 ± 0.1	10.7 ± 0.8	3.68	384
	min	16.3 ± 0.1	14.5 ± 0.1	0.47	297

Table 5. Results of chemical analysis for dry samples

Shrub species	C	H	N	O (by diff.)
Rhamus alaternus	49.02	6.32	1.56	43.1
Ulex europaeus	48.05	6.58	2.35	43.02
Prunus spinosa	50.01	7	2.14	40.85
Smilax aspera	47.01	6.04	1.98	44.97
Erica cinerea	51	6.19	1	41.81
Rubus ulmifolius	45.98	6.01	2.24	45.77
Pteridium aquilinum	46.01	5.75	1.74	46.5

By combining *GCV*, moisture, ash percentage and density (Table 4), the *FVI* of each species is calculated using equation (2).

Fig. 1 shows the *FVI* of twigs and wood for each range of moisture. The *FVI* for wood is much higher than that for twigs. This elevated value is observed because of the higher density, lower percentage of ash and lower moisture content in the wood. This finding suggests that those shrub collection systems in which the fine branches, including the leaves, are lost on the mountain improves the quality of the remaining fuel. The fuel quality differs among the species. The *FVI* for the wood of *Ulex europaeus* is near 40,000, that of *Prunus spinosa* is 34,000 and that of *Rhamus alaternus* is less than 30,000 at low moisture. For thin branches, the species *Ulex europaeus* also produces the highest *FVI* for all moisture levels.

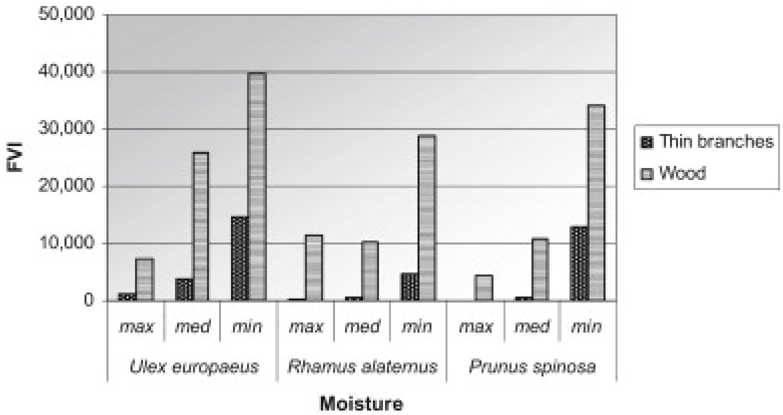

Fig. 1. *Fuel Value Index* for two fractions of *Ulex europaeus, Prunus spinosa* and *Rhamus alaternus* at different moisture levels.

Fig. 2 shows the *FVI* for different moisture levels of all species analysed. For the *Ulex europaeus, Prunus spinosa* and *Rhamus alaternus*, the *FVI* is shown for each fraction (twigs and wood, Table 3).

Erica cinerea is the shrub that offers the best fuel quality, achieving an *FVI* higher than 37,000, and *Ulex europaeus* is also relatively good, achieving an *FVI* higher than 32,000; both values were obtained at low moisture. Other shrubs, such as *Smilax aspera* and *Rubus ulmifolius*, had much lower FVI, i.e., 7,900 and 8,400, respectively, at low moisture. These results indicate that there are significant differences in fuel quality of the shrub species, despite their close calorific values. The other variables (density, generated ash and moisture) influence the *FVI* significantly.

Drying the biomass improves the *FVI*, from both the loss of moisture and the increase in *GCV*. High moisture content also adversely affects the efficiency of the combustion process, the costs of transport and the cost of the equipment [20].

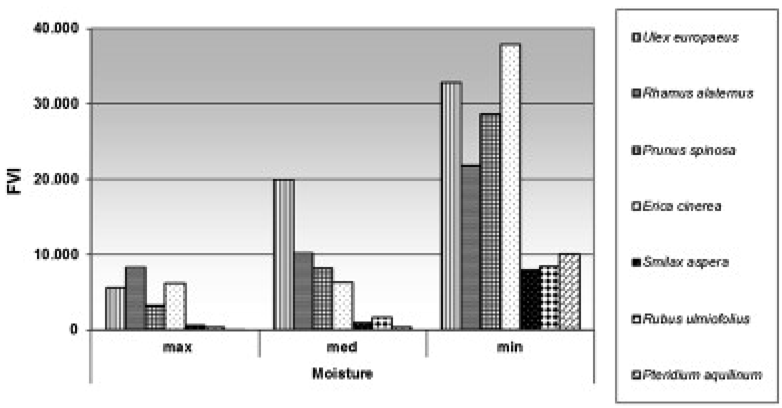

Fig. 2. *Fuel Value Index* for the species studied at different degrees of moisture.

Fig. 3 shows that herbaceous shrubs (*Erica cinerea, Smilax aspera, Pteridium aquilinum* and *Rubus ulmifolius*) improve as fuel while losing moisture. This phenomenon is observed because of the higher moisture content at the time of cutting. Practically, these species should remain in the field longer after cutting, to maximise moisture loss prior to transportation to the power plant. *Ulex europaeus* provides the highest quality fuel at average humidity. This finding is crucial because average humidity is easily achievable by natural drying in the field, but lower moisture levels are difficult to achieve because of the climatic characteristics of Cantabria. During the drying process, the density decreases, adversely affecting the *FVI*. This negative influence is negligible compared with the positive influence of moisture reduction. The most prominent case illustration corresponds to *Pteridium aquilinum*, whose *FVI* increases by a factor of 111 from high humidity (time of cutting) and low humidity, despite a density decrease of 40% (Fig. 3).

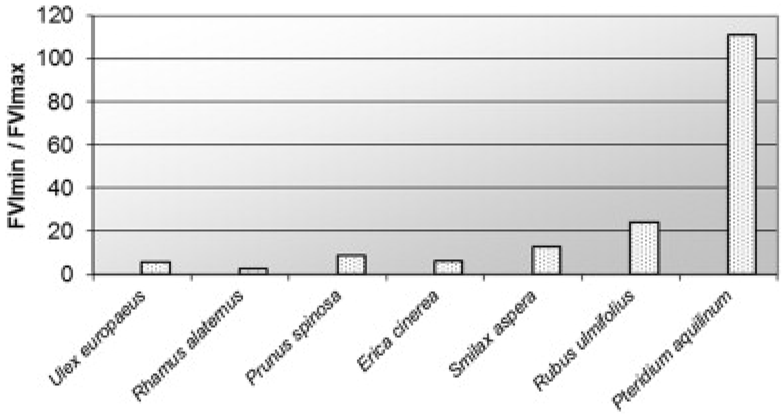

Fig. 3. Relationship between *FVI* at low moisture and *FVI* at high moisture for the species studied.

Table 6 presents the average production of the species analysed in this study in dry tonnes per hectare per year, and the amount of energy stored per hectare. These data should be treated with caution because there are large deviations in the productivity, even between places near one another. Productivity is subject to various factors such as age when harvested, soil fertility, depth and nature of the bedrock, climatic conditions, soil texture and pH. Thus, for *Ulex europaeus*, the values are between 7.5 t ha^{-1} $yr^{-1}$and 2.3 t ha^{-1} yr^{-1}. These data are low, when compared with the mean biomass production of fast-growing species, such as *Populus*, *Salix* and *Eucalyptus*, in experimental plantations [21]. However, the species in this study thrive in areas of low fertility because of their high adaptability.

One-factor ANOVA (species) revealed significant differences (p-value < 0.05) for the productivity. Using multiple comparison techniques (Newman-Keuls), two groups of productivity appeared, a first group with a 4.08 t ha^{-1} yr^{-1} average productivity *(Ulex europaeus, Rhamus alaternus, Prunus spinosa, Pteridium aquilinum and Rubus ulmifolius)* and a second group *(Smilax aspera* and *Erica cinerea)* with a 1.15 t ha^{-1} yr^{-1} average productivity.

Several studies [10] for other species do not address short-age cutting when determining productivity, which makes the comparison of this variable difficult. From an energy aspect, for *Ulex europaeus*, at high moisture content, an *NCV* of 9.45 MJ kg^{-1} has been reported [10]; in this study, *NCV* was 8.49 MJ kg^{-1}. This slight difference may be from variations in any of the variables (e.g., soil chemical composition, climate, season of harvesting, age of harvesting) that influence the shrub *NCV*.

Table 6. Average productivity, energy generated and installed power per ha from the shrub species studied

	Productivity t ha−1 yr−1	Energy density MJ ha−1 yr−1	Installed power W ha-1
Ulex europaeus	4.9 ± 2.6	81.7 ± 14.5	2.59
Pteridium aquilinum	3.5 ± 0.8	50.1 ± 18.9	1.59
Prunus spinosa	4.7 ± 2.5	81.2 ± 14.1	2.58
Smilax aspera	1.2 ± 0.3	20.4 ± 6.2	0.65
Rubus ulmifolius	3.3 ± 1.3	53.4 ± 10.7	1.69
Erica cinerea	1.1 ± 0.3	18.4 ± 3.1	0.58
Rhamus alaternus	4.0 ± 1.3	66.3 ± 9.9	2.1

Ulex europaeus and *Prunus spinosa* accumulate the most energy per hectare and have approximately the same value of 81 MJ ha^{-1} yr^{-1}. However, the data in Table 6 and in Fig. 2 indicate that *Ulex europaeus* combines fuel quality and production in a practical manner. *Erica cinerea* presents high *FVI*, but its productivity is low. To maximise production per ha per year, it is necessary to know the growth versus age curve of the species to determine the optimal time to harvest. This time coincides with the end of the maximum slope area in the growth curve. Because the shrubbery in an area is generally composed of several species, we must choose the harvest period of the species that best combines growth and *FVI*. In Cantabria, this species is *Ulex europaeus*.

The installed power is calculated assuming 8,600 hours of annual use. *Ulex europaeus* and *Prunus spinosa* are species for which more power per area are achieved with values of 2.59 W ha^{-1} and 2.58 W ha^{-1}, respectively (Table 6). These values are low compared with energy crops specialised in generating short rotation stands. The power from these plantations can reach average values of approximately 660 W ha^{-1}, inferred from studies in the field [22]. This potential implies that these species of shrub should be used as a complementary source of biomass. Using both shrub and energy crops it is possible to increase the performance of biomass power stations.

Table 7 presents a brief economic analysis of what the enhancement of shrub would mean to Cantabria. For the analysis, 40% utilisation of the forest is assumed to be covered by shrub (Table 1). The remaining area is free of exploitation, based on ecological criteria. An average production per hectare and an *NCV* is assumed, equally weighting the proportion of each species. An electrical efficiency of 20 % is assumed for the power plant (Rankine cycle) and an electricity selling price of 8.46 c€ kW-h^{-1} [23]. The exploitation of this area would generate an income of 14.6 10^6 €.

Table 7. Annual economic analysis in Cantabria

t ha−1 yr-1 (revenue dry)	Surface (ha)	NCV (MJ kg−1)	Electric efficiency (%)	Energy (MW-h−1)	Price electricity (c€ kW-h−1)	Total income (106 €)
3.3	87,120	16.51	20	172,404.162	8.46	14.6

The exploitation of this resource would contribute to oil dependence reduction and to the economic development of rural areas, mostly depressed areas [24, 25]. From the environmental point of view, these actions would help to reduce the risk of fire. The primary constraint is the high cost of harvesting and transportation to the power plant. Currently, there is no specialised equipment for this type of biomass. The development of this machinery would reduce costs and would support a more viable resource.

4. Conclusions

The native shrub species has an *NCV* good enough to ensure the viability of exploiting it as a sustainable source of alternative energy. *Erica cinerea* and *Prunus spinosa* produce the highest average *NCV* at low moisture, reaching 17.5 MJ kg^{-1} and 17.1 MJ kg^{-1}, respectively. *NCV* differences between the species *Ulex europaeus, Rhamus alaternus, Prunus spinosa, Erica cinerea, Smilax aspera* and *Rubus ulmifolius* are not statistically significant. *NCV* values for *Pteridium aquilinum* are significantly different from the rest of the species.

Wood shows a higher *FVI*, from its higher density, lower moisture content and lower amount of ash generated, than twigs and leaves. The *FVI* is greatly influenced by moisture content. At medium moisture, *Ulex europaeus* reaches a *FVI* near 20,000. However, at low moisture levels, the *Erica cinerea* and *Ulex europaeus* present higher fuel quality with *FVI* values of approximately 37,000 and 33,000, respectively. For herbaceous species, drying in the field is necessary because they contain more moisture at the moment they are cut down. This drying effect is especially remarkable in *Pteridium aquilinum*, which increases its *FVI* 111 times from the moment of harvest (high moisture) to the end of the drying process (low moisture).

The productivity per hectare of the species studied is conditioned to variables with large fluctuations, even in places near one another. Because of the degradation and poor quality of the soil in which the shrubs grow, the productivity of these species is low compared with other energy crops.

In this study, the species *Ulex europaeus* produced the most, averaging 4.9 t ha^{-1} yr^{-1}. This species best combined production variables with fuel quality, achieving 81.7 MJ ha^{-1} yr^{-1}. This result implies that the installed power was approximately 2.59 W ha^{-1}.

In this region, if 40% of the surface covered by shrub were used for electrical energy production, it would provide an annual income of 14.6 10^6 €. This resource would contribute to oil dependence reduction and to the economic development of rural areas.

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