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Study on the Potential of Forest Biomass Residues for Bio-Energy †

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Abstract: The Kyoto protocol officially recognised the role of forests as carbon sinks in the mitigation of global climate change factors, basically by reducing the atmospheric concentrations of CO_2. The utilization of forest biomass residues for bio-energy can help meet the need for renewable energy production. The aim of this research work is the development of a methodology to quantify and yield cartography of the prospective energy production of residual biomass from the most representative forest species of Biscay, province of the Autonomous Community of the Basque Country (ACBC, Spain), using a Geographic Information System (GIS) computer tool. A model of indirect estimation has been used in order to estimate the evolution of forest masses throughout in any area of Biscay. In the study area, residues from forest represent a large biomass potential. The stock of total forest biomass (aboveground and underground) (TB) existing in the forests of the province of Biscay in the year 2016 amounted to 16.380 Tg of dry material, which implies a sequestration of 29.874 Tg of CO_2. The results obtained after the statistical analyses of the data showed that the amount of mean forest biomass residue achieved with a 95% confidence interval was 73,216.7 Mg year^{-1}. The estimation of biomass quantities that may generate forest activity will allow us to accomplish its planned exploitation, taking into account both economic and environmental aspects, with the aim of determining which the optimum location for setting up an energy production plant is.

Keywords: bioenergy potential; resources map; forest residues

1. Introduction

Renewable energy has gained a lot of interest amongst many countries. In Spain, the 2011–2020 Renewable Energy Plan set the target of 20% of total primary energy needs to be met by renewable sources and about 10% of these by bioenergy [1]. In the Autonomous Community of the Basque Country (ACBC), biomass is currently the most widely used source of renewable energy. For example, in 2015, the total energy consumption was 6301 ktoe, of which 6.9% or 435 ktoe was renewable energy. Of this amount, 85% was biomass [2]. On the other hand, forest ecosystems represent one of the largest carbon reserves and sinks. The Basque Plan for the Fight against Climate Change 2008–2012 states that the forest and farming land of Biscay operated in the form of sinks in 2005 amounted to 0.6 million Mg and 297 million Mg of CO_2, respectively. One of the most important advantages of biomass use is its low atmosphere-pollutant production when compared with conventional fuels: minimum production of SO_2 due to its low S content; the emission of NOx is also significantly reduced since biomass combustion can take place at lower temperatures, almost without affecting its yield [3]. Apart from this, the use of forest biomass for energy purposes has a null CO_2

emissions balance since CO_2 emissions that occur as a result of its recovery as energy are offset by the amount absorbed by organisms for the production of biomass through photosynthesis.

The use of forest biomass as an energy source helps to reach the compromises acquired by the European Union in the Kyoto protocol. Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass material. Other options include gasification and pyrolysis. 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. Forestry residues (FR) can potentially be converted into different high value products including value added chemicals and energy sources.

One of the main barriers for using this resource is the lack of knowledge of its real forest-mass biomass production capacity. This is a key aspect, since it prevents to know the steady biomass supply that could assure production in thermoelectric plants that might use it. 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 Biscay (Spain). The estimation of FR that can generate forest activity in the area would allow to carry out their planned exploitation considering both economic and environmental aspects. This would also help to determine the optimum location for installing an energy production centre under the premise of being a resource sustainable exploitation.

2. Methodology

2.1. Study Area

This study was carried out in the province of Biscay, one of the three provinces of the Autonomous Community of the Basque Country (ACBC) in the north of Spain (43°46′–42°42′ N, 03°45′–02°40′ W). This province is situated on the banks of the Cantabria Sea, in the north of the Iberian Peninsula. Site characteristics were detailed in a previous paper [4]. It is a mountainous province with slopes often exceeding 30%. As a result of this, erosion in this stretches is considerable. The annual average rainfall is about 1200 mm and the mean annual temperature is 13.8 °C. Data from Fourth National Forest Inventory (NFI4, 2011) depict that forest surface in this province is 131,748 ha, representing about 60% of its surface (221,232 ha). The main forest species are *Pinus radiata* D. Don (PR) and *Eucalyptus globulus* Labill (EG) [5].

2.2. Estimation of Residual Forest for Energy Use

This study estimated the annual FBR for bio-energy in Biscay, obtained in the forestry treatments and its geographical distribution. 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. After reviewing the different forest residue estimating methods, the one chosen is the so-called indirect method, since this methodology provides similar results to those obtained through direct methods. Moreover, in indirect methods a higher quantity of quantitative information is used and this methodology can be applied to data from future forest inventories [6]. For estimation of the annual quantity of residual forest in Biscay (Q_{FR}, Mg year^{-1}), two factors must be determined: (a) Forest residue per unit of surface and time derived from a forest mass (Y_{FR}, Mg ha^{-1} year^{-1}) in terms of estimation of the species and forest treatment each mass has been subjected to, and (b) the surface S_i (ha) occupied by the forest mass this residue will generate:

$$Q_{FR} = \sum_{i} S_i * Y_{FRi} \tag{1}$$

The evaluation method should consider the different phases across the complete rotation of a forest stand and the forest tasks performed in each phase [6]. The rotation cycle of PR is an average of 30 years. After the final cutting, a reforestation with an initial average density of 1500 trees ha^{-1} is applied. In the tenth year, the first regeneration cutting takes place, removing 600 trees ha^{-1}. At this stage, all the usable biomass is aimed at woodchips, mainly for pulpwood or the cellulose pulp industry. The first commercial thinning takes place in the seventeenth year, removing 330 trees ha^{-1}. The second commercial thinning takes place in the twenty-fourth year, removing 220 trees ha^{-1}. After 30 years, the last cutting takes place, removing 100% of the existing timber volume. For EG a shift of 10 years was considered in this work. Clearing processes are not applied in the productive cycle of eucalyptus, and a one-time cut is made at rotation age. The methodology applied uses a GIS. In order to carry it out, the forestall species distribution vectorial information is analyzed with a spatial resolution pixel of 2 m terms of its most characteristic species. A further aim is to determine the ideal locations for setting up installations designed to use this fuel for energy purposes, for which 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 [7-9]. The basic concept is that a power plant would be located in proximity to a source of biomass. After 30 years, the last cutting takes place, removing 100% of the existing timber volume. For EG a shift of 10 years was considered in this work

2.3. Useable Residual Forestry Biomass

The usable residual biomass is found after applying a number of specific restrictions that impede the extraction of biomass. For both environmental and economical reasons, the collection of Q_{FR} should not be carried out in areas of steep slopes. Slope has a direct effect, restricting the type of machinery used to collect and extract biomass. With an increase in slope, the biomass extraction process becomes increasingly expensive and also reduces biomass harvesting productivity [10]. The slope map had to be previously digitised for its use by GIS. The extraction of biomass was considered only for slopes less than 60%, since, in addition to not being economically viable, steeper terrain might involve erosion and soil loss problems. The area of Biscay with slopes less than 60% was determined according to the following procedure: (a) the zone was reclassified starting from its slope layer in the GIS, assigning the value "1" to the areas involving slopes below slopes; (b) layers of slopes below 60%, which were obtained with the GIS from the basic topographical data, were merged [11].

2.4. Available Energy Potential

The potential energy of the residues (P) is a function of the lower heating value (LHV) times the total residue for each species considered:

$$P = Q_{FR} * LHV \tag{2}$$

where P represents potential energy (MJ year^{-1}) and LHV represents the lower heating value in humid base (MJ Mg year^{-1}) of the FR. The humidity considered in this study was 30%, being the humidity of the WL after a few days of being on the soil. For this reason, it was necessary to obtain the LHV of each fuel at this humidity level. The LHV can be calculated from the higher heating value (HHV) [12,13].

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. Most bio-power 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%.

2.5. Determination of Humidity, Chemical Property of Forest Biomass Residues (Q_{FR})

The samples were collected during December 2013 through March 2014. In each of the sampling areas, the samples of forest biomass collected—roughly 2 kg per sample—came from forest treatments of branches (with a varying diameter ranging between 3 cm and 1 cm). The forest residue samples used in the experiments were taken from previously-chopped bulk samples which were introduced in polyethylene bags for transport to the laboratory, since they can be sealed and thus loss of humidity can be minimized. The samples were air-dried then oven-dried (65 °C, 24 h) to a constant weight and milled (0.25 mm). Moisture levels were determined by thermogravimetric analysis in a forced air convection oven. The concentrations of total C, H, and N were determined by means of combustion in a LECO automated analyzer. An adiabatic bomb calorimeter (IKA C 5012) was used for determination of HHV.

2.6. Data Analysis

Once the fieldwork was carried out by obtaining the representative samples of the main forest species in the area, and after completing the necessary laboratory analyses, the project was fed into a personal geo-database (GDB), which in turn was implemented in a GIS from version ArcGIS TM 10.2. ESRI, Inc., Redlands, CA, USA. Normality tests of the data were also carried out to determine if the values of the random variable Y_{FR} presented a normal distribution. In order to do so, five different tests that belong to the R statistical software package Nortest were used (Anderson–Darling; Kolmogorov–Smirnov; Cramer–von Mises; Pearson; and Shapiro–Francia) [14,15].

3. Results

The total equivalent CO_2 in Biscay's forests increased by 1.629 Tg year^{-1} between 2005 and 2011. The stock of total forest biomass (aboveground and underground) (TB) existing in the forests of the province of Biscay in the year 2016 amounted to 16.380 Tg of dry material, which implies a sequestration of 29.874 Tg of CO_2, of which 22.284 Tg of CO_2 correspond to PR and 7.589 Tg to EG. The estimated total aboveground biomass in 2016 was 11.680 Tg (dry material), of which 8.760 Tg was timber aboveground biomass susceptible to commercial exploitation. When estimating the total residue considering all the strata together, global data does not follow a normal distribution, but if data is transformed by means of log(x + 1), the *p* values obtained in the normality tests will have a high enough significance. The results obtained after the statistical analyses of the data showed that the amount of mean forest biomass residue achieved with a 95% confidence interval was 73,216.7 Mg year^{-1}, from which 62,861.9 Mg ha^{-1} corresponded to PR residue and 10,354.8 Mg ha^{-1} to EG, this quantity represents about 72% of the annual growth obtained from non-timber without leaves biomass and the 52% of that increment including the leaves. This yields an equivalent potential energy supply of 1.45 TJ per year. These biomass resources can produce electric power of 10–20 MW depending upon the efficiency of thermal conversion.

4. Conclusions

The essential and traditional aim of forest management in the Basque Country has been to maximize the economic profits without risking the persistence of the mass. It is certain that carbon sequestration by forest masses has only recently been considered as another aim of management to be developed together with the economic factor. Former studies have shown that thinning intensification significantly increases the quantity of total biomass obtained (timber and residue biomass). However, this type of management can reduce carbon sequestration in forests [4]. For this reason, in this research an average forest management which optimizes economic (quantity of timber biomass) and environmental (CO_2 sequestration) factors has been assumed.

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