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Energy potential of native shrub species in northern Spain

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ABSTRACT

This paper we present an energy review of the waste generated by shrub species in soils of low fertility for use as fuel in a power plant. The residues analysed belong to the species: *Rhamus alaternus*, *Ulex europaeus*, *Prunus spinosa*, *Smilax aspera*, *Erica* sp., *Rubus ulmifolius*, and *Pteridium aquilinum*. Gross calorific value (GCV), net calorific value (NCV), density, elementary chemical analysis, moisture content, percentage of ash, productivity, energy density and FVI (fuel value index) have been measured. These parameters have been determined for three levels of moisture (maximum, medium and minimum). At medium moisture level, the residues of *U. europaeus* are those that reach the greatest FVI, 20,000. In the other extreme is the *P. aquilinum* with an FVI of 403. The average productivity of waste, in t ha^{-1}, of each species has been determined in order to know how much energy is stored per hectare. *U. europaeus* and *P. spinosa* are the species which accumulate more energy per hectare, with similar values of around 81 MJ ha^{-1} yr^{-1} and installed power of 2.59 W ha^{-1}. The energy recovery of the waste in a thermal power plant would generate an annual revenue of 14.6 M€, taking into account that 40% of the forest land covered by shrub in Cantabria is used for this purpose.

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 43° 28′N and longitude 3° 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.

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. *R. alaternus*, *U. europaeus* and *P. spinosa* are all bushes; thus,

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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

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 ha. 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. *R. alaternus*, *U. europaeus* and *P. 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 [6]:

$$NCV = GCV - 2442{*}0.01{*}(H_b + H_a) - 2442{*}0.01{*}9{*}H_d, \qquad (1)$$

where H_d is percent of hydrogen in the dry sample, H_b is percent of moisture in the sample and H_a is percent of 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]:

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

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

The FVI calculation of *U. europaeus*, *P. spinosa* and *R. 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.

Table 2
Average climatic parameters for the sampling areas [16].

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	74.9%
Total accumulated rainfall per year	855.26 mm
Annual average wind speed	11.4 km/h
Hydric deficiency	99
Mediterraneanity index	2.4

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 [6].

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.

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 14 °C and 855 mm, respectively. The Mediterraneanity index is 2.4 [17], 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 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 *P. aquilinum*, in which the ratio between $NCV_{moisturemín}$ and $NCV_{moisturemax}$ 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 *E. cinerea* and *P. 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 *P. 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 (*U. europaeus*, *R.*

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

Shrub species	Twigs (%)	Wood (%)
Ulex europaeus	27.22	72.78
Rhamus alaternus	28.75	71.25
Prunus spinosa	25.80	74.20