Combining an inter-sectoral carbon tax with sectoral mitigation policies: impacts on the French forest sector

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Abstract

As France works out its plan to tackle climate change issues, questions are arising in the forest sector as to how sectoral mitigation programs such as those designed to enhance fuelwood consumption or to stimulate in-forest carbon sequestration may coincide with an inter-sectoral program such as an economy-wide carbon tax. This paper provides insights into this question by exploring the impacts of (1) a combination of a carbon tax and a fuelwood policy, and (2) a combination of a carbon tax and a sequestration policy on (i) the economy of the forest sector, and (ii) the dynamics of the forest resource. To do this, we used a modified version of the French Forest Sector Model (FFSM) and carried out simulations on a 2020 time horizon. Basing our analysis on the fuelwood sector, we showed that wood producers always benefit from the combination of a carbon tax with either a fuelwood policy or a sequestration policy at the national level. Conversely, and although it favors wood products instead of non-wood substitutes, a carbon tax always decreases consumer surpluses by increasing wood product prices. As a consequence, the combination of a carbon tax with sectoral policies is likely to raise questions about the political economy of the mitigation program. This is particularly true in the case of a combination of a carbon tax with a sequestration policy, which already decreases consumer surpluses. We eventually showed that by increasing transport costs between domestic regions, the carbon tax reallocates production patterns over French territory which could lead to the necessity of a regional breakdown of policy-mixes in the forest sector.

Keywords: Forest sector modeling; Mitigation policies; Fuelwood, Carbon storage; Biomass energy; Carbon tax

JEL Classification: L52; Q23; Q42; Q54

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), there will be a significant economic potential for climate change mitigation in the next few decades. In particular, bottom-up analyses show that the international emissions reduction potential for the forest sector equals 1,1 (+/- 1) to 4,2 (+/- 1,5) Gt eq.CO_2/yr, respectively for carbon prices of 20 US$/t$CO_2$ and 100 US$/t$CO_2$ which represents 3 % to 14 % of the total CO_2 emissions (Nabuurs et al., 2007). The climate change ability of the forest sector can be broken down into two types of mechanisms: sequestration and substitution. Upstream, sequestration mechanisms consist of enhancing forest management practices such as densification, afforestation, reforestation and reduction of deforestation in order to increase the quantity of carbon sequestered in the forest biomass (Kurz et al., 1997; Nabuurs et al., 2007; Luyssaert et al., 2008; Grace, 2004; van der Werf et al., 2009). Downstream, sequestering carbon in long-lived wood products (*e.g.* construction wood) postpones its return to the atmosphere thereby delaying CO_2 release in the atmosphere (Vallet, 2005). Substitution mechanisms consist of reducing greenhouse gas emissions through the replacement of fossil fuels with fuelwood and by substituting non-wood products with wood products in the building, packaging and furniture sectors (Petersen, 2006; Petersen and Solberg, 2005).

So far, and in order to reach its ambitious mitigation targets[1], the French Government has opted to base its policy-mix on substitution mechanisms through sectoral policies. These policies aim at (1) structuring the French fuelwood sector through economic incentives, (2) changing domestic heating systems, for example, through the development of collective boilers, and (3) encouraging the development of medium- to large-scale biomass energy plants. The overall objective is to increase fuelwood consumption by 6 Mm^3/yr by 2020 (Puech, 2009).

In addition to these policies promoting the use of fuelwood, two other types of mitigation policies involving the forest sector are currently being discussed in France: a policy to enhance sequestration in forests and an intersectoral carbon tax based on substitution mechanisms, but in an indirect way, promoting low-carbon content products and discouraging their more carbon-intensive substitutes.

While the impacts of a sequestration policy and of its combination with a fuelwood policy are analyzed in depth in Lecocq et al. (2011), the impacts of a carbon tax on the forest sector and its interactions with sectoral policies, either fuelwood policy or sequestration policy, remain unclear.

[1] The European Union sets the objective of increasing the share of renewable energy in its overall energy mix to 20 % by 2020.

In the French context, a normative shadow price of carbon to be used in evaluating public investments was set at €100/tC, or €27/tCO_2, in 2000. For the preparation of the 2009 carbon tax proposal, an expert group of economists proposed an initial €45/tCO_2 (Quinet, 2009) that would progressively increase to €100/tCO_2 in 2030. The view was that this initial value and increase trajectory would be compatible with the achievement of the Factor 4 goal which consists in improving the energy efficiency and the use of renewable energy in order to divide CO_2 emissions by a factor of four before 2050. In 2010, a consensus value of €32/tCO_2 emerged from a broader expert consensus (Rocard, 2009) — with the same increase trajectory as in the previous report. After several months of discussion, an initial value of €17/tCO_2 + €2/tCO_2/yr was finally announced by the Government on acceptability grounds before it was killed by the French Constitutional Council in 2010.

Nevertheless, some form of carbon tax scheme is likely to be necessary in France in the future since the objective of mitigation remains. Such a tax would therefore coexist with previously enacted sectoral fuelwood policies and/or sequestration measures. One question that then arises is how would such an inter-sectoral substitution-based carbon tax interact with previously enacted sectoral? The answer obviously depends on which type of policy is combined with the carbon tax.

First, a combination of a carbon tax with sectoral fuelwood policies raises the question of sustainability since they both lead to increased wood harvest. Second, a carbon tax and a sequestration policy result *a priori* in conflicting impacts on forest resource dynamics. Therefore, the impact of their combination on the forest stock is ambiguous. In addition, since a carbon tax is likely to increase product prices (including those of wood products) and since sequestration policy decreases consumer surpluses (see Lecocq et al. (2011)), another important issue concerns the impacts of such a combination on consumer surpluses. This is even more important knowing that the political feasibility of such measures is highly dependent on their impacts on consumer welfare.

This paper aims at exploring these interactions from the point of view of both economics and forest stock dynamics. To do this, we use the French Forest Sector Model (Caurla, 2012b; Caurla et al., 2010) modified to model competition between wood and non-wood substitutes. Ideally, modeling a carbon tax would imply that all carbon emission processes for wood products and their non-wood substitutes (transformation, transport, carbon embedded in products) are represented and subsequently applying a carbon tax rate to all these processes. However, this is very data-intensive task that goes beyond the scope of our paper. For this reason, we chose to focus our analysis on a single product: fuelwood for heat production. As a consequence, competition is only represented for fuelwood and its energy source substitutes, i.e., coal, fuel oil, electricity and gas. Therefore, a carbon tax will only have an impact on the production and the consumption of these five products.

This paper is organized as follows. The first section presents a literature review of the topic. The second section presents a short description of FFSM and describes the modifications made in order to model a carbon tax. The third section presents carbon tax characteristics (tax rate, tax base) and describes the impacts on the French forest sector of a carbon tax applied without other policies. in the fourth section, we then analyze the combination of a carbon tax with current fuelwood policies. In the fifth section, we explore the impacts of a combination of a carbon tax and a sequestration policy. Finally the last section provides a discussion of our results and a conclusion to our paper.

Literature review

Impacts of sectoral carbon incentives over the forest sector have been extensively recognized and studied. This literature typically deals with carbon tax system as a policy tool for encouraging carbon sequestration. Focusing on a case study in Oregon, Im et al. (2007) show that a carbon tax leads to reduced harvest and increased carbon stock in the standing trees and understory biomass. Pajot (2011) suggests that such a result also holds for maritime pine forests in South-West of France.

The interactions between sequestration policies and substitution measures have been studied both from environmental (Marland and Schlamadinger, 1997; Seidl et al., 2007; Hofer et al., 2007; Pingoud et al., 2010) and bio-economic (Lecocq et al., 2011; Kallio et al., 2013) points of view. This literature suggests that sequestration policies are likely to be the most effective tools when considering carbon emissions in the short run while substitution policies might better perform in the long run. From the economic point of view, Lecocq et al. (2011) show that a sequestration policy is detrimental to consumers surplus which raises questions about the political economy of sequestration incentives. Meanwhile, Kallio et al. (2013) point out that an increased use of wood energy also means higher pulpwood prices, which benefit producers but increase the production costs in the pulp and paper industry.

However, few studies analyze the impacts of inter-sectoral carbon taxes over the forest sector. One exception is Sathre and Gustavsson (2007) who focus exclusively on construction materials sectors. Their results indicate that higher energy and carbon taxation rates increase the economic competitiveness of wood construction materials. Bohlin (1998) studies the impacts of a differentiated carbon tax on biofuel consumption in Sweden. He shows that, after the tax implementation, the biofuel use in the district heating sector increased from 36.7 PJ to 73.4 PJ, replacing primarily coal, thus leading to great carbon dioxide savings. However these two studies tend to focus on the environmental (i.e., GHG) implications of the carbon tax with an emission savings approach and with no attention paid to economic impacts over economic agents in the sector. Using the French Forest Sector Model, Barthes et al. (2012) analyze the impacts of an inter-sectoral carbon tax on competitiveness within the forest sector. By modeling competition between five wood products and their non-wood substitutes, they showed that forest products generally benefit from the introduction of such a tax. In fact, since wood products generally have a smaller carbon content than their direct non-wood substitutes, their consumption and, as a result, their production, decrease less than those of non-wood substitutes when a carbon tax is implemented.

Eventually, the interactions between an inter-sectoral carbon tax and a sectoral carbon policy within the forest sector have been barely studied in the literature. One notable exception is Timilsina et al. (2011) who use a multi-sector, multi-country computable general equilibrium model to study under what circumstances a carbon tax would help stimulate penetration of biofuels into the energy supply mix. They show that the most effective situation is when the carbon tax revenue is recycled into a biofuel subsidy while a recycling through a lump-sum transfer does not help stimulate biofuels significantly. Our aim here is different, since we use a partial equilibrium framework and we compare the combination of either sequestration policy or fuelwood policy with inter-sectoral carbon tax.

Materials and Methods

The French Forest Sector Model, a bio-economic model to assess the impacts of climate mitigation policies on the French forest sector

The French Forest Sector Model (Figure 1) was initially developed in order to understand the impacts of current policies and to explore those of potential future ones. As explained in detail in Caurla et al. (2010) and Caurla (2012b, pp.105-152), this model includes a representation of the forest resource and its dynamics in order to assess the environmental implications of mitigation policies. To assess the economic implications of mitigation policies, the model computes prices and quantities for three primary and six final wood products (Figure 2) from 2006 to 2020. It also makes it possible to compute producers' profits and consumers' surpluses. Moreover, wood trade is represented at the national level according to the spatial price theory of Samuelson (1952) and at the international level through the imperfect substitution model of Armington (1969).

On environmental aspects, the model projects the dynamics of national and regional forest resources broken down into 132 homogenous domains from the point of view of climate, species and management. It also computes the emission balance for the entire sector, taking substitution effects that take place downstream into account.

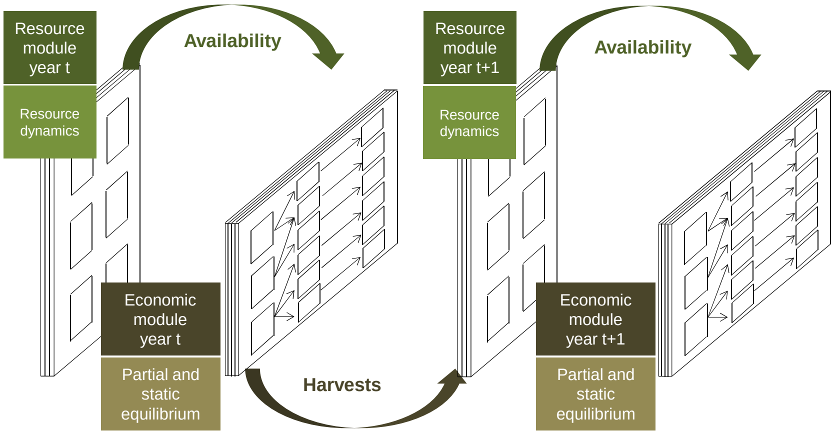

Figure 1: FFSM is based on a recursive and modular framework. The time horizon is 2020.

The FFSM mathematical structure can be found in Caurla (2012a) and Caurla (2012b, pp.307-327).

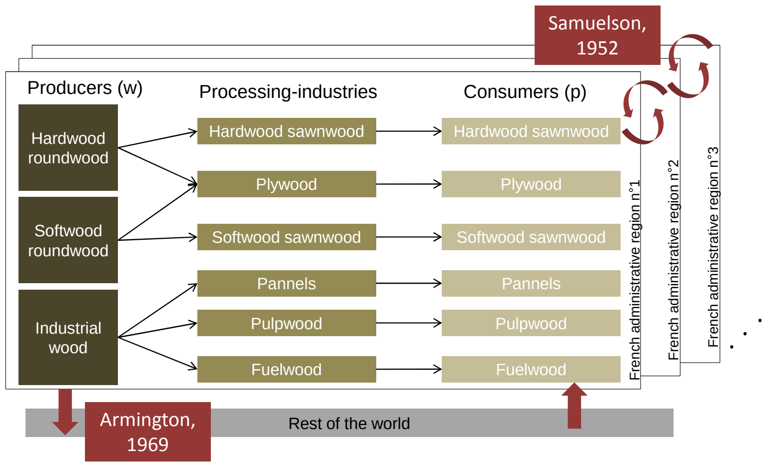

Figure 2: The economic module of FFSM represents three levels of the forest sector and distinguishes nine products.

Modeling competition between fuelwood and fossil fuels with FFSM

Competition is represented through a price competition approach. Basically, competition between fuelwood and substitutes is represented through a cross elasticity of demand:

$$D_{i,t} = D_{i,t-1} \left(\frac{\tilde{P}_{i,t}}{\tilde{P}_{i,t-1}} \right)^{\sigma_p} \underbrace{\prod_s \left(\frac{\left(\frac{\tilde{P}_{i,t}}{P_{s,i,t}} \right)}{\left(\frac{\tilde{P}_{i,t-1}}{P_{s,i,t-1}} \right)} \right)^{-\epsilon_s}}_{\text{Competition module}} \tag{1}$$

where:

- $D_{i,t}$ is the demand for a composite fuelwood product in region i at year t, as defined in Caurla et al. (2010). The demand for a composite product is defined as a function of the demand of import and the demand of domestic product considering a constant elasticity of substitution specification ;
- $\tilde{P}_{i,t}$ is the price of the composite fuelwood product in region i at year t as defined in Caurla et al. (2010) ;

- $P_{s,i,t}$ is the price of the substitute s in region i at year t;
- $\epsilon_{p,s}$ is the cross elasticity of demand;
- σ_p is the price elasticity of demand.

We consider here that fuelwood competes with four non-wood substitutes s: coal, fuel oil, electricity and gas. The price of substitutes s must be calibrated for the whole period. $P_{s,i,t}$ is defined as the average price of the apparent consumption of product s (apparent consumption is defined as French production plus imports less exports). These prices are assumed to be stable over the whole period of the simulation. The cross elasticities of demand $\epsilon_{p,s}$ were previously calculated with a linear regression approach using Equation 1. For France, their values are 0.1 for coal, 0.6 for electricity and ga and 0.9 for fuel oil.

Modeling an economy-wide carbon tax in FFSM

Carbon tax structure

Optimally, making endogenous the climate change externality would involve assigning a price tag on all forms of greenhouse gas emissions, and, conversely, providing a subsidy on any form of greenhouse gas removal from the atmosphere. In practice, however, limitations in the measurement of emissions, transaction costs and political economy considerations result in the implementation of a large array of instruments, each covering parts of the above-mentioned emissions.

In fact, although it is of importance for national emission targets under the Kyoto Protocol via articles 3.3 and 3.4, carbon removal from the atmosphere is, for the most part, excluded from the perimeter of existing climate policies. In addition, in the EU, the Emissions Trading Scheme (EU ETS) caps the CO_2 emissions of large point sources in certain sectors. Carbon taxes are thus considered as an option for limiting emissions from small-scale sources in the ETS-covered sectors, as well as emissions from the other sectors of the economy (e.g., transportation, agriculture, etc.).

A second set of issues regards emissions sources covered by the scheme. In this paper, since only energy products for heat production purposes are considered, we do not take into account either fossil-fuel emissions related to transformation processes (e.g., CO_2 emissions associated with cement production process) or carbon embedded in products (e.g., plastics).

Carbon tax rate

As presented in the introduction, an initial value of €17/tCO_2 + €2/tCO_2/yr was announced by the Government on acceptability grounds in 2009. Our simulations are therefore based on this value of €17/tCO_2 in 2010 + €2/tCO_2/yr.

Carbon tax base and economic implications for non-wood products

Since we only deal with energy products here, we assumed that the carbon tax only applies to CO_2 emissions from fossil-fuel combustion and to fossil-fuel consumed for transportation. In particular, we did not take CO_2 emissions from other chemical processes or fossil-fuel embedded in products into account. Emissions factors were taken from Traisnel et al. (2010)

Product	Emission factor (tCO_2/MWh final energy)
Coal	0.355
fuel oil	0.271
Gas	0.205
Electricity (for heating purposes)	0.180
Wood	0

Table 1: Emissions factors for the five energy sources considered in the paper

Concerning transport, we assumed that the road is the dominant transportation mode, with an average emissions level of 128 g eq. C/(t.km) (Barthes et al., 2012).

Results

Impacts of an economy-wide carbon tax in FFSM when implemented alone

We first simulated a €17/tCO_2 + €2/tCO_2/yr carbon tax without competition with other energy sources. We observed that fuelwood consumption decreases over time. This is due to the fact that a carbon tax on transport cost increases the final fuelwood price. As a consequence, fuelwood production decreases by approximately -0.5% at the national level.

Second, we explicitly introduced competition. Consequently, fuelwood production increases. Indeed, in this case, the consumer price for fuelwood increases but less than that of non-wood substitutes (see Equation 1) due to a lower carbon emission factor. Thus, the substitution effect between wood and non-wood products clearly dominates the income effect (i.e., the increase in the consumer price of wood products), resulting in net gains of welfare for fuelwood consumers and net gains of profits for fuelwood producers. Overall, fuelwood production increases by 1.8% at the national level with a €17/tCO_2 + €2/tCO_2/yr.

Nevertheless, even if production increases at the national level, Fig. 3 shows that this is not necessarily the case at the regional level. Indeed, by increasing transport costs, the carbon tax reallocates production next to consumption areas, therefore modifying the interregional trade pattern. More precisely, Fig. 3 shows that production either increases in importing regions when additional biomass is available enough. In other cases, it remains stable. Conversely, production either increases or decreases in exporting regions depending on their location: production increases in exporting regions located close enough to importing regions, whereas production decreases in exporting regions located far from importing regions. Modifications in transport patterns and, therefore, in regional production are consistent with spatial price theory of Samuelson (1952). In particular, some regions that were initially neither importer nor exporter can become exporter or importer because of the increase in transportation costs.

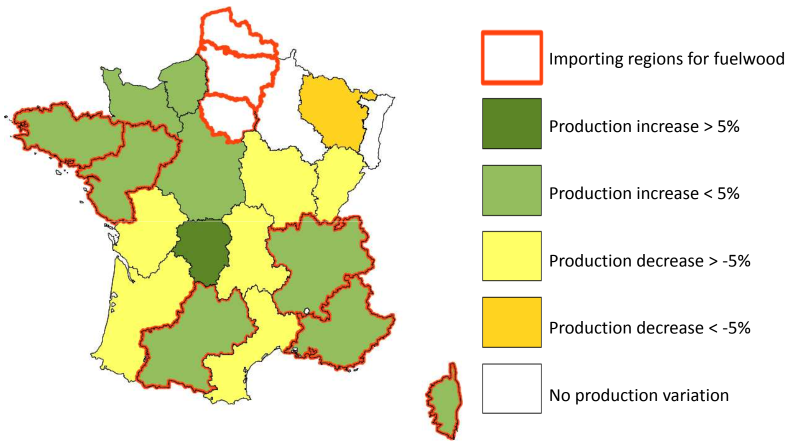

Figure 3: Regional variations in 2020 fuelwood production after a €17/tCO_2 + €2/tCO_2/yr carbon tax is implemented with regard to a scenario without tax.

Interestingly, this €17/tCO_2 + €2/tCO_2/yr carbon tax only increases fuelwood consumption by + 4.1%, i.e., 0.93 Mm^3. Therefore, this tax rate would not be sufficient to reach the target of 6 Mm^3/yr in 2020 in fuelwood consumption set by the French Government to match its overall mitigation objectives. More precisely, in our analysis, these national objectives would be reached for a €250/tCO_2 carbon tax, i.e., a very high value compared to current negotiated values.

Therefore, we have reason to believe that even if a carbon tax is implemented in the future, existing sectoral fuelwood policies would remain necessary. Our aim in the next section is precisely to assess the potential impacts of this combination.

Combining a carbon tax with sectoral fuelwood policies

Modeling fuelwood policies in FFSM

The European Union set the objective of increasing the share of renewable resources in its overall energy mix to 20 % by 2020. In France, where forest resources are abundant and where annual increment exceeds harvest levels, biomass energy is expected to play a major role to achieve this objective.

In the forest sector, some people fear these projects could strengthen the competition with the pulp, panel and paper sectors, which use the same raw materials as those used for fuelwood. Moreover, others fear an over-harvesting situation. Indeed, at the national level, Colin et al. (2009) and Ginisty et al. (2009) estimate an additional resource for industrial uses (fuelwood and pulp sectors) of approximately 12 Mm^3/yr. More precisely they estimate an additional amount of biomass available of approximately 40 to 50 Mm^3/yr from which they remove all of the resources that are technically impossible to harvest or for which harvest would be too costly. However this value may overestimate the real additional availability since, in fact, French forests combine a very diverse population of forest owners, and forest property rights are highly fragmented. In particular, some smallholders might not react to market incentives.

In order to contribute to and to clarify these two debates, we translated the official objectives of additional consumption of fuelwood into three policies to be simulated within FFSM during the 2012-2020 period. First, we modeled an exogenous increase in demand, which mimics the current policy of encouraging medium- to large-scale biomass energy plant development. In this case, the Government guarantees a given amount of public purchase on the market (*fixed-demand contracts*). We also considered two alternative policies to reach the same total increase in fuelwood demand: a *consumer subsidy* and a *producer subsidy*. These two subsidies represent the economic incentives to change collective and domestic boilers.

Caurla (2012b, pp.213-259) and Caurla et al. (2009) analyzed the impacts of these fuelwood policies with FFSM in-depth, differentiating between resource and economic impacts. From the point of view of resource impacts, they showed that the intensity of the tension over the forest resource depends on the nature of the policy as well as on the theoretical additional resource availability in the forest. To cope with uncertainty about additional resources, Caurla (2012b, pp.213-259) and Caurla et al. (2009) considered two levels of resource availability: an optimistic level based on the estimations of Colin and Chevalier (2009) and Ginisty et al. (2009) and a pessimistic one of approximately 6 Mm^3/yr, which takes uncertainties concerning the timber suppliers behavior into account. They showed that the three policies considered would lead to a harvest which exceeds biological increment in 2020 in the pessimistic case. On the other hand, only the producer subsidy would lead to tension in 2020 in the optimistic case. This result points out the differences between the three policies but also reveals the importance of mobilizing all of the forest owners, including small forest owners, to make further efforts in fuelwood production in order to avoid over-harvesting situations in some forests.

Combination of a carbon tax with a direct fuelwood policy

Since a carbon tax alone increases fuelwood production, a combination of fuelwood policies with a carbon tax may raise the question of sustainability of wood production.

However, in contrast to fuelwood policies that have homogenous impacts on the French forest resource, the impact of a carbon tax on the forest resource is different from one region to another. Since a carbon tax increases fuelwood production in regions with high consumption, whereas it decreases production in low-consumption regions, combining fuelwood policies and a carbon tax may lead to an over-harvesting situation in high-consumption areas – i.e., importing regions.

To test this assumption we compare the results of three scenarios. In the first scenario we simulate a €17/tCO_2 (+€2/tCO_2/yr) carbon tax alone, whereas in the second scenario we simulate a subsidy to fuelwood consumption calibrated to reach an additional 6 Mm^3/yr consumption by 2020. In the third scenario, we simulate a combination of a €17/tCO_2 (+€2/tCO_2/yr) carbon tax and a subsidy to fuelwood consumption calibrated to reach an additional 6 Mm^3/yr consumption by 2020. Results are reported in Table 2.

Results show that, when policies are implemented alone, both the carbon tax and the subsidy for fuelwood consumption decrease the forest stock at the national level, although the impact is much lower with the carbon tax. This impact is even greater when the two policies are combined. However this combination only slightly decreases the forest stock compared to a scenario with a fuelwood policy alone. More precisely, a regional analysis shows that adding a carbon tax to a fuelwood subsidy decreases the forest stock only in importing regions with regard to a scenario with a fuelwood subsidy alone. Conversely, a carbon tax decreases harvest and thus increases the forest stock compared to a scenario without a tax in exporting regions. Overall, the relatively low stock effect can be explained by the low carbon tax price, leading to a low increase in fuelwood consumption (+0.93 Mm^3/yr in 2020).

	Carbon tax alone	Fuelwood policy alone	Combination of fuelwood policy and carbon tax
Producer surplus	31.8	350.3	399.6
Consumer surplus	-54.7	146.6	93
Forest resource	-0.12%	-2.23%	-2.41 %

Table 2: Consumer and producer surpluses in 2020 in M€ at national level and forest resource stock in 2020 in % in the three policy scenarios with regard to a business-as-usual (BAU) scenario without a policy

From the economic point of view, combining a carbon tax and a fuelwood policy increases producers' profits with regard to a scenario with only fuelwood policy at the national level. This is because both policies increase consumption and, thus, production of wood products. Their impacts are therefore greater for producers' profits. However, the combination leads to an intermediary situation for consumers. Indeed, while a fuelwood subsidy increases consumer surpluses, the carbon tax increases wood product prices and, therefore, decreases consumer surpluses.

Combining a sequestration policy with a carbon tax

Presentation of the sequestration policy

The sequestration policy consists in paying forest owners for the environmental service they produce by sequestering carbon. Each year, timber suppliers receive a payment from the Government (P_t) that is computed as the difference between the amount of carbon sequestered in standing forests (C_t) and a reference amount of carbon sequestered in standing forests (C_t^{REF}), times the price of annual carbon sequestration (Pc_t): $P_t = Pc_t(C_t - C_t^{REF})$. Note that the payment can be negative (tax) if the carbon stock falls below a reference level. We only consider above-ground biomass, which under-estimates the environmental service but allows for easier accounting. We also use the rule-of-thumb approximation that one cubic meter of standing biomass stores one metric ton of CO_2 (Carbofor, 2004).

The annual payment for carbon sequestration P_{ct} is the constant annual value corresponding to a price of permanent (i.e., indefinite) sequestration of P_c equal to €17/tCO_2 (+€2/tCO_2/yr) using a 4% discount rate. In other words, the discounted sum *ad infinitum* of annual payments P_{ct}, at a rate of discount of 4%, is P_c. Like the price of permanent sequestration, this annuity is revised every year as the price of permanent sequestration increases and, therefore, increases from €0.68/tCO_2/year in 2010 to €1.48/tCO_2/year in 2020. With an annual payment based on measured sequestration, this policy is environmentally consistent. For example, accidental release of carbon via fires or hurricanes would result in lower annual payments, or even in negative payments (tax) if carbon stocks were to fall below a reference level.

It is important to note that, in practice, a payment for the environmental service sequestration is very likely to be voluntary. In other words, timber suppliers will self-select themselves and will enter the program only if it makes them better off to do so. We do not directly model this voluntary participation condition, but instead assume that participation is compulsory, and then test *ex post* whether suppliers are better off or not.

In addition, in the current version of FFSM, wood supply depends only on current market prices: expectations about future revenues and/or costs do not enter into timber suppliers' decisions. As a result, wood suppliers factor the payment for carbon storage in their supply decisions only to the extent it influences the *current* price of timber.

Using FFSM, Lecocq et al. (2011) show that this sequestration policy has negative impacts on the consumers welfare. Indeed, though it increases producers' profits through the payment for sequestered carbon, it also increases prices for consumers resulting in a decrease in consumer surpluses. Thus this policy is likely to raise political economy questions. From the environmental point of view, Lecocq et al. (2011) showed that a sequestration policy increases the forest carbon stock by decreasing harvest over the French territory.

Combination of a carbon tax and a sequestration policy

Combining a carbon tax and a sequestration policy *a priori* leads to ambiguous impacts from the point of view of both resources and economics.

To test this, we designed three scenarios: a scenario with a carbon tax alone, a scenario with a sequestration policy alone and a combination thereof. Table 3 gives the sum of producer and consumer surpluses at national level in 2020, and the variation of forest resource stock with regard to a business-as-usual scenario without policy.

First, results show that combining a carbon tax with a sequestration policy increases producers profits at the national level with regard to a scenario with a carbon tax or a sequestration policy alone. There are two components in this effect. On the first hand, in regions where the carbon tax increases production, the forest stock decreases and a sequestration policy acts as a tax. Consequently, the sequestration component of the policy turns into a net tax for reductions in carbon storage relative to a BAU scenario. This decreases producers' profits in these regions. On the other

	Carbon tax alone	Sequestration policy alone	Sequestration policy + Carbon tax
Producer surplus	31.8	5.3	38.7
Consumer surplus	-54.7	-3.4	-58.1
Forest resource	-0.12%	+0.05%	-0.07%

Table 3: Consumer and producer surpluses in 2020 in M€ at national level and forest resource stock in 2020 in % with regard to a business-as-usual scenario without a policy

hand, in regions where the carbon tax decreases production – by increasing transport costs – the sequestration policy acts as a subsidy and greatly increases producers' profits. Interestingly, adding these two opposite effects leads to an overall increase in producers' profits at the national level with regard to a scenario with a carbon tax or a sequestration policy alone. In contrast to conclusions stemming from Lecocq et al. (2011) when combining a sequestration and a substitution policy, the combination of a carbon tax with a sequestration policy globally increases producers profits with regard to a single policy scenario.

Second, results show that the consumer surplus is lower when combining a carbon tax with a sequestration policy than when a carbon tax or a sequestration policy are implemented alone. Indeed, both the carbon tax and the sequestration policy increase final wood product prices and these impacts are greater when combining the two policies. This impact on consumer surpluses raises the question of the political feasibility of a combination of these two policies.

From the point of view of the forest stock, the two policies are conflicting. In fact the sequestration policy increases the forest stock, whereas the carbon tax increases production and, therefore, decreases it. However, since we do not represent competition for all wood products and non-wood substitutes, the impacts of a carbon tax on the forest stock are very likely to be under-estimated in our simulations. In addition, the carbon tax does not decrease the forest stock in all regions. Again, in regions where the carbon tax decreases production, due to production reallocation, the combination of a sequestration policy and a carbon tax increases the forest stock regarding the BAU scenario. In the Aquitaine region, for example, the forest stock increases by +1.1% with regard to the BAU scenario and by +1% with regard to a scenario with only sequestration.

Discussion and Conclusion

What makes the relationships between mitigation policies within the forest sector complex are their potential antagonisms and complementarities over the economy and the resource. In order to reduce mitigation costs, it is necessary to favor complementaries and to avoid antagonisms. In this paper, our aim was to explore the effects of a combination of an inter-sectoral carbon tax with two sectoral-type mitigation policies, namely a sequestration policy and a fuelwood policy. Although such a combination does not exist in France yet, since no carbon tax is implemented, such a combination may take place in the near future. In addition, our conclusions can be transposed to other developed countries where an inter-sectoral carbon tax is likely to interact with sectoral policies. Precisely, we believe our results hold for developed countries with temperate forests such as the majority of European and North American countries. In fact, in developing countries, other issues such as governance issues may interact with the implementation of a carbon tax or a forest-carbon sequestration scheme. In addition, other types of forest sectors such as tropical ones differ from French one from both economic (wood products are different) and resource dynamics points of view.

Our analysis yields four main results. First, we show that implementing an inter-sectoral €17/tCO_2 (+€2/tCO_2/yr) carbon tax in addition to a sectoral subsidy for fuelwood consumption calibrated to increase consumption by 6 Mm^3/yr in 2020 does not threaten forest resource sustainability at the national level. This is because the relatively low carbon tax moderately increases fuelwood consumption and, therefore, moderately increases fuelwood production. However, one important limitation of this conclusion lies in the tax base chosen. In fact, we only simulate competition between fuelwood and non-wood energy sources here. In reality, an inter-sectoral carbon tax would increase the production of most wood products (Barthes et al., 2012). As a consequence, the forest stock is likely to decrease even more in reality. However, measuring the order of magnitude of this overall impact is beyond the scope of this article. It would be necessary to model all competitions between wood and non-wood products which, as Barthes et al. (2012) remind us, is a very data-demanding process (in terms of carbon emission factors, elasticities of substitution, aggregation, ...).

Second, we show that producers always benefit at the national level from the combination of an inter-sectoral carbon tax with either a sequestration or a fuelwood sectoral policy. In the case of a combination with a fuelwood policy, this is because both of the policies increase national fuelwood production and fuelwood price. In the case of a combination with a sequestration policy this is because the overall production increase in fuelwood exporting regions exceeds the overall production decrease in importing regions. The net overall effect is positive at the national level.

Third, the consumer surplus always decreases when a carbon tax is implemented in addition to an existing sectoral policy. This can be explained by the fact that the carbon tax increases wood product prices. In the case of a combination with a sequestration policy, which already decreases the consumer surplus, our simulations raise questions about the political feasibility of such a scenario[2].

A fourth important result is that by having an impact on transport costs, an inter-sectoral carbon tax would modify regional production patterns and inter-regional trade schemes. In the specific case where a carbon tax is combined with a sequestration policy, an interesting way to make these two policies complementary would be to consider sequestration as a voluntary process in regions where production decreases after a carbon tax is implemented. This would lead to a specialization of forests. In regions where a tax has a negative impact on production, timber that is not harvested for production might be left for sequestration. On the contrary, in high-consumption regions, forest owners would choose not to engage in sequestration processes. In addition making sequestration policies voluntary might raise their probability of success.

Eventually, it must be kept in mind that what happens in the rest of the economy makes the political economy of an integrative forest policy even more complex. For example, several concerns have been raised about the implication of a national carbon tax on international competitiveness. In particular the chemistry and metallurgy sectors could be burdened by such a tax. Thus, these sectors might benefit from a reduction of the tax level, whereas the forest sector would not. This would result in a differential tax with regard to the sector to which it applies, and the forest sector might no longer benefit in this case. One way to study these interactions in the future would be to conduct a similar analyse but using a general modeling framework.

References

Armington, P. S. (1969). A theory of demand for products distinguished by place of production. *IMF Staff papers*, 16(1):159–176.

Barthes, J., Lecocq, F., Caurla, S., Delacote, P., and Barkaoui, A. (2012). Would an economy-wide carbon tax hinder or help the forest sector? insights from the French Forest Sector Model. *Cahiers du LEF*, 4.

Bohlin, F. (1998). The swedish carbon dioxide tax: effects on biofuel use and carbon dioxide emissions. *Biomass and Bioenergy*, 15:283–291.

[2]However, this conclusion does not take into account general equilibrium considerations, such as the recycling of the tax revenues.

Carbofor (2004). Rapport final du projet Carbofor: séquestration de carbone dans les grands écosystèmes forestiers en France. Quantification, spatialisation, vulnérabilité et impacts de différents scénarios climatiques et sylvicoles. Technical report, GIP Ecofor.

Caurla, S. (2012a). Introducing Armington imperfect substituability in Samuelson spatial price theory: analytical resolution of the resulting model. *Cahiers du LEF*, 6. http://www7.nancy.inra.fr/lef/cahiers$_$du$_$lef/2012$_$06.

Caurla, S. (2012b). *Modélisation de la filière forêt-bois française. Evaluation des politiques climatiques*. PhD thesis, AgroParisTech. http://www7.nancy.inra.fr/lef/actualites/archives$_$actualites/these$_$caurla.

Caurla, S., Delacote, P., Lecocq, F., and Barkaoui, A. (2009). Fuelwood consumption, uncertainty over resources and public policies : Which impacts on the French forest sector? *Cahiers du LEF*, 03.

Caurla, S., Lecocq, F., Delacote, P., and Barkaoui, A. (2010). The French Forest Sector Model : version 1.0. Presentation and theoretical foundations. *Cahiers du LEF*, 04. https://www.nancy.inra.fr/lef/cahiers$_$du$_$lef/2010/2010$_$04.

Colin, A., Barnérias, C., Salis, M., Thivolle-Cazat, A., Coulon, F., and Couturier, C. (2009). Biomasse ligneuse forestière, populicole et bocagère disponible pour l'énergie sur la période 2006-2020. Technical report, ADEME. http://www.dispo-boisenergie.fr/doc/ADEME$_$boisenergie$_$rapport$_$final$_$dec2009.pdf.

Colin, A. and Chevalier, H. (2009). Rapport technique module biologique LEF. Technical report, Inventaire Forestier National.

Ginisty, C., Chevalier, H., Vallet, P., and Colin, A. (2009). Evaluation des volumes de bois utilisables à partir des données de l'IFN " nouvelle méthode". Technical report, CEMAGREF et IFN.

Grace, J. (2004). Understanding and managing the global carbon cycle. *Journal of Ecology*, 92:189–202.

Hofer, P., Taverna, R., and Werner, F. (2007). *The CO_2 effects of the Swiss forestry and timber industry: scenario of future potential for climate-change mitigation*. Environmental studies no. 0739. Federal Office for the Environment: Bern.

Im, E. H., Adams, D. M., and Latta, G. S. (2007). Potential impacts of carbon taxes on carbon flux in western oregon private forests. *Forest Policy and Economics*, 9:1006–1017.

Kallio, A., Salminen, O., and Sievänen, R. (2013). Sequester or substitute - consequences of increased production of wood based energy on the carbon balance in finland. *Journal of Forest Economics*, In Press.

Kurz, W. A., Beukema, S. J., and Apps, M. J. (1997). Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. *Mitigation and Adaptation Strategies for Global Change*, 2:405–421.

Lecocq, F., Caurla, S., Delacote, P., Barkaoui, A., and Sauquet., A. (2011). Paying for forest carbon or stimulating fuelwood demand? Insights from the French Forest Sector Model. *Journal of Forest Economics*, 17:157–168.

Luyssaert, S., Schulze, E. D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., Ciais, P., and Grace, J. (2008). Old-growth forests as global carbon sinks. *Nature*, 455:213–215.

Marland, G. and Schlamadinger, B. (1997). Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. *Biomass and Bioenergy*, 13(6):389–397.

Nabuurs, G., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W., Matsumoto, M., Oyhantcabal, W., Ravindranath, N., Sanchez, M. S., and Zhang, X. (2007). Forestry. *In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC, Cambridge University Press, Cambridge.*

Pajot, G. (2011). Rewarding carbon sequestration in south-western french forests: A costly operation? *Journal of Forest Economics*, 17:363–377.

Petersen, A. (2006). A comparison of avoided greenhouse gas emissions when using different kinds of wood energy. *Biomass and Bioenergy*, 30:605–617.

Petersen, A. K. and Solberg, B. (2005). Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden. *Forest Policy and Economics*, 7(3):249 – 259.

Pingoud, K., Pohjola, J., and Valsta, L. (2010). Assessing the integrated climatic impacts of forestry and wood products. *Silva Fennica*, 44(1):155–175.

Puech, J. (2009). Mise en valeur de la forêt française et développement de la filière bois. Technical report.

Quinet, A. (2009). La valeur tutélaire du carbone. *Rapport du Conseil d'Analyse Stratégique*, 2009-16.

Rocard, M. (2009). Rapport de la conférence des experts et de la table ronde sur la contribution climat et énergie. Technical report, MEEDDM.

Samuelson, P. (1952). Spatial price equilibrium and linear programming. *American Economic Review*, 42(3):283–303.

Sathre, R. and Gustavsson, L. (2007). Effects of energy and carbon taxes on building material competitiveness. *Energy and Buildings*, 39:488–494.

Seidl, R., Rammer, W., Jäger, D., Currie, W., and Lexer, M. (2007). Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. *Forest Ecology and Management*, (248):64–79.

Timilsina, G. R., Csordás, S., and Mevel, S. (2011). When does a carbon tax on fossil fuels stimulate biofuels? *Ecological Economics*, 70:2400–2415.

Traisnel, J.-P., Joliton, D., Laurent, M.-H., Caffiaux, S., and Mazzenga, A. (2010). Factor 4 in housing in france. Technical report, CLIP (Club d'Ingénierie Prospective Energie et Environnement). http://www.iddri.org/Publications/Habitat-Facteur-4 Access date: 10/04/2013.

Vallet, P. (2005). *Impact de différentes stratégies sylvicoles sur la fonction puits de carbone des peuplements forestiers*. PhD thesis, ENGREF.

van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G. J., Kasibhatla, P. S., Jackson, R. B., Collatz, G. J., and Randerson, J. T. (2009). CO_2 emissions from forest loss. *Nature Geoscience*, 2:737–738.