Forest Policy and Economics 17 (2012) 59–68

Contents lists available at SciVerse ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Contribution of cork oak plantations installed after 1990 in Portugal to the Kyoto commitments and to the landowners economy

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ARTICLE INFO

Article history:
Received 15 November 2010
Received in revised form 15 July 2011
Accepted 27 October 2011
Available online 23 December 2011

Keywords:
Cork oak
New plantations area
Wood
Carbon sequestration
Kyoto protocol

ABSTRACT

Cork oak stands are a part of the agroforestry ecosystem in Portugal, characterized by a low crown cover from cork oak trees, managed towards cork production, and sometimes in combination with grazing. In recent years, European Union policies gave impetus to a large area of new cork oak plantations, which have been established mainly for cork production purposes, and consequently with higher stand density than traditional agroforestry systems. These plantations are important not only for cork production but also for the carbon sequestered by these slow growing forests that won't be harvested for wood production. Thinning operations will be needed to avoid excessive inter-tree competition and wood extracted from these thinning may also provide income for the owners. In the present study, carbon sequestered and wood volumes resulting from thinning were estimated for the next 70 years. Three scenarios of different annual afforestation rates and different site indexes were tested. The resulting values for the considered scenarios show that, if the plantation rates are maintained, new cork oak plantations will have an important contribution to the Portuguese commitments to providing CO_2 offsets under the Kyoto protocol. Additionally, due to the increasing values of initial density in new cork plantations, cork oak forests will produce a significant volume of wood that may become an important contribution to the landowners' income.

1. Introducion

Cork oak (*Quercus suber* L.) is distributed along the western part of the Mediterranean basin. In Portugal the cork oak stands are one of the most important forest types, located mainly south of the Tagus river. According to the last National Forest Inventory (AFN, 2010), pure stands and mixed stands dominated by cork oak have an estimated area of 715,923 ha, which represents 23% of the total forest area in the country.

The main product of the cork oak stands is cork, a thick and continuous layer of suberised cells produced by the cambium, which is extracted from the outer bark of the tree. Portugal is the world major cork producer and exporter, being responsible for 52.5% of the world total cork production (Pereira et al., 2008). For this reason, cork has a large importance in the Portuguese economy, being responsible for approximately 12,283 jobs only in the transformation industry (not including jobs related to the cork harvesting or production) and representing 2.3% of the total value of Portuguese exports (APCOR, 2007).

Cork oak is a slow growing species, well adapted to adverse climatic conditions including hot summers and drought, on shallow and low fertility soils. Along with their economic and social value, cork oak stands play an important role in the ecological protection, water retention and soil conservation of large areas in southern Portugal and are important reservoirs of fauna and flora biodiversity (Aronson et al., 2009; Pereira, 2007). Considering the edapho-climatic conditions of the sites where the trees grow and the exploitation of cork that is made, the values of wood growth achieved by the species are quite noticeable. The very high wood density also provides a very high capacity for biomass production, thus revealing the cork oak as an interesting species for multiple objective forestry, including fixing carbon (Pereira, 2007).

In Portugal, traditional cork oaks are grown in silvopastoral agroforestry systems called *montados*, originated mainly from natural regeneration or artificial broadcast seeding. In typical *montados*, cork oaks are maintained at low density and low crown cover in order to combine cork production with agriculture or grazing. According to the 2005 National Forestry Inventory (AFN, 2010), average tree density is 66 trees ha^{-1} for pure stands. When analyzing the field plots measured in this inventory, just 2% of the pure cork oak stands have a crown cover percentage higher than 50%.

Since 1990 the artificial regeneration of cork oak stands by plantation or direct seeding, with higher stand densities, increased due to the European Union policies and incentives for afforestation of set-aside agricultural lands. Plantation rates in the periods 1990–1994 and 1995–2000 were 24,000 and 60,000 ha (Pereira et al., 2009), corresponding to annual afforestation rates of 4800 and 10,000 ha $year^{-1}$. Official values are not available for the period

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doi:10.1016/j.forpol.2011.10.005

2000–2005, but areas estimated in the 2005 National Forest Inventory (AFN, 2010) indicate that cork oak have increased between 1997 and 2005. Clearly, that these plantations are important not only for future cork production but also for the carbon sequestered as these long-lived forests won't be harvested for wood production. Wood from thinnings will be harvested to avoid excessive inter-tree competition and may also provide additional income for owners, if total wood availability will be enough to support commercial production.

According to the National Forest Strategy (Direcção Geral dos Recursos Florestais, 2007), the target for the year 2030 is to achieve an area of 780,000 ha of cork oak stands (pure and dominated by cork oak). The difference between this value and the 669,108 ha of pure and dominant cork oak stands estimated in 2005 (AFN, 2010) is 64,000 ha.

Spatially explicit analysis, using biophysical variables and land use datasets (Corine Land Cover), shows that 409,000 ha are still available where cork oak could be planted to create productive agroforestry systems (see Section 2.3). This potential plantation area can be very important under the article 3.3 of the Kyoto Protocol, which allows countries to use carbon capture in forests to meet their greenhouse gas emissions by sources and removal by sinks resulting from direct afforestation and reforestation taking place since 1990.

In the present study, carbon sequestered and wood volumes resulting from thinnings were estimated for the next 70 years with the regional forest simulator SIMYT (Tomé et al., 2010). Cork oak growth was assumed to be expressed by an average yield table, obtained with an existing growth model—SUBER (Tomé, 2004)—and information from average cork oak plantations installed after 1990 in Portugal. Several scenarios of plantation rates were tested. The effect of the average site index considered to build the yield table used by the regional simulator was also studied.

The objective of these simulations was to analyze the potential contribution of the new cork oak plantations to the Portuguese commitments for the Kyoto Protocol. Additionally, due to the increasing values of planting density in new cork oak plantations leading to the possibility to use wood from thinnings, it was also an objective to analyze if the new cork oak forests can produce a significant volume of wood that may be considered for new uses, alternatives to fuelwood (Knapic et al., 2011), and become an important contribution to the landowners' economy. The results of these simulations are thought to be important as a support for defining policies to promote new plantations with this species, as well as changes in national legislation regarding cork oak management.

2. Materials and methods

2.1. The SIMYT simulator

The SIMYT simulator (regional SIMulator based on a Yield Table) was used in order to estimate carbon stock changes originated from new plantations after 1990 (Tomé et al., 2010). This simulator allows the prediction of the evolution of the stands within a region or country, under one or several scenarios.

The use of this simulator assumes the following inputs:

- *Average yield table*: estimates of the most important stand variables for each one of the ages along the whole rotation.
- *Estimates of the areas*: estimates of the areas for each one of the ages along a rotation, at the starting year of the simulation. Since the objective was to study the impact of new plantations installed since 1990, the starting situation was represented by setting to zero all the areas in each age of the yield table, except age zero that corresponds to the area planted in 1990. Using the values of the total plantation area for the period of 1990–1994 given by Pereira et al. (2009), the annual mean value of 4800 ha was used for the year 1990.
- *Scenario*: set of annual values of the drivers for each year of the simulation period. The drivers are: wood demand, area burned, area of new plantations, and percentage of land that is abandoned.

Before a simulation, the user must define the following simulation parameters: starting year, length of the simulation (years), minimum age for harvesting, minimum age for industrial use after fire, usual age for harvesting, proportion of wood used after fire, proportion of non industrial stands harvested, proportion of uneven-aged stands harvested, mean annual increment of non-industrial and uneven-stands. Some of these simulation parameters, and the corresponding values used in the present research are shown on Table 1. Note that the parameters related to uneven and non-industrial stands are not relevant in this study, since the new plantations are even-aged stands.

The simulator works like a matrix model with one year age classes. In this way, in each year j all the area in one age class i (A_{ij}) will move to age class $i+1$, except the area that is burned and/or harvested. The projection is made for each year through a series of steps, considering the four different drives included in the simulator:

1. *Initial computation of the totals of the stand variables*. It starts by computing the totals of the stand variables at the end of year j for each age class i, by multiplying the value per hectare by the area correspondent to age class i.
2. *Estimation of volume harvested from thinnings*. Thinnings occur according to the management expressed in the yield table and are assumed to take place in the middle of the year. The volume harvested from thinnings ($V_{thinned}$) together with the value from the thinned biomass is computed by the simulator and corresponds to output variables.
3. *Simulation of fires and volume harvested from fires applied to each age class*. Fire occurrence is assumed not to depend on stand age. The percentage of area destroyed by wildfires in year j is computed, and this percentage is applied to each age class i. A percentage of the volume existing in the burned stands is assumed to be usable by the industry. This value, designated as the burned volume used by the industry (V_{burn}), together with the value from the biomass harvested in burned areas, are computed by the simulator and corresponds to output variable.
4. *Simulation of harvesting*. At this stage, the simulator compares the sum of the volume harvested and burned volume used by the industry ($V_{thinned}+V_{burn}$) to the wood demand in year j. If the sum is less then to the wood demand, the SIMYT simulates the final harvest, starting by simulating the harvest in the non-industrial and uneven-aged stands (not used in the present case study). The harvest then continues in the even-aged stands, from the oldest to the ones presenting the minimum allowed age for industrial use. This operation is maintained only while the wood demand value has not been achieved, and produces more output variables: harvested volume ($V_{harvested}$) and biomass residues for each type of stand. Note that simulations of harvesting are not used in this study, as cork oak is not managed for wood production.
5. *Simulation of growth*. Growth simulation is made by updating the areas corresponding to each age. Areas for each age class at the

Table 1
Parameters used by the SIMYT simulator, and corresponding values used for the simulation of new plantations of cork oak.

Initial year of projection	1990
Length of projection	70
Minimum age for harvest	120
Minimum age for industrial use after fire	Not relevant for this simulation
% of use by industry after fire	Not relevant for this simulation
% of non-industrial stands harvested per year	Not relevant for this simulation
% of uneven-aged stands harvested per year	Not relevant for this simulation
Maximum age for industrial stands	140