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Carbon stock estimates for forests in the Castilla y León region, Spain. A GIS based method for evaluating spatial distribution of residual biomass for bio-energy

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ARTICLE INFO

Article history:
Received 27 February 2008
Received in revised form
26 July 2010
Accepted 4 August 2010
Available online 15 September 2010

Keywords:
Aboveground biomass
Allometric equations
Biomass expansion factors
Carbon stock
Residual biomass
GIS

ABSTRACT

Analysis of aboveground biomass and carbon stocks (as equivalent CO_2) was performed in the Castilla y León region, Spain. Data from the second and third Spanish Forest Inventories (1996 and 2006) were used. Total aboveground biomass was calculated using allometric biomass equations and biomass expansion factors (BEF), the first method giving higher values. Forests of Castilla y León stored 77,051,308 Mg of biomass, with a mean of 8.18 Mg ha^{-1}, in 1996 and 135,531,737 Mg of biomass, with a mean of 14.4 Mg ha^{-1}, in 2006. The total equivalent CO_2 in this region's forests increased 9,608,824 Mg $year^{-1}$ between 1996 and 2006. In relation to the Kyoto Protocol, the Castilla y León forests have sequestered 3 million tons of CO_2 per year, which represents 6.4% of the total regional emission of CO_2. A Geographic Information System (GIS) based method was also used to assess the geographic distribution of residual forest biomass for bio-energy in the region. The forest statistics data on area of each species were used. The fraction of vegetation cover, land slope and protected areas were also considered. The residual forest biomass in Castilla y León was 1,464,991 Mg $year^{-1}$, or 1.90% of the total aboveground biomass in 1996. The residual forest biomass was concentrated in specific zones of the Castilla y León region, suitable for the location of industries that utilize biomass as energy source. The energy potential of the residual forest biomass in the Castilla y León region is 7350 million MJ per year.

1. Introduction

Emissions of greenhouse gases have grown with industrialization, and particularly from the burning of fossil fuels, such as coal and petroleum to power industry, to heat, cool and light homes and offices and to transport goods and passengers. After fossil fuels combustion, deforestation is the second largest source of carbon dioxide emissions into the atmosphere [1]. In the last few years some international agreements, like the Kyoto Protocol, have been written up in order to reduce the atmospheric emissions of gases that are thought to contribute to global warming. The reason underlying these agreements is the crucial importance of taking measures in the face of a possible global climatic change.

In relation to carbon dioxide emissions, forests have a twofold importance: firstly, they are considered a major sink for atmospheric carbon dioxide [2], and secondly the energy use of residual forest biomass would reduce additional emissions of CO_2 from fossil fuels combustion. This article will study both possibilities in the forests of Castilla y León region, Spain.

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doi:10.1016/j.biombioe.2010.08.004

On one hand, extraction and storage of excess carbon from the atmosphere into the forests is considered as one of the mechanisms for mitigation of global climatic change [3]. Therefore, an accurate and precise estimation of the biomass and carbon stored and sequestered in forests have gained importance as a result of the United Nations Framework Convention on Climate Change and the Kyoto Protocol [4].

From the forestry point of view, it is important to bear in mind that the Kyoto Protocol explicitly considers ARD (afforestation, reforestation and deforestation) activities in order to calculate the carbon captured or net greenhouse gas emissions. Carbon sequestration through forest maintenance or reduced deforestation may be a cost-effective approach to reducing global atmospheric concentrations of CO_2. That is, the forest's ecological function as a CO_2 sink is endorsed in the protocol as a policy measure to mitigate this problem.

Recently a new report by the Intergovernmental Panel on Climate Change, the Good Practice Guidance for Land Use, Land-Use Change and Forestry [5], has called for monitoring and transparent reporting of carbon sinks. It provides guidance for the estimation of emissions and removals of CO_2 for the Land Use, Land-Use Change and Forestry (LULUCF) sector. It is consistent with the approach taken in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines). The latest report states that techniques and methods for measuring, monitoring, and estimating terrestrial carbon pools based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys are applicable.

Both the dynamics and natural variability inherent in the ecosystems makes the forestry sector different from, for example, the energy or industrial sector. Consequently, it can be assumed that carbon sinks in the forestry sector are highly uncertain [6]. For existing forests, databases provided by National Forest Inventories are the most practical means for estimating aboveground forest biomass carbon, as the data are generally collected at the required scales and from the population of interest in a statistically well-designed manner [7]. Therefore, forest inventory data are sources of useful information for comparing the amount of biomass in a forest area over time, and they are widely used for quantification of forest carbon budgets. The inventories provide a good basis for estimates of carbon stocks and fluxes in tree biomass, since the aboveground whole-tree biomass can be converted to carbon quantities by using conversion factors [8].

The size and spatial distribution of the carbon sink across forests is at the centre of the discussion in Europe. Therefore, a detailed spatial analysis of the forest biomass will be necessary. The results will be more useful if the spatial unit is smaller. Therefore, we have estimated biomass in the Castilla y León region in order to know it on a species-province level.

There are two approaches for estimating aboveground biomass in trees: a direct approach using allometric equations, and an indirect approach using biomass expansion factors. In the direct approach, the diameter at breast height (DBH; typically measured at 1.3 m aboveground) of trees on the sample plots above a minimum diameter is measured. Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements. If it is possible, the use of local allometric equations based on field measurements is recommended. Moreover, the IPCC report [5] presents general allometric equations for estimating the aboveground biomass for different forest types using diameter at breast height as the independent variable.

The indirect approach, based on the commercial volume of the trees, is an alternative method for estimating aboveground biomass of forests. The biomass equations can be applied to tree-level data of the national forest inventory, but the indirect method is based on factors developed at the stand level and cannot be used for estimating biomass of individual trees. As with the direct approach, the diameter of all trees above a minimum diameter is measured. The volume of the commercial component of each tree is then estimated based on locally derived methods or equations. The volume is then summed for all trees in a stand and expressed as volume per unit area. Once the volume of the merchantable component is estimated, simple models have been developed to convert this to biomass using the biomass expansion factors (BEF represents the ratio of total aboveground biomass to commercial volume). The inventories usually provide wood volumes, which can be converted into carbon contents of whole-tree biomass using species- and region-specific conversion factors.

A few studies have estimated the biomass and/or carbon stocks of some species in Spanish forests [9–16] and therefore, there are a few local equations that are available.

On the other hand, the spatial distribution of biomass or carbon sinks across forests is also relevant, not only with respect to the national Kyoto Protocol commitments or management alternatives aimed at sequestering carbon in the forest, but also with respect to other management alternatives aimed at harvesting biomass for bio-energy [8]. Wood waste may be burned with energy recovery, and thus may substitute fossil fuels [17]. If the energy structure of Castilla y León is analyzed, it can be observed that all the provinces have a deficit of fossil fuels; however biomass is abundant in Castilla y León and constitutes an alternative energy source worthy of consideration [18]. According to the new energy strategy of the Spanish government, biomass has a great potential for becoming one of the most relevant sources of renewable energy. This makes the knowledge of the potential biomass resources and its spatial distribution in the region essential. As a result, the rather dispersed geographical distribution of biomass potential has raised interest in using Geographic Information Systems (GIS) for the evaluation of the biomass supply among researchers.

The research reported in this paper contributes to a better estimation of the role that forests have as regards atmospheric carbon dioxide emissions in Castilla y León, Spain. Data from the Second and Third Spanish National Forest Inventory (NFI2y NFI3) were used. Thus, our first objective was to estimate aboveground biomass in order to quantify the amount of carbon dioxide accumulated in Castilla y León forests by means of stratum-specie-based forestry statistics. To achieve this end, we (1) calculated the total aboveground biomass by means of local allometric biomass equations and biomass expansion factors, (2) calculated the CO_2 fixed in biomass through the biomass/carbon ratio and (3) compared the results of both years in order to calculate the annual increment of biomass and fixed CO_2, comparing the results obtained from both methodologies.