Bioenergy potential of forest residues in the north of Spain

E. Mateos[1], J.M. Edeso[2]

[1] Department of Chemical and Environmental Engineering
E.U.I.T.I., University of the Basque Country (UPV/EHU)
Paseo Rafael Moreno "Pitxitxi" 3, 48013 Bilbao (Spain)
phone:+34 946 014343, fax:+34 946 014300, e-mail: **esperanza.mateos@ehu.eus**

[2] Department of Mining and Metallurgical Engineering and Materials Science
E.U.I.T.I., University of the Basque Country (UPV/EHU)
Nieves Cano12, 01006 Vitoria (Spain)
phone, +34 945 013229 , e-mail: **josemiguel.edeso@ehu.es**

Abstract. The use of biomass for energy production has created a great deal of interest recently, which is due partly to environmental reasons. These reasons are mainly the problems caused by climate change and the need to search for a solution to the foreseeable exhaustion of fossil fuels. The aim of this research work is the development of a methodology to determine the amount of residual forest biomass for its energy valuation and to map the results by means of Geographic Information Systems (GIS). After analyzing statistically the results obtained 74,591 Mg year^{-1} of residual total biomass have been estimated. This yields an equivalent energy potential of 947,000 GJ year^{-1}.

Key words

Residual biomass, GIS, Renewable energy, Bioenergy

1. Introduction

Biomass is the most common form of renewable energy, widely used in the third world but until recently, less so in the Western world. Latterly much attention has been focused on identifying suitable biomass species, which can provide high-energy outputs, to replace conventional fossil fuel energy sources and, moreover, it could decrease environmental pollution [1]. The use of biomass with energy purposes means a series of advantages over fossil fuels. The following can be underlined:

1 *Neutral balance of emitted carbon dioxide during combustion, since the CO_2 of the living biomass forms part of a flow of continuous circulation between atmosphere and vegetation*

2 *The combustion of residual biomass does not emit either sulphured or nitrogenous pollutants, or hardly solid particles, thus being much more respectful with the environment.*

3 *The exploitation of residual biomass means to change a residue into an energy resource.*

4 *Decrease of external dependence on fuel supply.*

5 *Technological innovation processes will let optimize the energy yield of biomass*

6 *Contribution to reducing external energy dependence*

Biomass is the third largest primary energy source in the world following coal and petroleum. It is still the main source of energy for more than half of the world's population and provides about 1.25 billion toe (tons of oil equivalent) of primary energy, or about 14% of the world's annual consumption of energy [2].

The objective of this work is to quantify and to map potential the power production of residual biomass coming from the more representative forest species in Bizcaia (Spain). A further aim is to determine the ideal locations for setting up installations designed to use this fuel for energy purposes, for which Geographical Information Systems (GIS) will be used. With the support of the different cartographies performed periodically, the GIS tool is of great use as it allows the rapid and fairly reliable quantification of the resources available in the study area [3-6]. The basic concept is that a power plant would be located in proximity to a source of biomass.

The biomass would be brought into the power plant and burned as a feed stock to generate electricity. Forestall biomass includes two types of forest products that nowadays have almost no exploitation and as a result of this they are considered residues: a) Vegetable residues from different forest treatments such as pruning, bud selection, fitosanitarium cuttings and underbrush cleaning; b) Wood exploitation residues, either from final o from intermediate cuttings, or vegetal matter from energetic cultivation installed in forest fields.

Spain is a country with particularly low oil and natural gas reserves, and its coal reserves are low because of a mining crisis, so it has a negative energy trade balance. However, it has healthy forest and agro-industries that generate a huge amount of non-useful wastes, circumstances suggesting that a profound study of biomass for energy production is advisable [7]. Typical biomass electricity generation in Spain is similar to conventional, fossil-fuel generation: biomass is burned for heat to produce steam, powering turbines that generate electricity (though other methods of converting biomass to electricity exist).

In complete biomass-based fuel combustion the only by-products are carbon dioxide (CO_2) and water (H_2O), but is assumed to be carbon neutral since new biomass growth absorbs previously emitted carbon. Biomass contains less sulphur and ashes than coal, thus generates low emissions of SO_x and particles.

Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass material. Other options include gasification, pyrolysis, and anaerobic digestion. Gasification produces a synthesis gas with usable energy content by heating the biomass with less oxygen than needed for complete combustion. Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen. Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen [8].

Compared to many other renewable energy options, biomass has the advantage of dispatchability, meaning it is controllable and available when needed, similar to fossil fuel electric generation systems. Biomass is the only renewable source with guaranteed energy supply to the grid. The specific features of the economy of scale restrict the design of energy plants to those with a minimum production capacity of at least 1.5 MW, this corresponds to a need for 7,000 Mg of raw material. In many cases, biomass can be installed close to the centres where it is consumed, thus reducing grid losses. The disadvantage of biomass for electricity generation, however, is that the fuel needs to be procured, delivered and stored [9].

Most biopower plants use direct-fired combustion systems. They burn biomass directly to produce high-pressure steam that drives a turbine generator to make electricity with efficiencies of approximately 20%. (Figure 1).

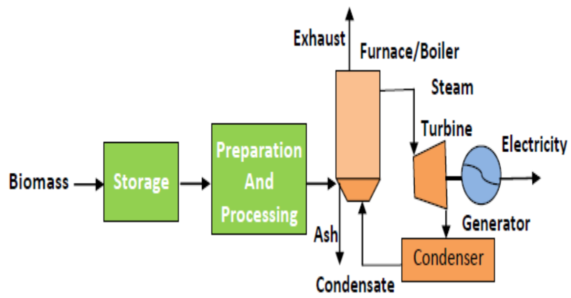


Fig. 1. Direct Combustion/Steam Turbine System

The combined heat and power (CHP) systems greatly increase overall energy efficiency to approximately 80%. Data related to the use of biomass for electric power generation through cogeneration or co-firing systems have placed Spain in a modest position (ninth place) compared to countries in northern Europe such as Sweden, Finland, Germany, Poland, and Austria. However, studies have shown that the combined technical potential of agriculture and forestry residues in Spain is equivalent to 11.25% of the net electrical energy generated in Spain in 2008 [10].

One of the major problems of biomass management is the cost associated to collection and transport activities. As will be noted below, GIS-based techniques are of particular utility in assessing the costs of biomass supply at a regional level [11].

2. Methodology

2.1. Description of the area of study

Bizkaia is located in the north of Spain and extends over 2,217 km^2. This province is located in the north of Spain at latitude 43º16´N and longitude 2º56´W (Fig. 2). It is an abrupt and mountainous province, crossed by deep valleys that descend quickly towards the sea from the near mountains close to the also abrupt and cliffy coast. The lands of Bizkaia form a very rugged set in which erosion has produced an important dissection of the land. The climate in the area, warm and humid (Atlantic climate), is conditioned by its proximity to sea, and it notably influences the proliferation of forest species, typical in this climate, especially pine forests.

Fig. 2. Territory of Bizkaia

2.2. Estimation of Residual Forest for Energy Use

A geographic data base is worked out within the inital phase of the project. This is carried out by gathering data from several sources of information so that a "Map of Energetic Resources of forest biomass in Bizkaia" is obtained at a scale of 1:50,000 (MFE50) . For estimating the amount of annual biomass (metric tons/year) that might be generated by current forest masses in Bizkaia, the methodology applied uses a Geographic Information System (GIS) with the help of the Arcview GIS 10 program. In order to carry it out, the forest species distribution vectorial information is pasterized with a spatial resolution pixel of 2 meters terms of its most characteristic specie [12-13].

The methodology used to determine the annual amount of residual forest biomass (RFB) in Bizkaia, expressed in tons $year^{-1}$ of dry weigh is determined after considering two factors (Fig. 3):

1. *The quantity of forest residue per unit of surface and time (Tons ha-1year-1) of the main forest species and*

2. *The surface (ha) occupied by such species that is going to produce this residue.*

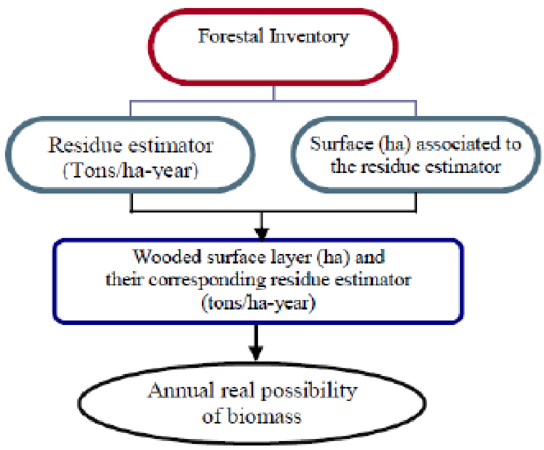
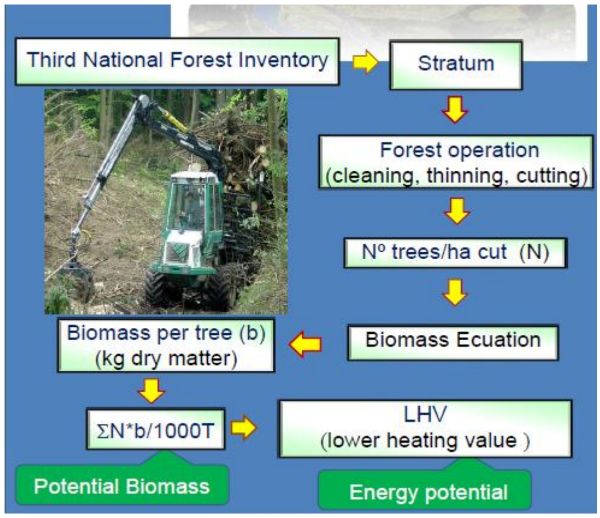


Fig. 3. Potencial anual possibility of biomass

The main forestry mass of Bizkaia, considering the area it occupies, pertains to plantations of *Pinus radiata* D. Don (72,674 ha), *Quercus robur* L. (13,270 ha) and *Eucalyptus globulus* Labill (10,120 ha). In this study, the mass of Quercus robur L. has not been considered as a potential source of residual biomass, in spite of the extent of its dispersion, due to the high market value acquired by products obtained from pruning.

Fig. 4 shows a schematic representation of the procedure used to determine the forested area that could be used for energy production.



Fig, 4. Schematic diagram of the methodology

TABLE I. - Strata from 3 IFN of Bizkaia

Stratum	Predominant forest species	Mass stage	Covered fracc (%)	Room (Ha)
01	*Pinus radiata*	*Sawtimber, poles*	70 - 100	45.210
02	*Pinus radiata*	*Sawtimber, poles*	5 - 69	5,589
03	*Pinus radiata*	*Saplings.Seedlings*	40 - 100	12,382
04	*P. radiata and P. nigra with Q. robur, Castan s. and River trees*	*Saplings.Seedlings*	5 - 39	8,655
05	*Cham. lawsoniana,* and *Larix spp.*	*All*	5 - 100	4297
06	*P pinaster* and *E. nigra*	*Sawtimber, poles*	5 - 100	5,250
07	*Q. robur y Q. robur with C. sativa, C. avellana,*	All	5 - 100	17,650
08	*Q ilex y Q ilex with Q. faginea, or Q. robur*	All	5 - 100	6,563
09	*Eucalyptus spp.*	*Sawtimber, poles*	5 - 100	9.183
10	*E. spp, and Eucaspp. with P. radiata*	*Saplings. Seedlings*	5 - 100	3,804
11	*F. sylvatica y F. sylvatica with B spp., Castanea s or Q. robur*	All	5 - 100	5,523
12	*River trees*	All	5 - 100	2,522

In order to determine the residue estimator generated in each sampling plot, it is only necessary to know what stratum, from which the plot of the surface was taken, is catalogued.

Once the forestry masses had been classified by strata, the forestry treatments, which must be undertaken in each stratum for 10 years, were identified. To do this, previous studies performed by the Regional Government of Castilla y León, 1989, were considered.

The residual forest biomass Er (tons ha^{-1} $year^{-1}$) of *P. radiata* and E. *globulus*, which was obtained after the forestry treatments in the strata where both species are predominant, was estimated for each sampled and documented tree in the parcels inventoried in the NIF3.

Strata 1, 2, 3, in which *P. radiata* appears as the predominant species, are selected. As far as *E. globulu* is concerned, stratum number 9, whose mass state (Sawtimber, poles) advises a final clearing or cut, is selected. The estate of *eucalyptus* masses in stratum number 10 (Saplings. Seedlings) does not currently add, in a meaningful way, any residual biomass [15].

The most common procedure for estimating biomass in forests is to use allometric regression equations based on diameter at breast height (DBH) and individual tree biomass [4]:

$$W = a\ X^b \tag{1}$$

An appropriate method for estimating biomass stocks is the use of the concept "stratum", which is defined in the Third National Forestry Inventory (3NFI) [14].

Every stratum is formed by grouping the forest surfaces of similar features, whose perimeter is marked out to a 1:50,000 scale. The 3NFI defines 12 strata in Bizkaia (Table 1).

Where W represents the biomass for each tree (expressed in kg dry mass); X (cm) is the DBH, typically measured at 1.3 m of trees on the sample plots above a mínimum diameter (7.5 cm); and a and b are the two specific regression parameters. The final result should be multiplied by a correction factor, obtained from the standard deviation of the estimation, in order to eliminate the bias introduced by potential transformation [16].

The estimator of forest residue (Eri, tons $ha^{-1}year^{-1}$) in tons dry mass is:

$$E_{ri} = \frac{\sum_{i=1}^{n} W_i}{1000 \cdot T} \tag{2}$$

Where T is the time of forestry treatments (year) and n is the number of trees cut per hectare. The amount of annual forest residue Wr (tons ha^{-1}) capable of being used for energy purposes has been estimated by the use of the area (Ai , ha) of the resulting sites and the estimators of woodland residue:

$$W_r = \sum_i A_i\, E_{ri} \tag{3}$$

2.3. Physical characteristics of Residual Forest Biomass

With the aim of characterizing residual forest biomass from the viewpoint of energy, dry matter content (DMC) at 105 ◦C according to the Standard TAPPI, T-11m-59; ash content (AC); elemental analyses (%C, H and N), humidity, and Lower Calorific Potential (LHV) of each sample have been estimated

2.4. Available energy potential

We calculate the quantity of forest residue generated by the main forest species of Bizkaia. After this has been done, the potential energy that could be achieved with those residues is estimated, taking into account their sustainable exploitation.

The energy potential represents the total amount of Forests residues from the selected species in Bizkaia that is available for energy production purposes, and may be regards as the upper limit for the value of energy tan can be obteined fron¡m such kind of wastes [17].

The potential energy of the residues P is a function of the lower heating value (LHV). The analytical expression used for the estimation of the residual biomass is the following:

$$P = \sum_i A_i\, E_{ri}\, \mathrm{LHV} \tag{4}$$

Where P represents the potential energy (GJ $year^{-1}$) and LHV the lower heating value (GJ Mg^{-1}). A conversion efficiency of 30% was used for estimating technical electrical energy generation [18].

The potential energy of biomass expressed in kJ/ha is calculated by using SIG tools (Ackview GISTM). In order to carry it out, the forestal species distribution vectorial information is pasteurized with a spatial resolution pixel of 1 ha in terms of its most characteristic specie.

3. Results

3.1. Heating values

Table 2 presents the heating values used to determine the energy potential of the forests biomass under study. These heating values were used to calculate the values of both the theoretical and available energy potentials.

TABLE 2. Heating values (GJ kg^{-1}) of the types of residue under study

	P. radiata	*E. globulus*
Mean	20,75	20,96
Standard deviation	0,34	0,51
CV	1,63	2,42
Maximum	21,32	21,90
Minimum	19,84	19,98

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3.2. Residual Biomass

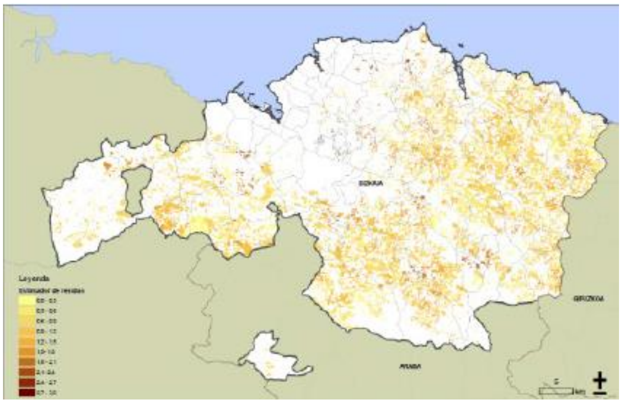
Table 3 shows the results of biomass calculations for the main forest species in Bizkaia. From these, 52,214 tons $year^{-1}$ dry matter and 74,591 tons $year^{-1}$ wet matter of residual total biomass have been estimated. This yields an equivalent energy potential of 947,000 GJ $year^{-1}$. Most of this residue derives from the P. radiata, due to the predominance of this species in Bizkaia.

TABLE 3. Potential of residues production (tons year^{-1}) and Potental Energy (GJ year^{-1})

Forest species	Usable (ha)	Biomass Residues (Tons year^{-1})	Pot . Energy (GJ year^{-1})
P. radiate	63,181	44,689	808,871
E. globulus	9,183	7524.5	138,129
All	72,364	52,213.5	947,000

Estimators for the *P. radiata* forest ranged from 286 to 885 kg ha^{-1} year^{-1}, and 346 to 2,156 kg ha^{-1}year^{-1} of *E. Globulus* (dry mass, which corresponds to 408.6-1,264.3 and 494-3,080 kg ha^{-1} year^{-1} wet mass). These biomass resources can produce electric power of 10-20 MW depending upon the efficiency of thermal conversion.

The utilization of forests biomass for production of electric power can help to reduce the environmental emissions while achieving energy security and sustainable development. Figure 5 shows the values of the residue estimator (metric tons/ha year) that correspond to stratum 1 (dominant species Pinus radiata) from Bizkaia



Fig, 5. Map of residue estimator E_r (Mg ha^{-1} year^{-1})

4. Conclusion

The use of residual forest biomass for energy purposes would permit the exploitation of residues, increasing regional socio-economic development through additional local employment and infrastructures. The major challenges faced by these energy conversion technologies include how to collect, prepare (chipping, briquetting, etc.) and transport biomass to electric power plants with the lowest possible financial and environmental costs, and how to assure supplies over time.

GIS is a powerful tool of great use for evaluating forest biomass resources since it efficiently combines both cartographic data and information from different databases that facilitate the work of mapping the results. Through the use of forest biomass, an important reduction is expected in forest fires, which at this time are a cause for concern in the study area.

Using residual forest biomass as an energy source provides employment and creates new business opportunities in rural communities. Biomass fuels reduce the dependence on fossil fuels and increase levels of energy self-sufficiency.

The increase in the use of residual forest biomass as an energy source instead of fossil fuels involves environmental advantages, such as a reduction in sulphur emissions and particles, and minimum emissions of polluting agents and will help to follow the aims of the EU policies in terms of energy rationalization and fight against global heating, and thus, 20% of the energy consumed in 2020 would come from renewable sources.

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Key words: Bioenergy potential, Biomass, forestal residues, resources map

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