FOREST WASTE ENERGY EVALUATION OF PART OF EUROPE'S LARGEST WOODLAND (CENTER N.E. OF PORTUGAL)

Fernando Silva
Polytechnic of Viseu, ESTV, Wood Engineering Department, Campus Politécnico, 3504-510, Viseu, Portugal, fsilva@demad.estv.ipv.pt

João Paiva
Polytechnic of Viseu, ESTV, Mechanical Engineering and Industrial Management Department, Secção de Energia e Fluidos, Campus Politécnico, 3504-510, Viseu, Portugal, jmonney@demgi.estv.ipv.pt

Carlos Pinho
CEFT-DEMEGI, Faculty of Engineering, University of Oporto, Rua Dr Roberto Frias, s/n, 4200-465, Porto, Portugal, ctp@fe.up.pt

Abstract. *The need to feed with reliable data an experimental investigation concerning the use of wood waste produced by the cleaning of forests and other sylviculture operations, as biomass to produce energy, was the starting point of this work. The main issue was the evaluation of the adequacy of using such materials as alternative fuels capable of, in the long run, producing electricity as well as useful heat in suitable plants. An area of 160000 ha was defined and a methodology for gathering samples adopted. The field work setup is described and some preliminary results concerning the forest biomass waste properties, as well as some useful biological characteristics regarding the commonly established combustion techniques, were determined.*

Keywords. *Alternative energy, Forest waste, Xyloenergy, Biomass.*

1. Introduction

Portugal is an integral part of the European Union (UE) since 1986 and the Union is committed to achieving a certain number of environmental goals: waste recycling, nature protection, water quality assurance and improvement, amongst others. Union funds are available to help these aims, namely FEDER, FEOGA and ENVIREG. Not being able to keep the pace will have as consequences a low execution rate, a lack of the advantages arising from its implementation and especially having to pay for substantial fines. As well as the Union's remaining countries, Portugal is strongly dependent of fossil fuels consumption, on which is based 90% of the energy production. Until 2010, and for the whole Union, 39% of this energy production will have to be based on renewable resources, which will have, as an important attraction, the fact of replacing import costs by investment ones, creating new industrial sectors (component parts, plants, services). Particularly for Portugal, it will diminish the external dependence, increase regional development (if the model adopted is of a small/average scale) and is capable of significantly reducing emissions (Hammond and Stapleton, 2001).

The present problem for mankind is not so much the limited available fossil energy resources as the experience has been showing that the more expensive is energy, the more it can be paid to look for such energy resources in wilder and more distant regions, but the huge amounts of carbon that are being released to the atmosphere as carbon dioxide, with all climatic and environmental problems already very well known.

When renewable energies are concerned and in particular solar energy it must be stressed that wood is the most ancient solar energy transporter known by mankind and even nowadays it still is may be the most relevant energy source for a reasonable part of the humankind (McKendry, 2002; McKendry, 2002a; McKendry, 2002b; Obernberger, 1998; Strehler, 2000). Our forest should then be considered not only as a raw materials source and a CO_2 sink but also as reasonably efficient solar energy collector.

Presently, 15 % of the energy consumed by mankind, for the production of thermal energy and useful heat, comes from wood and ligneous residues combustion (Bhattacharya, 1998), although the efficiency of such energy conversion is usually low.

As conditions in the region of Viseu are adequate for forest growing fuel biomass and the technological development required to take the maximum of environmental conditions must be achieved in due course, a project was started aiming at targeting those issues in due time.

The use of biomass as an energy source through wood combustion can be the object of any of two complementary approaches: fast growing trees harvested only for energy production allowing a biomass output of about 80 t/ha/year, or a more general use of the forest for different ends and using only forest cleaning wastes as energy source, and in this case an annual value of 3 t/ha can be obtained. The above referred numbers for either of the scenarios are typical for the Atlantic Coast of the Iberic Peninsula (Nuñez-Regueira *et al.*, 1997; Nuñez-Regueira *et al.*, 1999; Nuñez-Regueira *et al.*, 2001; Nuñez-Regueira *et al.*, 2001a).

Forest cleaning must accordingly be considered as an operation which at the same time that allows a better control or elimination of forest fire spreading conditions as well as a forest grow control tool, it will eventually yield a certain amount of biofuel to be used in proper conditions so that cleaning costs can be partially recovered (Boyle, 1996; Zerbe and Skog, 1988). There will be a continuous and reliable fuel supply in closely controlled conditions to feed small power plants for electricity production or energy cogeneration of electricity and useful thermal power (Nuñez-Regueira *et al.*, 1997; Nuñez-Regueira *et al.*, 1999; Nuñez-Regueira *et al.*, 2001; Nuñez-Regueira *et al.*, 2001a).

Whatever approach is followed, dedicated biomass production for energy conversion or forest cleaning wastes only, the useful energy production scheme will use a closed CO_2 cycle (El Bassam, 1998; Klass, 1998; Werther *et al.*, 2000).

Electricity or thermal energy production costs through wood burning techniques must be carefully evaluated as in many situations such conversion procedures cannot compete with low price fossil fuels. There are however situations were wood is a competitive energy source and a recommended strategy is to use minimum biomass transportation distances. Biomass is a low energy density source and transportation can represent up to 70 % of fuel cost at power plant entrance (McKendry, 2002). This extremely negative situation is enhanced when considering forest cleaning residues. However if the small power plants can be built close to the waste source forests, the transportation of the produced electricity to the final consumers will surely be cheaper than the transportation of the original biomass.

This is the basic reasoning that led to the start of studying the forest biofuel availability in the region of Viseu. To guarantee a successful approach a proper work methodology was adopted, so that the energy resources of the region are defined while laboratorial working conditions are developed to stimulate the formation of qualified technicians and researchers. These are the issues that we are reporting in this paper.

2. Species characterization

The characterization of the sylvan species with energy content, as well as the techniques for selecting the pick up places, the collecting methodologies of forest samples and the definition of the yearlong periods more adequate to samples pickup (in a way that makes them the most representative possible of the energy capacities of that particular area), were approached with success for the northern part of the Atlantic coast of Iberic Peninsula (Nuñez-Regueira *et al.*, 1997). There are however some important climatic differences between that region and the centre of Portugal, namely the very important factor concerning altitude, with the Galicia zone ranging from sea level to 100 m high, and the north/center of Portugal, that goes from 40 to 600 m, the annual rainfall index and the temperature amplitude, especially during the summer season (and, writing this, one can't avoid thinking that there have been some significant climatic changes that will require a more focused approach for the time to come). The methodology to proceed with the characterization of the sylvan species, from the energy point of view, keeping in mind the particularities of the Viseu's arborisation area, is due to start with a large gathering of data, concerning this biomass issues. A recent joint venture developed between FEUP/ESTV and the University of Valladolid in Spain has shown some significant hiatus on accessing some basic information, especially from the Portuguese side, when applying to INTERREG European program seeking to initiate some research and transfer technology on biomass combustion and decentralized energy production. Albeit our work's scope encompass a multidisciplinary approach, some areas will not be undertaken, such as a careful investigation of the relationship among the rate of removal of the residues, the balance of the nutrients in the soil of the forest submitted to the cleaning action (Zerbe, 1988) and the interdependence of the climate characteristic and the soil and places in analysis. These are fundamental aspects of the works to accomplish and, therefore, were directed to another team with adequate agronomical background and will not be referred at this time.

2.1. Climate and sylvan species

The District of Viseu, located in the centre/north zone of Portugal, northeast of the ancient Beira Litoral County, is composed by 24 municipalities, corresponding to an area of 501.685 hectares.

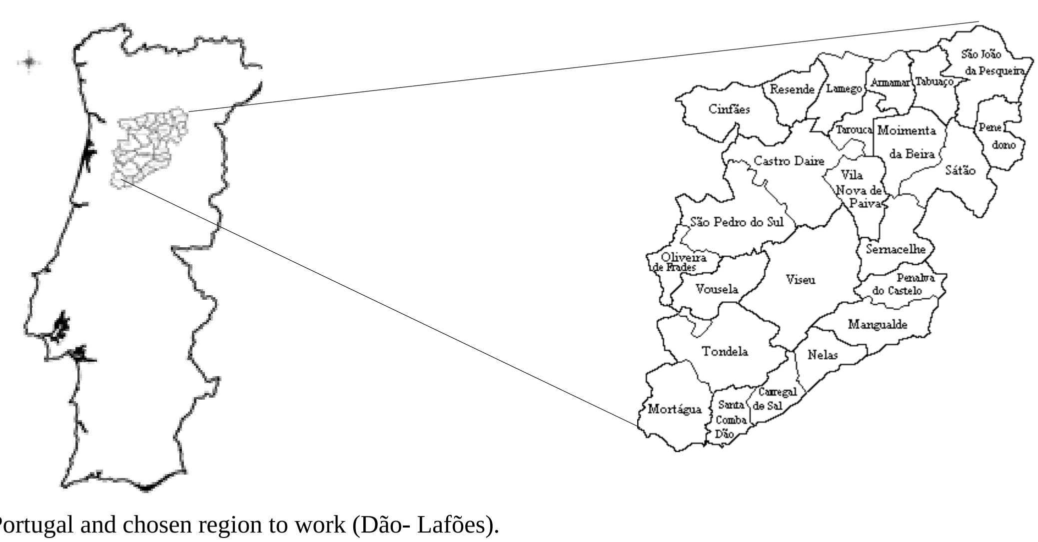


Figure 1. Portugal and chosen region to work (Dão- Lafões).

Taking into consideration the largest woodland area of the district, the following municipalities will be considered in the present study, representing part of the 'Dão- Lafões Tourism Area' (Fig. 1): Carregal do Sal, Castro Daire, Mangualde, Mortágua, Nelas, Oliveira de Frades, Penalva do Castelo, Santa Comba Dão, S. Pedro do Sul, Sátão, Tondela, Vila Nova de Paiva, Viseu and Vouzela. There is a climate division that crosses this zone, separating climate areas with Atlantic influence from others where the Continental influence is dominant. The presence of massive mountainous countries (Estrela-Gardunha-Lousã and Buçaco-Caramulo-Montemuro chains), is fundamental for this separation to occur.

The climate of the zone in study presents accentuated variations and it can be classified as wet in the mountainous areas turned to the Atlantic Ocean (where the air relative humidity, HR, measured at 9:00 G.M.T., has values ranging from 75 to 80%), dry in the low lands (HR between 55 and 75%) and temperate (colder at north and mountains), with the Summer season being, in general, dry and hot, or not very hot but long (Fabião *et al.*, 1992). The temperature distribution and the precipitation in this region are strongly conditioned by the presence of the mountainous chains of Buçaco-Caramulo-Montemuro and Estrela-Gardunha-Lousã. As in the Northern Hemisphere the temperature of the air decreases when the altitude and the latitude increases, the values of the thermal amplitude increase towards inland.

Table 1 – Main characteristics of the chosen zone (CMM, 2003)

Mortágua	
Altitude	90 m
Annual rainfall index	1500 mm
Mean annual temperature	15º C
Mean daily maximum temperature of the warmest month (August)	25º C
Annual average number of insolation hours	2600
Dominant species	*Eucalyptus globulus* Labill and *Pinus pinaster*
Other species	*Quercus Robur* Labill and bush species

The precipitation distribution grows from the coast to the mountainous highlands, decreasing progressively afterwards. The precipitation distribution is associated to the occurrence of North Atlantic depressions, during the winter, and to the displacement of the subtropical anti-cyclones, during the summer. Thus, precipitation is relatively abundant during the whole year, excepting summer, a moment when it is quite reduced. The values of the real transpiration by vaporization are within the range of 600 to 700 mm, and it is in the municipalities of S. Pedro do Sul, Tondela and Santa Comba Dão that these values are higher (Henrique and Nuno, 2000).

Table 2 – Main forest species engaged areas (ha), municipalities of the district of Viseu belonging to the Dão-Lafões region (DGF, 2001).

Municipalities	Total	Wild Pine-tree	Stone Pine	Other Resinous/ Softwood	Oak	Eucalyptus	Chestnut tree	Other Psalteria/ Hardwood	Forest	Arborization rate (%)
Carregal do Sal	11710	2940	70	-	420	1050	-	70	4550	39
Castro Daire	37625	7910	-	-	1610	1190	70	560	11340	30
Mangualde	22072	6160	-	-	420	140	-	-	6720	30
Mortágua	24859	3430	-	-	280	17850	-	-	21560	87
Nelas	12452	2730	140	-	210	-	-	-	3080	25
Oliveira de Frades	14745	5250	-	-	1050	2380	-	70	8750	59
Penalva do Castelo	13593	4270	-	70	280	70	-	210	4900	36
Santa Comba Dão	11254	1960	-	70	420	2590	70	-	5110	45
S. Pedro do Sul	34868	8050	-	70	1190	1690	-	840	11830	34
Sátão	19840	7490	-	-	70	560	-	280	8400	42
Tondela	37325	13860	-	-	1890	4970	-	70	20790	56
Vila Nova de Paiva	17737	2310	-	140	70	70	-	560	3150	18
Viseu	50720	23520	-	140	1,750	700	-	210	26320	52
Vouzela	19165	6720	-	-	1610	630	-	140	9100	47
Dão-Lafões	327965	96600	210	490	11270	33890	140	3010	145600	44

The forest region, based in the available data, is fundamentally constituted by ligneous plants of the resinous/softwood group (predominantly wild pine-tree- *Pinus pinaster*) and of the psalterium/hardwood group (dominant specie- the eucalyptus- *Eucalyptus globulus* Labill). According to the National Forest Inventory of Portugal (DGF, 2001)- the most recent available-, only the areas occupied by forest species are pointed out. The composition (mixed or pure), the non-ligneous species (other biomass) and the exploration method are not discriminated. This hiatus does not help in determining which areas, either peopling, or forest exploration, are better managed, thus conditioning the possibility of estimating their effective production. The species distribution that is ascertained by DGF (2001), Table 1, shows that the wild pine-tree continues to be the most abundant specie in the area in study, occupying 66% of the forest area (96600 ha). Eucalyptus is next, with 23.3% (33890 ha) and, finally, the other psalteria/hardwood, where oak ('roble' and 'alvarinho'- *Quercus robur* Labill) has a substantial weight with 9.9% (14420 ha).

2.2. Species biological characterization and forest samples collecting methodologies

The soil utilization in Dão-Lafões region is stratified. The main occupation areas are: agriculture- 26%, social- 4%, hydric- 2%, non-used- 23% and forest- 45%. The forest coverage in this region is characterized by the strong presence of the wild pine-tree, eucalyptus and riverain vegetation along the water lines. Beyond oak, other psalteria/hardwood exist in negligible quantities and are considered protected species, therefore lacking interest from a mass production point of view. Bulk samples were collected within a square meter area from previously chosen 1 ha forest, in each zone. These bulk samples were reduced to a representative sample of, approximately, 1 kg, by means of an adequate procedure (Nuñez-Regueira *et al.*, 1997).

2.3. Selection of pickup places

These gross values shall be analysed in detail for each sub-region. They are defined according to the type of soil, topography, orography and situation of the existing individual forest species. After choosing a homogeneous biomass zone, some representative items of the forest species were collected on a basis concerning the height of the tree and its total volume. The total mass was quartered and its residues separated from timber-yielding wood. These residues were separated in leaves, branches of bigger size and branches of smaller size (Nuñez-Regueira *et al.*, 2001a). The different samples were weighed and hermetically stored, so that its moisture content could not change when travelling from the forest to the laboratory. The defined yearlong periods, for each of the sub-regions, shall be a summation of 8 alternate days per season, so that the collected samples are representative of an average energetic value, regarding the main physics and chemical characteristics and taking into consideration the vegetative productivity periods (Nuñez-Regueira *et al.*, 1997). This choice of periods can be re-evaluated according with the experience obtained in determining the thermochemical parameters and the assessment of the influence of the biological and bioclimatic changes.

3. Energy characterization

The determination of biomass composition must follow adequate methodologies and the analysis of several papers produced by a research team from the University of Santiago de Compostela (Nuñez-Regueira *et al.*, 1997) was followed in the present work as an adequate experimental methodology. This team has been working for several years on the characterisation of forest biomass residues obtained from Galician forests (Nuñez-Regueira *et al.*, 1997; Nuñez-Regueira *et al.*, 1999; Nuñez-Regueira *et al.*, 2001; Nuñez-Regueira *et al.*, 2001a). Taking as reference the value from these forests (3 ton per ha and per year), the total region biomass production is expected around 436800 ton per year. As there shall be some caution about the enforcement of conclusions from studies performed on an arborisation area to another arborisation area, though relatively close, it became necessary to accomplish these studies in the area of Viseu. Given the shortage of analysis equipments, the first samples were delivered to INETI, a state technological institute. A project for home-manufacturing a proper calorimetric device is being implemented and is expected to be working by the end of July, 2003.

4. Experimental procedures

The center of Portugal possesses a forest area that corresponds to approximately 30% of the country's total forest area (Alves, 1982, Barreto, 1998, Paixão, 1999).

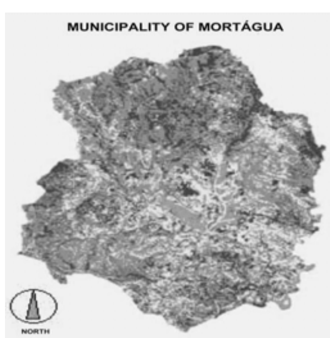


Figure 2. Mortágua municipality chart (darker areas equals higher forest density).

The municipalities belonging to part of this geographical region are referred to as the area of Dão-Lafões, within the district of Viseu. This region is located at Northeast of the old county of Beira Litoral. The district of Viseu is composed by twenty-four municipalities, corresponding to an area of 501.685 hectares. For this first stage of the study, the municipality of Mortágua was chosen (Fig. 2). It belongs to the mentioned region of Dão-Lafões and it is the one with the largest arborization rate (87%). Beyond the type of soil characteristics, the orography and the topography, it possesses the dominant forest species (*Pinus Pinaster* and *Eucalyptus Globulus* Labill).

The samples were picked up in a zone located in the freguesia of Sobral, at approximately 500m of the 228 National Road (Mortágua - Caramulo) at km. 45, during the period from December to February. The area presents a mountainous relief, with a schistous type of soil prevails. It presents both an Atlantic and continental climate influence (Fabião *et al.*, 1992). The annual average temperature is 13,6ºC. August is the hottest month with a daily average of 20,5ºC and January the coldest one with 7,4ºC. As to the average value of annual precipitation index it presents a value of 2151,5 mm, February being the rainiest month with 389,6mm and July the driest with 25,4 mm (CMS, 1997).

The experimental study began with the sampling work. In this exploration phase, the task consisted of picking up homogeneous biomass in that zone, regarding the selected forest species. After treefeling operations were prosecuted with tree blunting (separation of the shaft's residues). The log's wood, after being cut in trunks/stumps is used mainly as raw material for pulp production, typically with eucalyptus, and used in furniture manufacturing, for the case of wild pine-tree. Therefore, the samples were chosen in order to be the best representative of the expected morphological composition of biomass disposed to be left in place and burned by usual means, *i.e.*, the parts of the forest biomass that timber-merchants, after treefeling, consider having no economic benefit due to the charges associated with the reaping, gathering and transport freights. The forest residues were then divided in three parts:

Leaves (pine-needles in the case of wild pine trees),

Branches/small logs with diameters smaller than 3 cm

and

branches/small logs with diameters between 3 and 6 cm.

The different samples were marked and kept separately in plastic bags (polypropylene) and were transported to the laboratory in less than eight hours time. Each sample was weighed with a thousandth of gram resolution, using a Precisa 205ASCS scale. They were then heated to constant weight in a WTB-BINDER F115 natural desiccating stove, at a temperature of 103 ± 2 ºC, and the moisture calculated from the knowledge of the weight loss of the sample after treatment in the stove. The methodology used to present the values was based on the weight of the dried sample, *i.e.*, the ratio between the weight of the lost moisture and the weight of the sample after being dried in the stove:

$$moisture = \frac{W_o - W_{sd}}{W_{sd}} \cdot 100 \qquad (1)$$

where W_0 is the original weight and W_{sd} the 'stovedry' weight (McMillen, 1956). The rate of drying was also recorded. Test samples were kept in a refrigerator so that they could be used in reruns or as a reference to assess future data analysis.

5. Preliminary results and discussion

Since the knowledge of chemical composition is necessary for calculation of calorific values, elementary chemical analyses were determined. Several sets of samples were tested, representing a total of 20 units, within the diameters mentioned before (and represented in Fig. 3) and for the morphological parts described.

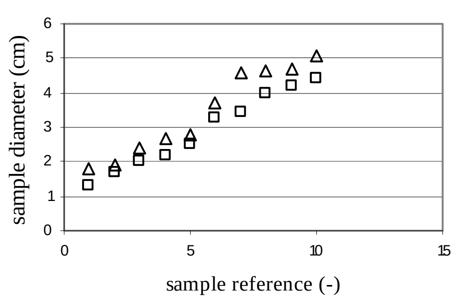


Figure 3. Samples average diameter (squares- eucalyptus, triangles- wild pine).

They were chromatographically tested for detection of Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur, by means of an elemental analysis, and dried to assess the level of moisture. As to the elemental analysis, the results of the elementary chemical composition are exposed in Table 3, for the studied specimen obtained from eucalyptus and pine-tree logs, as well as for eucalyptus leaves and pine-needles.

Table 3. Experimental results of the elemental analysis made on the biomass samples (sulphur*- see text below).

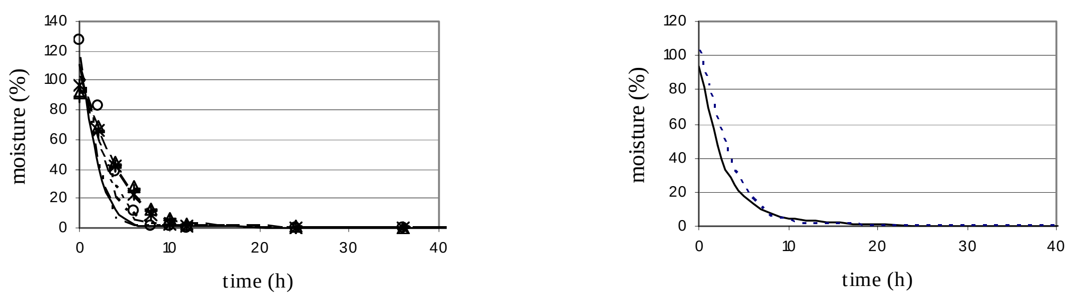
Biomass sample	*E. Globulus* Labill logs	*Pinus Pinaster* logs	*E. Globulus* Labill leaves	*Pinus Pinaster* needles
Ref.	106.104/147	106.104.148	106.104.150	106.104.149
C (w- %)	37.13	44.3	53.67	47.53
H (w- %)	6.52	6.15	7.07	6.58
O (w- %)	> 48.84	> 41.92	> 31.25	> 37.60
N (w- %)	0.07	0.19	0.57	0.85
S (w- %)	*	*	*	*

The results obtained by these analyses show no regular dependence between the two species and the content of carbon. In fact, the average value of this element is less present in eucalyptus logs than in pine-tree ones, whilst that the opposite happens between eucalyptus leaves and pine-needles. Nonetheless, as can be seen in Table 3, ‘dead’ biomass samples, *i.e.*, the forest residue usually abandoned after forestry tasks, has higher carbon content than the noble part of wood. Though there is still much work to be done, namely on the final outcome that represents the actual available heating value this is a quite noticeable aspect of this primary assessment. As to the sulphur content, its value was below the detection limit (7.44 %), as this was the lowest value capable of quantification by the chromatography equipment used (Fisons Instruments NA1500 N). This fact was confirmed through several analysis using enriched phenantren from Elemental Microanalysis (0.6 % sulphur). Nonetheless, this is no proof of the non-existence of sulphur in the analysed samples and, due to the importance of this item, a more accurate and higher resolution equipment is sought to be used to test the samples in the near future.

Table 4. Experimental results of the mean moisture content of the biomass samples collected in a winter season.

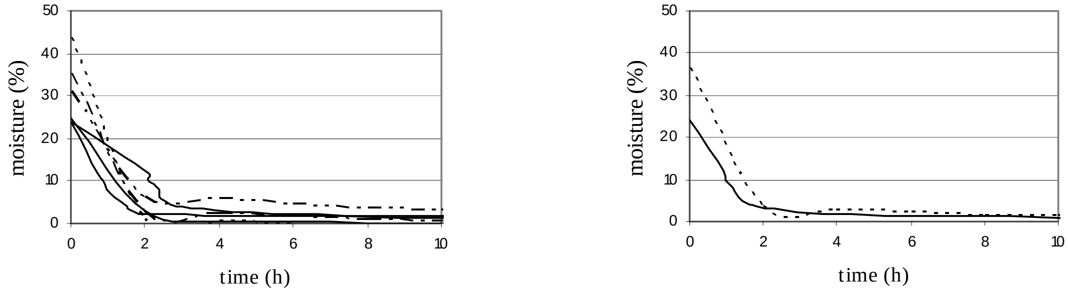
Biomass sample ref.	*E. Globulus* Labill logs	*Pinus Pinaster* logs	*E. Globulus* Labill leaves	*Pinus Pinaster* needles
%1	93.842	110.865	22.681	43.923
%2	88.934	103.466	24.768	35.450
%3	95.258	103.635	24.875	30.801
%4	99.886	108.869	23.235	32.458
%5	94.789	115.980	23.458	42.815
%6	96.589	97.325	-	-
%7	91.469	127.686	-	-
%8	89.292	88.670	-	-
%9	95.126	92.242	-	-
%10	88.782	91.102	-	-

The degree of variation encountered is portrayed in Figs. 4-6.



(a) (b)

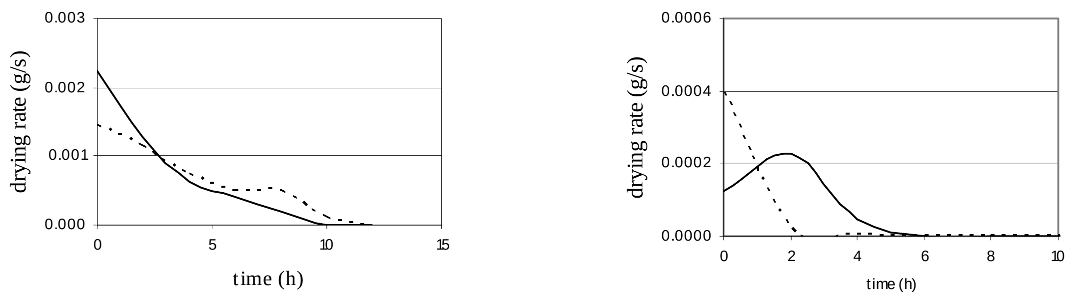
Figure 4. (a) Moisture content (weight of water by weight of totally dried sample) evolution with time, several samples of wild-pine and (b) branches moisture content evolution with time, average values (solid line- eucalyptus; dashed line- pine).



(a) (b)

Figure 5. (a) Moisture content (weight of water by weight of totally dried sample) evolution with time, several samples of wild-pine and (b) branches moisture content evolution with time, average values (solid line- eucalyptus; dashed line- pine).

The moisture content of log samples of the two species, obtained in preliminary tests, is shown in Fig. 5. Figure 6 represents the value of the corresponding rate of drying values, recorded for logs and leaves of eucalyptus and logs and pine-needles of wild pine-trees.



(a) (b)

Figure 6. Logs (a) and leaves (b) drying rate with time (g/s), average values (solid line- eucalyptus; dashed line- pine).

Considering the relatively small area under analysis, the level of diversity is considerable and is the cause of one of the major problems of the existent 12 MW Mortágua power plant: the difficulties of burning considerable amounts of mixed (and bulk) biomass, proceeding from twenty different municipalities, in order to ensure the required supplying quantities.

6. Conclusions

Some useful data gathering concerning the areas of the region to study was performed, with respect to the existent dominant sylvan species. The level of variation of biomass characteristics, though only its moisture content has begun being assessed with this incipient experimental work, enforces the feeling that smaller power plants will burn forest wastes from a limited area and the fuel physico-chemical and morphological characteristics of the biofuel will have a smaller variability facilitating the burning process and control. This brings some advantages to the fuel preparation technique, furnace feeding devices and consequently in terms of regulation and control of the combustion regime and pollutants emission. Seasonal biomass variations will be smaller and fluctuations on the fuel moisture content will also be reduced. The final result will be a better quality of combustion and higher thermal conversion efficiency from biomass to the final electrical energy. Social and environmental disadvantages due to the existence of a power plant will be spread among different places and typical social stresses arising from such situation will consequently be reduced.

This is a first report of a preliminary work that was carried out since November 2002.

Subsequent tasks will enable deepening this incipient analysis as well as enfolding gathering data that allows the calculation of:

- ligneous wastes and woods immediate composition;
- ligneous wastes and woods elemental composition;
- the thermal conductivity of the wood and ligneous residues as a function of the different sylvan species involved as well as their moisture content (this knowledge is important for theoretical, experimental and numerical studies on the reaction front propagation studies, during drying and devolatilization and combustion of ligneous particles (Liodakis *et al.*, 2002; Thunman e Leckner, 2001);

- ligneous and forest wastes low heating values;
- flammability limits of ligneous powders and dusts (tests covering two typical situations: self-ignition temperatures, self-ignition limits and forced ignition limits);
- ligneous and forest wastes laboratory size combustion studies in fixed and in fluidized bed furnaces, either bubbling or circulating .

7. References

Alves, A. M., 1982, "Técnicas de Produção Florestal", INIC-Instituto Nacional de Investigação Científica, Lisboa.

Barreto, L. S., 1998, "A Floresta, Estrutura e Funcionamento", Serviço Nacional de Parques, Reservas e Conservação da Natureza (eds.), Lisboa.

Bhattacharya, S.C., 1998, "State of the art of biomass combustion", Energy Sources, 20, pp. 113-135, Taylor and Francis.

Boyle, T., 1996, "Biodiversity of Canadian forests, with particular reference to the west coast forests". In R.G. Lawford, P.B. Alaback and E. Fuentes (eds), High-latitude Rainforests and Associated Ecosystems of the West Coast of the Americas. Ecological Studies 116, Springer-Verlag, New York, pp. 353-378.

CMM, 2003, "Caracterização Climática", Motágua-info, Câmara Municipal de Mortágua, Mortágua.

CMS, 1997, Referring monthly average values of the period between 1955 and 1984, Caramulo meteorological station.

DGF, 2001, "Inventário Florestal Nacional", Ministério da Agricultura , Desenvolvimento Rural e Pescas, publicações periódicas, Setembro de 2001, Lisboa.

el Bassam, N., 1998, "Energy Plant Species.Their Use and Impact on Environment and Development", James and James (Science Publishers) Ltd, London.

Fabião, C., Silva, F. and Silva, R., 1992, "Estudo dos ordenamentos cinegéticos, aquícolas and apícolas das áreas do Baixo Dão-Lafões e Entre Dão e Mondego", Instituto Superior de Agronomia, eds. C.N.A. (1982), Lisboa.

Hammond, G.P. and Stapleton, A.J., 2001, "Exergy analysis of the United Kingdom energy system", Proc. Instn. Mech. Engrs., Vol. 251, Part A, pp. 141 – 162.

Henrique, M. and Nuno, A., 2000, "Roots for the Development of the Forest", DGF eds, Viseu.

INF, 1999, Klass, D. L.,1998, "Biomass for Renewable Energy, Fuels , and Chemicals", Academic Press, London.

Liodakis, S., Bakirtzis, D. and Dimitrakpoulos, A., 2002, "Ignition characteristics of forest species in relation to thermal analysis data", Thermochimica Acta, 390, pp. 83-91.

McKendry, P., 2002, "Energy production from biomass (part 1): overview of biomass", Bioresource Technology, 83, pp. 37-46.

McKendry, P., 2002, "Energy production from biomass (part 2): conversion technologies", Bioresource Technology, 83, pp. 47-54.

McKendry, P., 2002, "Energy production from biomass (part 3): gasification technologies", Bioresource Technology, 83, pp. 55-63.

McMillen, J.M., 1956, "Methods of determining the moisture content of wood", SU Press, New York.

Núñez-Regueira, L., Rodríguez-Añón, J.A. and Proupín-Castiñeiras, J., 1997, "Calorific Values and Flammability of Forest Species in Galicia. Continental High Mountainous and Humid Atlantic Zones", Bioresource Technology, 61, pp. 111-119.

Núñez-Regueira, L., Rodríguez-Añón, J.A., Proupín-Castiñeiras, J., Vilanova-Diz, A. and Montero-Santoveña, N., 2001, "Determination of calorific value of forest waste biomass by static bomb calorimetry", Thermochimica Acta, 371, pp. 21-31.

Núñez-Regueira, L., Rodríguez-Añón, J.A., Proupín-Castiñeiras, J., and Núñez-Fernández, O., 2001a, "Calculation of forest biomass indices as a toll to fight fores fires", Thermochimica Acta, 378, pp. 9-25.

Obernberger, I., "Decentralized Biomass Combustion: State of the Art and Future Development", 1998, Biomass and Energy, Vol. 15, No. 1, pp. 33-56.

Paixão, N., 1999, "Forest Array in the Concelho of Mortágua", Portuguese Catholic University press, Pole of Viseu.

Strehler, A., 2000, "Tecnologies of wood combustion", Ecological Engineering, 16, pp. S25-S40.

Thunman, **X.** and Leckner, B., 2001, "Ignition and propagation of a reaction front in cross-current bed combustion of wet biofuels", Fuel, 80, pp. 473-481.

Wagman, D., Evans, W., Parker, V., Schumm, R., Halow, L., Bailey, S., Churney, K. and Nuttall, R.J., 1982, Phys. Chem. Ref. Data, p. 11.

Werther, J., Saenger, M., Hartge, E.U., Ogada, T. and Siagi, Z., 2000, "Combustion of agricultural residues", Progress in Energy and Combustion Science, 26, pp. 1-27.

Zerbe, J.I. and Skog, K.E., 1998, "Sources and Uses of Wood for Energy", Proceedings from international symposium: Energy options for the year 2000: Contemporary concepts in technology and policy, pp. 1243-1254.