Environmental Modelling & Software 101 (2018) 86–101

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Cost-efficient climate policies for interdependent carbon pools

Katarina Elofsson*, Ing-Marie Gren

Department of Economics, Box 7013, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden

A R T I C L E I N F O

Article history:
Received 3 November 2016
Received in revised form
1 July 2017
Accepted 10 December 2017
Available online 4 January 2018

JEL classification:
Q23
Q28
Q48
Q54

Keywords:
EU
Climate policy
Carbon sequestration
Bioenergy
Timber
Policy instruments

A B S T R A C T

The purpose of this paper is to investigate cost-effective climate policy instruments for bioenergy and timber, adapted to the impacts on interdependent forest carbon pools, and applied in the EU climate policy to 2050. We develop a discrete time dynamic model including forest carbon pools in biomass, soil, and products, as well as fossil fuel consumption. The analytical results show that the optimal taxes on forest products depend on the growth in the respective carbon pool. The application to the EU 2050 climate policy for emission trading shows that total costs for target achievement can be reduced by 33 percent if all carbon pools are included, and the carbon tax on fossil fuel can be reduced by 50 percent. Optimal taxes on forest products differ among countries and over time depending on the potential for increased carbon sequestration over the planning period.

1. Introduction

Terrestrial carbon pools[1] have received attention for their climate change mitigation potential and the comparatively low associated costs. Increased carbon pools in natural ecosystems could thus be an alternative and complement to other measures, such as reduced fossil fuel use and increases in renewable energy (Bosetti et al., 2009; Murray et al., 2009; Sohngen, 2009). It can be costly to ignore forest carbon flows and stocks when developing strategies against climate change. In Europe, the sequestration of carbon in forest biomass and soils corresponds to 8–10 percent of the total emissions (Kuikman et al., 2011; Lal, 2005), and sequestration tends to increase over time (Kauppi et al., 1992; Liski et al., 2002). Consideration of the risk for future carbon losses and the potential for targeted increases in carbon sequestration could thus be of importance for economic and environmental reasons.

Within the European Union (EU), crediting of increases in natural carbon pools against the CO_2 burden allocation is not allowed in spite of the substantial cost savings it could entail (Gren et al., 2012; Michetti and Rosa, 2012; Münnich-Vass and Elofsson, 2016). Arguments against the introduction of policies to enhance carbon sinks in the EU include the complexity and mutual interdependence of forest carbon pools, and the difficulties of designing appropriate incentive structures (Kuikman et al., 2011). Forest carbon consists of two main natural pools; above-ground carbon in the biomass and below-ground carbon in the soil (Lal, 2005). Forest harvesting decisions affect the stock of carbon in growing biomass, but also indirectly influence the stock of soil carbon (Jandl et al., 2007; Kuikman et al., 2011; Lal, 2005). Neglect of this dependency will lead to false conclusions about the impact of forest management on total forest carbon sequestration. The dependency between forest carbon pools further aggravates policy design for

* Corresponding author.
E-mail address: katarina.elofsson@slu.se (K. Elofsson).

[1] We use the IPCC (2003) definitions as presented by FAO (2014) where carbon pool refers to carbon reservoirs with the capacity to accumulate or release carbon, carbon stock to the amount of carbon in the pools at a specific point of time, sequestration as the process of increasing the carbon content in the pools, and carbon sink as a process for removing carbon content from the atmosphere.

https://doi.org/10.1016/j.envsoft.2017.12.006

carbon sink enhancement. Even if only a single carbon pool is considered, there are challenges concerning monitoring of carbon stock changes and verification of the additionality and permanence of such changes (cf., Bento et al., 2015; Engel et al., 2015; Mason and Plantinga, 2013). Much of the literature on policy instruments for carbon sequestration deals with instruments directed towards individual forest owners which require measurement and monitoring of changes in each forest owner's carbon pool (Guthrie and Kumareswaran, 2009; Latta et al., 2011; Lecocq et al., 2011; Updegraff et al., 2010; van Kooten et al., 1995). Policies targeting forest products could then have an advantage because of the comparatively lower costs to measure and monitor these products (Hoel and Sletten, 2016). Additionality can still be a concern, but the issue would be reduced to evaluation of the aggregate additionality, rather than the additionality of sequestration achieved by each forest owner.

The purpose of this paper is to analyze the design of policies on forest products to enhance carbon sequestration in interdependent carbon pools as a complement to reductions in emissions from fossil fuels. The analysis is applied to carbon sequestration in forest biomass and soils, and carbon storage in forest products, in the EU climate policy from 2010 to 2050. Within the EU, inclusion of a single carbon pool can be seen as a feasible alternative if, for example, there is disagreement about the advantages of including several carbon pools. We therefore compare separate and complete inclusion of biomass, soil, and forest product pools in the policy decision, in order to assess whether separate inclusion is a step in the right direction, or even counterproductive. In addition, we investigate the cost-efficient economic incentives for achieving increased carbon sequestration. This is done with an aim to evaluate the potential for common policy instruments at the EU level to promote carbon sinks.

For these purposes, we construct a discrete dynamic model for cost-efficient attainment of future targets on carbon emission as suggested by the EU 2050 climate policy (EUCOM, 2012) by means of reduced combustion of fossil fuels and forest products and enhanced carbon sequestration. The interlinked carbon pools are managed by taxes targeting timber and bioenergy, which differ with respect to the displacement of fossil fuel. It is shown analytically that the cost efficient carbon taxes on timber and bioenergy can either increase or decrease when both biomass and soil pools are considered, instead of only one of these pools. The direction of impact depends on the effect of harvesting on the growth rate in the respective pool. It is also shown that the tax on timber decreases for a delayed combustion of wood products because of the larger discounting of future costs of carbon emissions. The empirical results show that inclusion of carbon sequestration reduces overall costs for reaching EU 2050 climate targets by 33 percent, and the optimal carbon tax on fossil fuel by up to 50 percent. If only a single carbon pool is included, the choice of pool to include matters, not only for the cost savings achieved, but also for the net impact on carbon emissions. The optimal tax on fossil fuels is increasing over time for all countries but the carbon tax on wood products can either increase or decrease depending on the forest growth rate and the time path of reduction targets.

Our study belongs to two main strands of the literature; economics of carbon regulation by forest management and design of policy instruments for carbon sink enhancement. Several earlier economic studies on forest management include more than one forest carbon pool in the analysis, such as Lubowski et al. (2006), Newell and Stavins (2000), Sohngen and Mendelsohn (2003), van Kooten et al. (1999), and Wise and Cacho (2005). However, we have not found any study which compares a second-best policy, including only a single carbon pool, with the first best policy, where several interlinked pools are included. A number of studies analyze policy instruments applied to a single (biomass) carbon pool. Using a national forest sector model, Caurla et al. (2013) and Lecocq et al. (2011) compare the impact of alternative combinations of climate policy instruments on the forest sector and resources. van Kooten et al. (1995) show that a combination of carbon taxes and subsidies can be used to achieve socially optimal forest rotation, and Latta et al. (2011) investigate the consequences of a tax/subsidy scheme, voluntary or mandatory, in a forest sector model.

With respect to the literature on policies for carbon sink enhancement, Mason and Plantinga (2013) conclude that a uniform carbon subsidy scheme implies higher costs for achieving sequestration than a contract design system. Bento et al. (2015) analyze the role of the additionality problem and monitoring costs for the design of carbon offset contracts. Using a real options model with uncertain future timber prices, Guthrie and Kumareswaran (2009) compare subsidies paid in proportion to the actual amount of carbon sequestered to credits that are allocated according to the long-run potential to sequester carbon, showing that the former generates more sequestration. Using a globally aggregated model, Hoel and Sletten (2016) analyze optimal taxes on energy consumption, differentiated between fossil fuel energy and bioenergy to account for the impact on forest sequestration. Compared to those, our study contributes through analysis and empirical calculation of cost-efficient, nationally differentiated taxes on timber, bioenergy and fossil fuels for reaching politically determined targets on carbon dioxide emissions, while accounting for the role of carbon pool interdependence.

The paper is organized as follows; first, the numerical model is described, followed by the derivation of the cost-efficient policy instruments. Then, data are described and results are presented. The paper ends with a discussion and conclusions.

2. Numerical model

Consider the EU, with $i = 1, \ldots, 27$ different countries. Together, the countries have agreed on a CO_2 emissions reduction path until 2050, which they wish to implement at least cost. The emission reductions can be achieved by either reduced consumption of fossil fuels within the EU Emission Trading Scheme, or by implementing changes in forest management. The potential to use forests for different purposes is, ultimately, determined by the existing forest biomass and its development over time. The development of the growing stock of trees[2] on an average hectare of land is defined by:

$$V^i_{t+1} = V^i_t + G^i_t\left(V^i_t\right) - H^i_{t+1} \tag{1}$$

$$V^i_0 = \overline{V^i_0},$$

where variables are measured in cubic meters: H^i_{t+1} is the harvest in country i, which is assumed to take place in the beginning of the year,[3] V^i_t is the growing stock measured directly after the harvest, and $G^i_t(V^i_t)$ is the annual growth. Total stem wood volume in a country is $A^iV^i_t$, where A^i is the area of forest land, measured in hectares. It is assumed that $G^i_t(V^i_t)$is positive, differentiable and

[2] The growing stock is typically defined as the volume of all living trees in a certain area of forest with a minimum diameter at breast height, and includes the stem from ground level or stump height up to a given top diameter, and may also include branches above a certain diameter. Here, the growing stock is assumed equal the merchantable tree volume.

[3] The choice of timing of the harvest (in the beginning rather than in the end of each time period) is made because this, later, facilitates the interpretation equations (15) and (16).