Energetic Characterization of Lignocellulosic Biomass from South-West Spanish

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Abstract

For energetic production, differents lignocellulosic biomass sources were characterized energetically along two years in Huelva (South-west region, in Spain). Then, the differents kinds of lignocellulosic biomass were evaluated and classified for using like fuel for electric power generation in the area.

The groupings of the average humidity values and average gross heating values (over dry basis) of samples analyzed were made based on the type of material and in larger groups, were estimated the average values in subgroups. In areas dominated study samples related to the cultivation of eucalyptus account for 35% of the samples. The next group of materials is made up of different waste materials derived from agricultural crops (cotton, olive, corn, grapes), to 21.1%. The next group is derived from the cultivation of pine, with 18.0%, garden waste with 13.7% and fruit crop residues with 7.0%. Table 1 presents in descending order of average gross heating value, except for some individual samples from the bottom of the table.

The 6-cluster scheme allowed us to classify the different groups of materials. Thus, cluster 1 in this scheme coincided with the Cinder and Coal Characteristic Group (60% of samples). Also, the gross heating value of cluster 2 differed by only 3.8% and 2.2% from the mean gross heating value for Pine Bark and Wet Marc, respectively. The gross heating value for cluster 3 differed by only 0.6% from that for the Pine derivatives with the lowest heating values (Sawdust, Sawmill Residues, Pine Grindings and Pine Splinters), and by 0.1% and 3.4% from those for the Eucalyptus derivatives with the highest values (Eucalyptus Splinters and Grindings, respectively). Cluster 4 was associated to Eucalyptus Bark, with a difference of only 1.3% from its mean gross heating value. Finally, the other clusters encompassed the different types of residues (Agricultural, Gardening, Fruit) and waste (Sewage Sludge).

The average gross heating values of the different clusters (six groups) and the different raw materials showed significant similarities. Softwood and related materials typically have values in the region of 20.0 MJ/kg and hardwood such as that from *Eucalyptus globulus* yields about 18.0 MJ/kg, whereas other deciduous plants (and their residues) give lower values.

Keywords

Gross Heating Value, Energetic crops, Lignocellulosic Biomass, Clusters Analysis

1. INTRODUCTION

Lignocellulosic biomass is a promising renewable energy source. The availability of biomass of the world is 220 billion (dry ton -odt-) per year or 4500 EJ (1018 J). This is largest and most sustainable energy resource in the world. With the increase of amount of energy produced from biomass, the fossil fuel consumption can be reduced [1]. Lignocellulosic biomass can be used in its solid form or gasified for heating, applications of electricity generation, or it can be converted into liquid or gaseous fuels. The use of lignocellulosic biomass to produce heat and power can be environmentally beneficial because biomass is a renewable resource. Also the difficulties of the dependence of imported fossil fuels for many countries can be solved and its combustion does not contribute with additional greenhouse gases to the atmosphere [2].

Many countries around the globe have developed a growing interest in the use of biomass as a renewable energy source, and therefore various technological developments in this field are ongoing. Although major technological developments have already been achieved, most bioenergy technologies are not yet commercially feasible without political support. In order to achieve wider application of modern bioenergy technologies, individual countries have set varying targets and implemented promotional policies. As a result of increased support for bioenergy technologies, major progress have been made [3].

In European and national level (Spain) there is a huge energy dependency of fossil fuels. This has led to the development, in recent years, a whole series of policies to promote and encourage the use of renewable energy. EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020. These are a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, 20% of EU energy consumption to come from renewable resources and 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency. Collectively they are known as the 20-20-20 targets [4]. Also Spain, according to the regulations (RD 661/2007), establishes the right to receive a special pay for energy produced at the facilities included in the special regime, that is, with a power below 50 MW, and also those that having a greater than 50 MW power, if cogeneration, renewable energy or waste were used [5]. On the horizon of 2013, different percentages of supplies through the use of these energies were marked as targets. These percentages became 17% in the Andalusian Energy Plan (South of Spain) [6]. In the field of renewable energies, the highest percentage of generation refers to the use of lignocellulosic biomass energy.

Combustion is the main applied technology to produce heat and power from lignocellulosic biomass and is generally economically feasible. The use of lignocellulosic biomass as fuel has many environmental and economic advantages. Because, it is a cheap, clean and renewable source of energy [7]. In addition to social benefits, since the activities related to biomass production comes to creating jobs and obtained a consolidation of the rural population, which is being lost in Spain, with the consequences that entails.

According to the compounds and the complex structures found in the lignocellulosic biomass there is significant variability in the chemical energy that can hold this biomass. Cellulose, hemicellulose, lignin and extractive compounds are the major constituents of biomass which are present in different ratios and structures in different species. In a way, the gross heating value of lignocellulosic biomass is an indication of the energy chemically bound that in the combustion process is converted into heat energy. Gross heating value is the most important property of a fuel which determines the energy value of it [8].

In addition to the use of renewable lignocellulosic biomass or different residual biomass sources, these reasons have favored the use of alternative for agricultural and forest soils and the development of so-called SRC Short Rotation Crops Conventionally, SRWC (when are woody), for the production of energy by direct combustión of biomass collected. The examples found in the literature are numerous in countries like the United Kingdom [9], Cánada [1], Brazil [10], India [11], China [12], etc… In these examples, various aspects were raised: aspects about the culture of energetic or industrial crops, selection of lignocellulosic biomass from different origin such as agricultural residues, wild grass and forest residues; various aspects about chemical and thermochemical characterization of lignocellulosic biomass or the use of regional biomass for supplying electrical power for remote communities.

In this work, differents commercial sources of lignocellulosic biomass, for energetic production use by the group ENCE, were characterized (Gross Heating Values) along two years in Huelva (South-west region, in Spain). Then, the differents kinds of lignocellulosic biomass were evaluated and classified for using like fuel for electric power generation in the area. The electric power group ENCE S.A. currently has 230 MW, and it will be 440 MW for the 2015 [13].

2. MATERIALS AND METHODS

2.1. Raw material. Provision and characterization

Differents samples of lignocellulosic biomass were collected in the geographical environment of the city of Huelva (SW of Spain, 37.307941,-6.863131) in a radius of about 100 km. A total of 256 samples were analyzed. They are considered a representative sample of the various types of biomass produced in the environment in significant quantities.

The samples were subjected to a cold milling to avoid disruptions in components of the material. This reduces the sizes of chips between 1 and 3 cm in length, using a Retsch mill (SM 2000) for solid samples. Alternatively, for certain samples, a laboratory mill IKA MF 10 was used. For the calorimetric characterization, the samples were crushed and sieved through a mesh size of 1 mm and bagged in airtight bags to ensure no change in moisture content.

2.2. Humidity determination

To refer the data to a base constant calculation, all operations were performed on dry (moisture free). The moisture determination was performed by applying the standard Tappi T 258 om-06 (dried in an oven at 105 ° C to constant weight).

2.3. Gross Heating Value determination

The Gross Calorific Values (constant volume) were determinate according "CEN/TS 14918:2005 (E) Solid biofuels—Method for the determination of calorific value" and UNE 164001 EX standards by using a Parr 6300 Automatic Isoperibol Calorimeter. Sample pellets of 1.0g were used for each analysis. A cotton thread was attached to the platinum ignition wire and placed in contact with the pellet. The bomb was filled with oxygen at 25°C with 1.0cm^3 of water added to the bomb. The calorimeter was placed in an isothermal jacket with an air gap separation of 10mm between all surfaces. The electrical energy for ignition was determined from the change of potential across a 1256 or 2900μF capacitor when discharged from about 40V through a platinum wire. The bomb calorimeter was submerged in a calorimeter and filled with distilled water. The calorimeter jacket was maintained at constant temperature by circulating water at 27°C.

Statistical programme

STATISTICA v.5.0 from StaSoft was used for Cluster Analysis. Humidity and Gross Heating Value were the independent variables used in the Cluster Analysis.

3. RESULTS AND DISCUSSION

3.1. Samples (lignocelulosic raw material) characteristics

In table 1 show the average humidity values and average gross heating values (over dry basis) of samples analyzed. The groupings were made based on the type of material and in larger groups (with a significant dispersion of the values of gross heating value), were estimated the average values in subgroups or "Featured Groups". To select the characteristic groups, the following approximate criteria were adopted: to reduce by half the coefficient of variation; that the coefficient of variation was below 5-6% or the percentage of samples not covered by the group will not exceed characteristic 20-30% of the total samples of each type.

In areas, dominated study samples related to the cultivation of eucalyptus, account for 35% of the samples. The next group of materials is made up of different waste materials derived from agricultural crops (cotton, olive, corn, grapes), to 21.1%. The next group is derived from the cultivation of pine, with 18.0%, garden waste with 13.7% and fruit crop residues with 7.0%. Table 1 presents in descending order of average gross heating value, except for some individual samples from the bottom of the table.

Highest to lowest average gross heating value, RM1 group (table 1) appeared clearly highlighted. This group corresponds to samples of coal or coal derivatives, with values of gross heating values above 24 MJ /kg with a very low moisture content (<6%). Groups RM2, RM4 and RM5 are constituted by a set of derived from the cultivation of pine with gross heating values of the above value of 19 MJ /kg and low relative humidity values(below 32%). The next group consists of a set of olive residue samples (RM6). However, the waste with a higher fat content derived from the cultivation of olives (RM3) clearly stand and lie just beneath the bark of pine (RM2) with average gross heating values above 20 MJ /kg. Appear after a series of groups associated with the cultivation of eucalyptus (RM7 to RM10) with average gross heating value above 17 MJ /kg. The waste from the cultivation of olive and eucalyptus, are revealed as more hygroscopic, with values of the humidity content of up to above 40% for the bark of eucalyptus which is the largest group ((RM10) of those tested . Other agricultural waste, fruit trees and garden waste have generally a lower gross heating values and a significant spread in the values of humidity.

3.2. Statistical analysis of gross heating values

In order to predict the Gross Heating Value of a given material or sample before performing the test in the laboratory of its Gross Heating Value, a statistical method of Cluster analysis was used to group the data significantly depending on the values of humidity and Gross Heating Value. With Cluster analysis, the dispersion can be analyzed, and the homogeneity of the groups or clusters in a dataset can be identified and evaluated. This grouping can be made on the basis of the results of Humidity and Gross Heating Value without any other factor.

The analysis was carried out grouping different possibilities were tested. Variable also considering a "temporary" has not proved to be a significant statistical effect. Temporary or seasonal variables such as: time of year (spring, summer, autumn, winter), month or weeks within the year were considered (data not show).

After selecting the clustering methods and minimization of errors, the groups were optimized according to the dendrogram of Figure 1. The dendrogram includes 256 samples of biomass. From it, the cluster levels in 11, 6 and 4 clusters, the more clearly defined in Figure 1, were selected at different levels of the Euclidean distance (Gross Heating Value).

The representative values of each cluster for both the humidity and for the Gross Heating Value are shown in Table 2. In subsequent columns show the groups for the three levels of grouping selected (11, 6 and 4 clusters).

3.2.1. Grouping in 11 clusters

Cluster 3 contained only 3 samples. Clearly, it corresponded to the RM1 Characteristic Group (60% of samples), which included cinder, coal and charcoal derivatives. This group was also clearly present in the next clustering level, which encompassed 6 clusters.

Cluster 2 was heterogeneous. Thus, it contained 26 samples and was that having the second highest mean gross heating value after the Coal derivative group. The gross heating value for this group was close to the mean value for Pine Bark and Wet Marc (Table 1). The cluster included the 3 samples of Wet Marc (RM3), 7 from the Olive/Olive Leaf/Olive Stone group (RM6) –which was among those exhibiting the highest dispersion (particularly the 3 samples of Olive Stones), the 2 coal and cinder samples (RM1) no included in the first group of Table 1, individual samples such as Pine Cone Bark or

Maize Pellets, and, essentially, samples from the Pine Bark and Pine Derivative groups (RM2 and RM4, respectively).

Cluster 3 contained 45 samples, most of woody species. Basically, it corresponded to Pine Splinters (RM4) and also to Saw Dust/Sawmill Residues/Pine Grindings (RM5) in Table 1, which jointly accounted for roughly 50% of the group. The remainder consisted of individual samples of Pine Nut Shells; the 5 samples of Eucalyptus Bark (RM10) and the 2 of Pine Bar (RM2) not included in Table 1; and the 11 samples of Eucalyptus Splinters (RM7) in Table 1. This cluster was also scarcely significant.

Cluster 4 contained 26 samples, most from eucalyptus. Thus, it includes 6 samples of Eucalyptus Bark (RM10), 8 of Eucalyptus Splinters (RM7) and 5 of Eucalyptus Grindings (RM9). Together with Australian Pine correcto?? (RM8), the previous samples accounted for 70% of the group, the remainder consisting of Pine Splinters (RM4), Pine Grindings (RM5) and 2 samples of Gardening Residues. We can thus relate the mean gross heating value of 18.67 MJ/kg to an “Eucalyptus derivative” group; this assignation, however, is not categorical since the cluster included other materials in addition to eucalyptus bark and wood.

Clusters 5 and 6 were two subgroups of the Eucalyptus Bark group in Table 1 (RM10). In fact, 42% of the 57 samples consisted of this material. The group additionally contained Eucalyptus Splinters, various Pine derivatives, Eucalyptus Grindings, several samples from the Cotton and Olive/Cotton groups and 2 of Gardening Residues.

Cluster 7 contained the next major group of Eucalyptus Bark (RM10, with 11 of the 33 samples). It additionally contained 21% of the samples in the Cotton/Olive–Cotton group (RM12), as well as most of the Fruit group with the highest Heating Value (RM13, 5 samples), Gardening Residues (RM14, 4 samples), Grape Marc and Peach Stones. This cluster was also scarcely significant.

Clusters 8–10, with mean heating values from 15.32 to 10.99 MJ/kg, consisted of a heterogeneous mixture of Cotton/Olive–Cotton, Gardening Residues, Fruit Residues, Agricultural Residues and Sewage Sludge, mainly. Cluster 8 included 30 samples: 7 of Eucalyptus Bark (RM10), 7 of Cotton (RM12), 7 of Gardening Residues (RM14) and several from various other groups. Cluster 9 contained 18 samples, mainly of Gardening Residues (RM14, 5 samples), Cotton (RM12, 4 samples), Fruit Residues (RM15, 3 samples) and Agricultural Residues. Finally, cluster 10 contained 19 samples including 9 of Gardening Residues (RM14) and 4 of Fruit Residues (RM15) in addition to Sewage Sludge, Cotton, Agricultural Residues and other materials.

Cluster 11 contained 5 samples [viz. Gardening Residues (RM14) and Olive Leaves (RM6)] and exhibited the lowest mean heating value: 6.99 MJ/kg.

3.2.2. Grouping in 6 clusters

Clearly, the previous 11 clusters were rather heterogeneous, which led us to rearrange them in order to reduce their number. To this end, we reduced the clustering level (specifically, to 6 and 4 clusters) in accordance with the dendrogram. Table 2 shows the mean moisture contents and gross heating values for the 6-cluster scheme.

The new cluster 1 contained the 3 samples of Coal and Cinder with the highest heating value (RM1), and coincided with cluster 1 in the 11-cluster scheme and the Cinder/Coal Characteristic Group (60% of samples) in Table 1.

Cluster 2 contained 33 samples coinciding largely with cluster 2 in the 11-cluster scheme. The largest number of samples in it was that of Pine Derivatives (RM2, RM4 and RM5, with 10 samples), Olive Leaves and Stones (RM6, 9 samples), Wet Marc (RM3, 3 samples), Eucalyptus Splinters and Grindings (RM7 and RM9, 3 samples), Sawmill Residues (RM5, 2 samples), and Pine Cone Bark and Fine Cinder (RM1). This was a relatively well-defined cluster including the Pine derivatives with the highest heating power (Pine Bark and various other derivatives) and other materials with an also high heating value obtained from olive crops (Olive, Olive Leaves, Olive Stones and Wet Marc).

Cluster 3 contained 69 samples, most from woody species, but especially from Pine derivatives (RM2, RM4 and RM5, 16 samples), Eucalyptus Grindings (RM9, 8 samples), Eucalyptus Splinters (RM7, 5 samples), Eucalyptus Bark (RM10, samples) and Pine Nut Shells, among other materials. The cluster included another, relatively well-defined group consisting of Pine derivatives with a low heating value (Sawdust, Sawmill Residues, and Pine Grindings and Splinters), as well as Eucalyptus derivatives with a high heating value (Eucalyptus Splinters and Grindings). This cluster exhibited a substantially increased moisture content relative to the previous one.

Cluster 4 contained 85 samples, also from woody species. The largest group contained 32.5% of all samples, Eucalyptus Bark (RM10) accounting for 40% of the group. The other materials, in decreasing order of the number of samples included Pine Splinters and Pine Grindings (RM4 and RM5, 9 samples), Cotton (RM12, 9 samples), Eucalyptus Splinters and Grindings (RM7 and RM8, 8 samples), Gardening Residues (RM14, 7 samples) and Olive Leaves (RM6, 6 samples) in addition to Fruit Residues (RM15), Pine Cone Bark, Peach Stones and Grape Marc. This cluster coincided to some extent with the Eucalyptus Bark group in Table 1. Its mean heating value fell in the middle of the sampling space, which explains the presence of samples with heating values above and below the means for the group.

Cluster 5 contained 44 samples, most of Gardening Residues (RM14, 40% of samples) or Cotton and Cotton/Olive mixtures (RM12, 9 samples, which essentially distributed between clusters 5 and 6), Eucalyptus Bark (RM10, 8 samples), Fruit Residues (RM15, 5 samples, which also distributed between clusters 5 and 6), Eucalyptus Splinters and Sawmill Residues (RM7 and RM5, 4 samples), Olive Branches (RM6, 3 samples) and Fine-grained Coal (RM1).

Cluster 6 contained 28 samples including Gardening Residues (RM14, 13 samples), Cotton and Cotton/Olive mixtures (RM12, 6 samples), Fruit Residues (RM15, 4 samples), Sewage Sludge (RM17, 2 samples) and Agricultural Residues (RM16, 2 samples).

The Gardening Residues group in Table 1 was rather heterogeneous. In fact, it exhibited the highest coefficient of variation (24.9%), which is consistent with its distributing between clusters 5 and 6 in the 6-cluster scheme. A similar comment applies to the Cotton and Cotton/Olive group in Table 1, the coefficient of variation of which was reduced to 5.6% at the expense of discarding 34.6% of samples. In this way, clusters 5 and 6 consisted largely (58.3%) of samples from two groups in Table 1, namely:

Gardening Residues, and Cotton and Cotton/Olive mixtures. Likewise, nearly 70% of the samples in these two groups distributed between clusters 5 and 6.

There was no separate cluster with a heating value below that for cluster 6, which therefore included the samples with the lowest values shown in Table 1.

3.2.3. Grouping in 4 clusters

Table 2 also shows the mean moisture contents and gross heating values for a 4-cluster scheme.

The new cluster 1 contained 31 samples (11.8% of all) and exhibited a very high mean heating value (21.82 MJ/kg). The cluster included Olive derivatives (RM6), 22% of Pine derivatives (RM2, RM4 and RM5) and various other samples with a high gross heating value specially prominent among which were Coal derivatives (RM1) and Wet Marc (RM3). Basically, cluster 1 was the result of combining clusters 1 and 2 in the 6-cluster scheme.

Cluster 2 contained 113 samples and its largest group accounted for 43.1% of all samples. The cluster included Eucalyptus Bark (RM10, 31%), Eucalyptus Splinters and Grindings (RM7 and RM9, 33%) and Pine derivatives (RM2, RM4 and RM5, 20%) in addition to samples of Cotton and Cotton/Olive mixtures (RM12), Olive derivatives (RM6), Fruit Residues (RM15) and Australian Pine OK?? (RM8). This cluster lacked interest as it consisted basically of an undifferentiated mixture of pine and eucalyptus derivatives.

Cluster 3 contained 81 samples (31% of all) and exhibited a mean heating value of 16.05 MJ/kg. Like the previous cluster, it consisted largely of Eucalyptus Bark (RM10, specifically the 42% of samples not included in cluster 2), Cotton and Cotton/Olive mixtures (RM12), Gardening Residues (RM14), Pine derivatives (RM2, RM4 and RM5), Olive derivatives (RM6), Fruit Residues (RM13), Eucalyptus Grindings (RM9), Grape Marc and Peach Stones.

Cluster 4 contained 37 samples (14% of all), had a very low mean gross heating value (11.16 MJ/kg) and consisted largely of Gardening Residues (RM14), Fruit Residues (RM15) and Cotton (RM12). Overall, the groups in clusters 3 and 4 were indistinguishable from those in clusters 5 and 6 in the 6-cluster scheme (Section 3.2.2). Therefore, using only 4 clusters allowed no useful information to be derived with a view to classifying the samples.

Table 3 shows selected Calorific Values reported by several authors. In short, softwood and related materials typically have values in the region of 20.0 MJ/kg and hardwood such as that from *Eucalyptus globulus* yields about 18.0 MJ/kg, whereas other deciduous plants (and their residues) give lower values.

The average gross heating values of the different clusters (six groups) and the different raw materials in Table 3 showed significant similarities. For example, the case of cluster 2 for the most part derived from samples of pine and olive cultivation with values greater than 20.0 MJ / kg of gross heating values. In the case of cluster 3, consisting essentially of derivatives of pine and eucalyptus, an intermediate value between bibliographic values for pine and eucalyptus was obtained. Approximately between 20.0 and 18.0 MJ / kg. The bark of eucalyptus was the majority that represents the cluster number 4. This cluster has a value of gross heating value similar to that of eucalyptus in the bibliographics referents. A value close to 17.0 MJ / kg. The cluster number 5 and 6 are constituted mainly of garden waste samples and derived from cotton. The gross heating value presented very low values we buy with those in Table 3. This is possibly owing to the heterogeneity of the samples and the clustering of samples with lower values.

4. CONCLUSIONS

The groupings of the average humidity values and average gross heating values (over dry basis) of samples analyzed were made based on the type of material and in larger groups, were estimated the average values in subgroups. In areas dominated study samples related to the cultivation of eucalyptus account for 35% of the samples. The next group of materials is made up of different waste materials derived from agricultural crops (cotton, olive, corn, grapes), to 21.1%. The next group is derived from the cultivation of pine, with 18.0%, garden waste with 13.7% and fruit crop residues with 7.0%. Table 1 presents in descending order of average gross heating value, except for some individual samples from the bottom of the table.

The 6-cluster scheme allowed us to classify the different groups of materials. Thus, cluster 1 in this scheme coincided with the Cinder and Coal Characteristic Group (60% of samples). Also, the gross heating value of cluster 2 differed by only 3.8% and 2.2% from the mean gross heating value for Pine Bark and Wet Marc, respectively. The gross heating value for cluster 3 differed by only 0.6% from that for the Pine derivatives with the lowest heating values (Sawdust, Sawmill Residues, Pine Grindings and Pine Splinters), and by 0.1% and 3.4% from those for the Eucalyptus derivatives with the highest values (Eucalyptus Splinters and Grindings, respectively). Cluster 4 was associated to Eucalyptus Bark, with a difference of only 1.3% from its mean gross heating value. Finally, the other clusters encompassed the different types of residues (Agricultural, Gardening, Fruit) and waste (Sewage Sludge).

The average gross heating values of the different clusters (six groups) and the different raw materials showed significant similarities. Softwood and related materials typically have values in the region of 20.0 MJ/kg and hardwood such as that from *Eucalyptus globulus* yields about 18.0 MJ/kg, whereas other deciduous plants (and their residues) give lower values.

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Table 1. Groups of samples according to the type of raw material

<table>
<tr><th rowspan="2">Raw Material / Code group</th><th colspan="2">Average Humidity, % (Standard deviation, Coefficient of variation, %)</th><th colspan="2">Gross Heating Value, over dry basis (J/g) (Standard deviation, Coefficient of variation, %)</th><th colspan="2">Samples</th></tr>
<tr><th>Group characteristic</th><th>All samples</th><th>Group characteristic</th><th>All samples</th><th>Percentage of samples in the Characteristic Group, %</th><th>Number of samples</th></tr>
<tr><td>Carbonilla, Carbonilla + finos, Carbón vegetal grano grueso y fino, carbón / RM1</td><td>5.8 (2.8, 49.0)</td><td>4.9 (2.6, 54.4)</td><td>28248 (304, 1.1)</td><td>24319 (5128, 21.1)</td><td>60</td><td>5</td></tr>
<tr><td>Corteza de pino /RM2</td><td>20.5 (6.0, 29.0)</td><td>19.7 (6.2, 31.5)</td><td>21071 (538, 2.6)</td><td>20444 (1365, 6.7)</td><td>77.8</td><td>9</td></tr>
<tr><td>Alperujo / RM3</td><td colspan="2">23.4 (1.9, 8.0)</td><td colspan="2">20739 (313, 1.5)</td><td>100</td><td>3</td></tr>
<tr><td>Astilla de pino / RM4</td><td>18.6 (13.5, 7.3)</td><td>19.6 (14.6, 74.5)</td><td>19362 (545, 2.8)</td><td>18946 (964, 5.1)</td><td>80.0</td><td>15</td></tr>
<tr><td>Serrín, Residuos Aserradero y Pino triturado / RM5</td><td>32.0 (12.8, 40.0)</td><td>28.6 (13.8, 48.5)</td><td>19236 (941, 4.9)</td><td>19002 (1608, 8.5)</td><td>82.4</td><td>17</td></tr>
<tr><td>Olivo, Hojas de Olivo, Hueso de Olivo / RM6</td><td>36.3 (7.9, 21.7)</td><td>37.9 (8.4, 22.1)</td><td>19175 (2426, 12.7)</td><td>17258 (4391, 25.4)</td><td>85.0</td><td>20</td></tr>
<tr><td>Astillas de Eucalipto / RM7</td><td>25.2 (9.3, 3.7)</td><td>25.7 (9.6, 37.5)</td><td>19102 (663, 3.5)</td><td>18792 (1753, 9.3)</td><td>84.6</td><td>13</td></tr>
<tr><td>Causarina / RM8</td><td colspan="2">25.2 (4.7, 18.8)</td><td colspan="2">19027 (467, 2.4)</td><td>100</td><td>2</td></tr>
<tr><td>Triturado de Eucalipto / RM9</td><td>29.0 (12.4, 42.9)</td><td>28.9 (12.6, 43.7)</td><td>18472 (945, 5.1)</td><td>18199 (1848, 10.2)</td><td>86.4</td><td>22</td></tr>
<tr><td>Corteza de Eucalipto /RM10</td><td>44.2 (10.7, 2.4)</td><td>44.4 (11.1, 25.0)</td><td>17430 (977, 5.6)</td><td>17349 (1291, 7.4)</td><td>91.2</td><td>57</td></tr>
<tr><td>Hojas y Ramas de Pino / RM11</td><td colspan="2">31.8 (14.8, 46.5)</td><td colspan="2">17133 (40.1, 0.2)</td><td>100</td><td>2</td></tr>
<tr><td>Algodón y mezclas algodón/olivo / RM12</td><td>15.6 (6.2, 40.0)</td><td>21.6 (12.2, 56.3)</td><td>16160 (898, 5.6)</td><td>15344 (2113, 13.8)</td><td>65.4</td><td>26</td></tr>
<tr><td rowspan="2">Residuos árboles frutales / RM13</td><td colspan="2" rowspan="2">26.7 (10.5, 39.3)</td><td>18166 (724, 4.0)</td><td rowspan="2">15525 (2990, 19.3)</td><td>50</td><td rowspan="2">14</td></tr>
<tr><td>12884 (1199, 9.3)</td><td>50</td></tr>
<tr><td>Residuos Jardinería / RM14</td><td colspan="2">20.5 (10.7, 52.3)</td><td colspan="2">13724 (3427, 24.9)</td><td>100</td><td>35</td></tr>
<tr><td>Residuos de Fruta /RM15</td><td colspan="2">33.1 (8.6, 25.9)</td><td colspan="2">13421 (2496, 18.6)</td><td>100</td><td>4</td></tr>
<tr><td>Residuos agrícolas / RM 16</td><td colspan="2">47.6 (0.1, 0.1)</td><td colspan="2">11790 (614, 5.2)</td><td>100</td><td>2</td></tr>
<tr><td>Lodos de depuradora / RM 17</td><td colspan="2">63.7 (2.1, 3.3)</td><td colspan="2">10375 (1189, 11.5)</td><td>100</td><td>2</td></tr>
<tr><td>Pellet de maíz</td><td colspan="2">12.9</td><td colspan="2">22227</td><td>100</td><td>1</td></tr>
<tr><td>Residuos de Maíz</td><td colspan="2">9.6</td><td colspan="2">17332</td><td>100</td><td>1</td></tr>
<tr><td>Jara</td><td colspan="2">16.4</td><td colspan="2">18249</td><td>100</td><td>1</td></tr>
<tr><td>Mezcla de astillas trituradas</td><td colspan="2">30.5</td><td colspan="2">19773</td><td>100</td><td>1</td></tr>
<tr><td>Hueso de melocotón</td><td colspan="2">19.7</td><td colspan="2">16830</td><td>100</td><td>1</td></tr>
<tr><td>Orujo de uva</td><td colspan="2">70.8</td><td colspan="2">16928</td><td>100</td><td>1</td></tr>
<tr><td>Cáscara de piña</td><td colspan="2">7.3</td><td colspan="2">20710</td><td>100</td><td>1</td></tr>
<tr><td>Cáscara de piñón</td><td colspan="2">8.9</td><td colspan="2">20335</td><td>100</td><td>1</td></tr>
</table>

Table 2. Descriptive statistical for differents cluster groups

11 Cluster groups			6 Cluster groups			4 Cluster groups		
Cluster Number	Gross Heating Value	Humidity	Cluster Number	Gross Heating Value	Humidity	Cluster Number	Gross Heating Value	Humidity
1	28248 (373)	5.8 (3.5)	**1**	28248 (373)	5.8 (3.5)	**1**	21821 (2207)	23.4 (13.5)
2	21196 (535)	25.1 (12.0)	**2**	20979 (637)	23.5 (12.7)			
3	19644 (324)	27.5 (13.5)	**3**	19128 (529)	28.8 (13.8)	**2**	18702 (831)	30.1 (14.2)
4	18686 (211)	27.6 (15.3)						
5	17965 (182)	31.8 (14.2)	**4**	17211 (606)	32.3 (16.7)			
6	17399 (186)	32.7 (16.7)				**3**	16052 (924)	29.8 (17.6)
7	16544 (263)	32.3 (18.6)						
8	15316 (378)	30.2 (17.4)	**5**	14773 (921)	29.6 (16.1)			
9	13305 (648)	29.3 (13.8)				**4**	11161 (2046)	32.8 (15.1)
10	10988 (817)	32.3 (16.5)	**6**	10472 (1880)	33.2 (15.3)			
11	6992 (910)	38.6 (11.7)						

Table 3. Gross heating values for different raw materials (bibliographic references)

Raw material	**Gross calorific value (MJ/Kg)**
Pine Cone	27.35 [14]
Wood bark, Agba, Iroko , Atlas Cedar, Wheat straw	20.5 – 20.3 [15,16]
Spruce wood, Softwood, common Douglas-fir, Pinewood	20.1-19.6 [1,15,16]
Hazelnut shell, Hazelnut seedcoat, Beech wood, Narrow-leafed Ash, Jatobá, Olive husk, Sapele, Ailanthus wood	19.3 -19.0[15,16]
Populus euro-americana, Hardwood, English oak, Castanea sativa, Sycamore Maple, Sweet cherry, Babylon Willow	18.8-18.2 [15,16]
Corn stover, Tobacco stalk, Eucalyptus globulus, Tobacco leaf, Tea waste, Waste material, Corncob, Flax straw, Soybean stalk	17.8-17.0 [1,15,16]
Timothy grass, Barley straw	16.7 -15.7 [1]

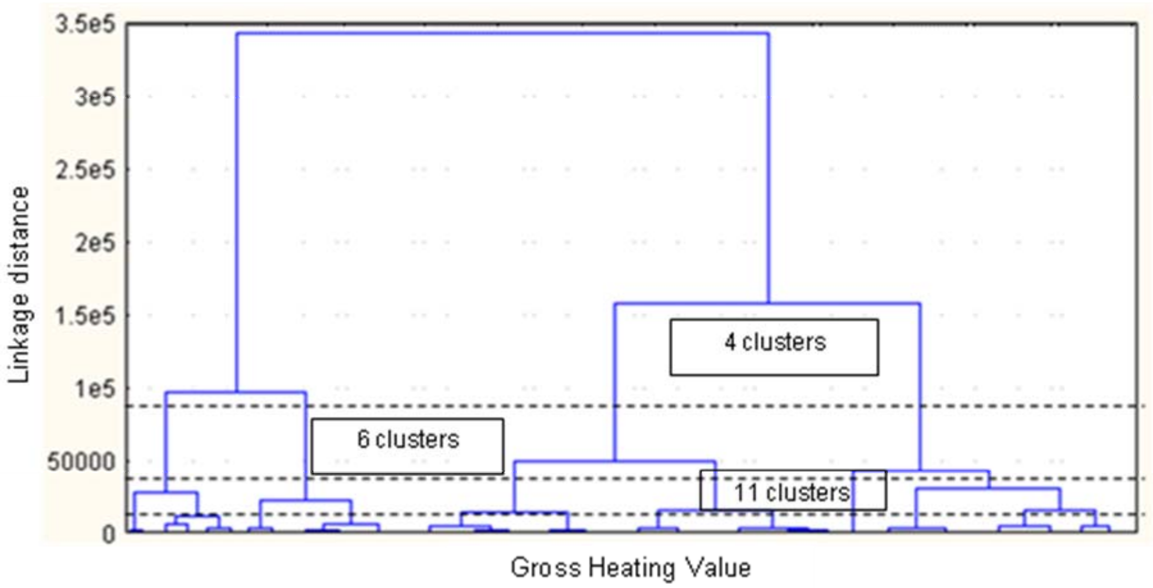

Figure 1. Dendrogram. Tree Diagram for 262 cases. We have used the clustering method of Ward and Euclidean distance separating cases. Gross Heating Value in MJ/kg (over dry basis)