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Document de travail
n° 2010-02

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Retributing Forest Carbon vs. Stimulating Fuelwood Demand Insights from the French Forest Sector Model

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Résumé

Les forêts contribuent à la lutte contre le changement climatique en séquestrant du carbone dans la biomasse, et en remplaçant les énergies fossiles par le bois-énergie. Cet article analyse les impacts, sur la filière forestière française, économiques et en terme de bilan carbone, d'une politique de "stock" (paiement pour séquestration in situ), d'une politique de substitution (subvention à la consommation de bois énergie), et d'une combinaison de ces deux politiques. Pour cela, nous utilisons le Modèle du Secteur Forestier Français (FFSM), qui combine un modèle dynamique de la ressource forestière française, et un modèle d'équilibre partiel dynamique du secteur forestier français. Nos simulations couvrent la période 2010-2020. Nous montrons que la politique de stock est la seule qui a un bilan carbone positif sur la période considérée. Sur cette période, l'effet de substitution cumulé d'une politique de substitution est insuffisant pour compenser le destockage massif de la ressource. Cependant la politique de stock est celle qui pèse le plus sur le bien être des consommateurs. La combinaison des deux politiques conduit à des résultats intermédiaires et est donc moins effective que de se concentrer sur une seule politique.

Mots clés : Stockage du carbone, Énergie de la biomasse, Modélisation du secteur forestier.

Abstract

Forests can contribute to climate mitigation by sequestrating carbon in forest biomass and by replacing fossil-fuel with fuelwood, with potentially conflicting implications for forest management.The present paper assesses the mitigation and the economic impacts of a "stock" policy (payment for sequestration in situ), a "substitution" policy (subsidy to fuelwood consumption),and a combination thereof on the French forest sector. The policies are consistent in that they are based on the same social cost of carbon. To do so, we use the French Forest Sector Model (FFSM), which combines a dynamic model of French timber resource, and a dynamic partial equilibrium model of the French forest sector. Simulations show that over the 2010-2020 period, the stock policy is the only one that performs better than Business As Usual (BAU) in terms of carbon. Over this period of time, the cumulative substitution benefits of the substitution policy are not sufficient to offset the loss of carbon in standing forests. However, the stock policy has also negative impacts on consumers welfare, and increasingly high costs as carbon in excess of BAU is accumulated in forests. Combining both policies brings intermediate results and is thusless effective than focusing on a single policy.

Key words : Carbon storage, Biomass energy, Forest Sector Modeling.

Classification JEL : L52, Q23, Q42, Q54.

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1 Introduction

Forests contribute to mitigating climate change in two ways: by sequestrating carbon in forest biomass and in timber products – *"stock effect"* –, and by replacing fuelwood with fossil-fuel and non-timber with timber products, the production of which is less energy- and emissions-intensive –*"substitution effect"* ([Naaburs et al., 2007]).

Though both contributing to the same environmental goal, stock and substitution policies are markedly different. Policies that favor the stock effect (hereafter "stock policies") will focus on the upstream part of the forest sector, whereas policies that favor substitution effects ("substitution policies") will focus on the transformation and on the demand for timber products. Though markets should redistribute rents throughout the sector, stakeholders within the sector are clearly very sensitive to where the policy applies.

In addition, stock and substitution policies may have conflicting implications for forest management. Stock policies often imply longer rotations, at least when they provide incentives for increasing carbon storage in biomass. Substitution policies, on the other hand, often lead to shorter rotations as they provide forest owners with incentives to increase yields.[1]

The complementarities and trade-offs between carbon sequestration in biomass and climate benefits of timber products have been recognized and studied since the mid-1990s at least (see e.g., [Marland and Schlamadinger, 1997]). The studies typically rely on coupled forest management / timber-products cycle models with geographical scales ranging from project level (e.g., [Masera et al., 2003]) to forest management unit (e.g., [Seidl et al., 2007]) to national level (e.g., [Hofer et al., 2007], [Pingoud et al., 2010]); and with focus ranging from single products to the whole range of forest sector outputs.

Three key messages stem out of this literature. First, these studies consistently suggest that higher carbon gains can be made by increasing timber use in long-lived products and burning those for energy at end-of life, than by focusing directly on biomass energy. Second, the trade-off between stock and substitution policies is not absolute, and strongly depend on the context. Strategies that both increase carbon storage and increase substitution can be devised, notably (following the previous point) via increased basal area and additional sawlog production. Third,

[1]The trade-off is not absolute, however, because for a variety of reasons forests are not necessarily harvested at economically optimal rotation lengths, and because foresters can play on other variables than rotation lengths to increase biomass or increase fluxes of timber (e.g., density, intensity of thinning, choice of species, etc.). Moreover, all the annual biological increment is not harvested. In this context of under-harvesting, implementing a substitution policy does not necessarily lead to shorter rotations, at least at first.

time matters. For example, [Hofer et al., 2007] show in the Swiss case that stock policies lead to the highest CO_2 gains in the short term, but that sequestration policies take over in the medium- to long-term.

However, the scenarios tested in this literature are typically expressed as changes in forest management practices–with little insights on the economic rationale that would drive those changes, or even on their economic implications for forest owners. (One exception is [Seidl et al., 2007] who complement their analysis of trade-offs between storage and sequestration at the Forest Management Unit in Austria with estimates of the opportunity cost of sequestration and substitution.) This is because the underlying models do not usually capture economic dynamics, notably market dynamics.

The objective of the present paper is thus to compare the implications of stock, substitution and combined policies for both carbon accounting and for the economics of the French forest sector. To do so, we rely on the French Forest Sector Model (FFSM, [Caurla et al., 2010a]) which couples a dynamic model of the French timber resource and a dynamic, partial-equilibrium model of the French forest sector. In particular, this framework allows us to specify our "stock" and "substitution" policy scenarios as consistent market incentives, precisely, (i) a subsidy to fuelwood consumption (substitution); (ii) a subsidy to carbon storage in standing forests (stock); and (iii) a combination the two previous instruments built that rely on the *same* social value of carbon.

To this regard, our analysis rests on the same logic as [Eriksson et al., 2009], who discuss the implications of increased timber use in the European construction sector by coupling forest resource and socio-economic models (namely EFI-GTM), and thus go all the way to price and market consequences. The difference is that we focus on a single country, focus on bioenergy, and, in the current paper, test only price instruments instead of quantity instruments.

Our results show that the stock policy is the only carbon improving policy by the 2020 horizon. Indeed, the important negative stock effect is not compensated by the positive cumulative substitution effect when the substitution policy is implemented. In terms of welfare, consumers and producers benefit from a substitution policy. Consumers get negative welfare impacts from the stock policy, while producers benefit. Finally, combining both the stock and substitution policies leads to an intermediary situation.

Section 2 presents the structure of the FFSM. Section 3 presents the three scenarios of public policies. Section 4 analyzes the impacts of those policies, and section 5 concludes.

2 A Brief Introduction to the FFSM

The *French Forest Sector Model* (FFSM, [Caurla et al., 2010a]) is a dynamic simulation model of the French forest sector. The model is built around two modules: a forest dynamics (FD) module and an economic (E) module. At each period (year), the E module computes optimal harvest given forest resources, transformation technology and capacity constraints, and supply and demand functions for raw timber products and first-transformation timber products. Imports are represented on processed timber product markets while exports are represented on raw timber product markets. Harvest levels are then passed on to the FD module, which computes the state of the Forest at next period, and so forth. The model is implemented under GAMS and is currently used over periods of approximately 10 years.[2] (See figure 1)

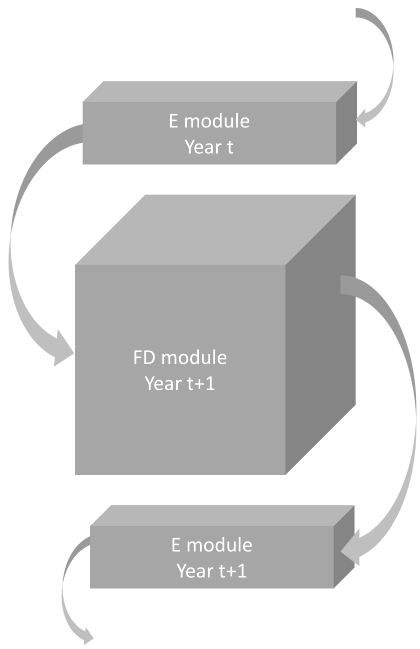


Figure 1: The French Forest Sector Model: a modular and recursive structure

The FD module simulates the growth of the timber stock using a diameter-class approach. Relative to other European countries, French forests are very diverse in terms of climate, soils, and species and types of management are historically very diverse, and forest dynamics highly

[2]In the current version, investment behaviors of both forest owners and transformation industry are exogenous, thus making the model ill-suited to longer-term simulations.

depend on those characteristics. Thus the dynamics of the forest in the FD module differ by region (22 administrative regions are considered), and within each region by type of management (high forests, coppices, mixtures and uneven-aged forests), species (coniferous and broadleaved) and diameter classes (13 diameter class); for a total of 1,716 different cells or *forest domains*. The FD module has been calibrated by the French forest inventory service ([Colin and Chevalier, 2009]) using data from the 2005-2007 French forest inventories.

The E module is a partial-equilibrium model of the French forest sector. It encompasses both raw timber products (fuelwood, pulpwood, hardwood and softwood roundwood) and processed timber products markets (hardwood sawnwood, softwood sawnwood, plywood, pulp, fuelwood, fiber and particle board). Three groups of agents are thus represented in the model: forest owners (timber suppliers), transformation industry and consumers (demand for processed goods)[3]. Inter-regional trade (the E module distinguishes 22 administrative regions within France) is modeled assuming perfect competition and full substitutability of products across regions, *à la* [Samuelson, 1952]. International trade between France and the Rest of the World is modeled assuming imperfect substitutability using [Armington, 1969] framework. The E module is calibrated using literature data and specific estimates, as presented in [Caurla et al., 2010a] and [Sauquet et al., 2010].

3 Policy scenarios

3.1 Substitution policy

We test three policy scenarios. First, a substitution policy (scenario S1) consisting of a public subsidy to end-user fuelwood consumption. Fuelwood consumption is a clear example of substitution effect. In fact, to the extent fuelwood originates from sustainably managed forests (a condition that is met in France), fuelwood-based electricity and heat production emits less greenhouse gases than fossil-fuel production would, as emissions from fuelwood combustion are compensated by forest regrowth.

The market impacts of the fuelwood consumption subsidy are illustrated in Figure 2. The consumer inverse demand curb is translated upwards by the amount of the subsidy s when the subsidy is implemented. Consumers perceive a smaller price than the market price, which, everything else equal, increases final demand for fuelwood. As a result of the subsidy, demand shifts from q_0 to q_1 and the perceived price shifts from p_0 to p_1.

[3]Only first-transformation industry is represented, not second transformation.

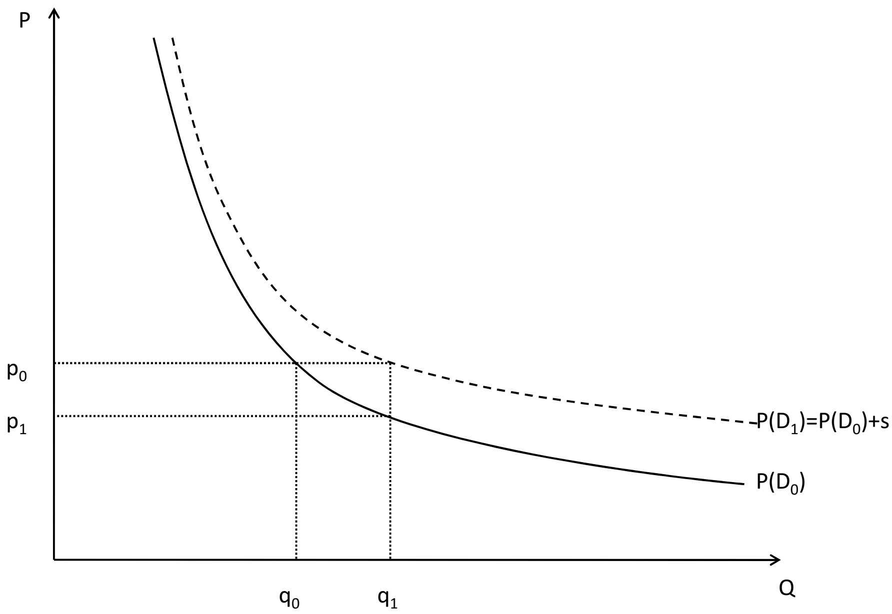


Figure 2: How consumers react when implementing a subsidy

We calibrate the subsidy assuming that it perfectly internalizes the social benefits associated with fuelwood consumption. The level of the subsidy is thus computed as the amount of carbon saved per cubic meter of fuelwood consumed (substitution coefficient) times the social price of carbon.

The substitution coefficient depends on the efficiency of the energy production technology, of the type of fuelwood that is used (pellets, sticks, logging residues) and of the nature of the substitute (gas, oil, renewables). According to the French Environment and Energy Management Agency ([ADEME, 2005]) burning 1 m^3 of fuelwood saves approximately 0.625 ton of CO_2 on average.[4] We retain this figure in the paper.

There is currently no consensus on the social price of carbon, because of uncertainties about both the risks associated with climate change, and the costs of mitigation and adaptation (e.g., [Watkiss and Downing, 2008]). In the present paper, we use the recently announced value of 17

[4]The coefficient is low relative to other Europan countries because of the dominant share of nuclear in French electricity mix.

euro per ton of CO_2 as an indication of domestic willingness to pay for climate mitigation. We also assume that this value increases linearly by 2 euros per year to reach 37 euro/tCO_2 in 2020.[5]

Increased use of other timber products relative to BAU are assumed to result in net gains in GHG emissions. The products include, *inter alia*, use of timber beams for framing (reducing use of emissions-intensive steel), of paper bags (instead of plastic), or of timber flooring (instead of plastic or carpets). Yet these products are not considered in the present paper for three reasons. First, the emissions savings occur in the production process, not in the consumption process. As a result, the gains may be difficult to trace and attribute, especially for end products of complex production chains. Second, substitution coefficients are often uncertain, and depend strongly on normative assumptions such as, for example, whether end-of-life emissions are accounted for or not. Third, existing climate policies focus solely on biomass energy, and do not fully cover over substitution effects.

Finally, the choice of a subsidy as policy instrument is justified for two reasons. First, price instruments are efficient ways of internalizing externalities in the context of perfectly competitive markets–as modeled in the FFSM. Second, a price mechanism allows for easy coordination with stock policies (via the socially agreed price of carbon). We have examined elsewhere alternative policies, notably the introduction of a fixed demand by the Government ([Caurla et al., 2009]).

3.2 Stock policy

The second policy scenario we test (S2) consists of retributing forest owners for the environmental service of carbon storage in excess of business-as-usual (BAU). Each year, timber suppliers thus receive a payment from the Government (P_t) computed as the difference between the amount of carbon sequestered in standing forest (C_t) relative to BAU (C_t^{BAU}), times the price of carbon sequestration (Pc_t): $P_t = Pc_t(C_t - C_t^{BAU})$. Note that the payment can be negative (tax) if the carbon stock falls below BAU level. We only consider above-ground biomass, which under-estimates the environmental service, but allows for easier accounting. And we use the rule-of-thumb approximation that one cubic meter of standing biomass stores one metric ton of CO_2 ([Dupouey et al., 1999]; [Carbofor, 2004]).

[5] In 2009, the French administration proposed an across-the-board carbon tax or "*contribution climat énergie*" (CCE). Expert recommended an initial value of 32 euros per ton of CO_2 ([MEEDDAT, 2009], [Quinet, 2009]) with a 2.4 euro per year increase until 2020. But after negotiations the President finally announced a 17 €/tCO_2 (Presidential speech on climate mitigation, Artemare, 10 September). After being partly struck down by the constitutional council, the CCE was withdrawn undefinitely in early 2010.

The annual retribution for carbon storage $p_{c,t}$ is the constant annual value corresponding to a price of permanent (i.e., indefinite) sequestration of p_c defined in the above section–based on a 4% discount rate. This annuity is revised every year as the price of permanent sequestration increases (see previous section)–thus it goes from 0.68 €/tCO_2 per year to 1.48 €/tCO_2. The stock policy is thus environmentally consistent. In particular, accidental release of carbon via e.g., fires or hurricanes, would not compromise the environmental integrity of the policy. The forest owners would simply see their annual payment decrease (or even become negative if carbon stocks fall below BAU).

In the current version of the FFSM, at any given period, forest owners choose their level of supply depending only on current market prices. As a result, in the current version of the model, forest owners will factor the retribution for carbon storage in their supply decisions only to the extent it does influence the *current* price of timber. Since carbon storage is directly (and negatively) correlated with timber harvest, the stock policy creates an opportunity cost to timber supply and it impacts on forest producers as a "tax" of the same amount would. However, this analogy is contingent on the fact that, in the current version of the model, expectations about future revenues and/or costs, and in particular the fact that the carbon payment will be repeated as long as the carbon is stored, do not enter into timber suppliers' decisions.[6]

Figure 3 shows how the stock policy reduces the timber supply. When the policy is implemented, timber suppliers integrate the new opportunity cost of the stock policy in their supply behavior, which shifts upward the supply curve.

The stock policy we test is a natural extension of payments for carbon sequestration already in place in projects under the Clean Development Mechanism of the Kyoto Protocol, or in the so-called "voluntary carbon market" (see [Hamilton et al., 2009] for a review). To our knowledge, however, there is currently no policy in operation that would pay forest owners for carbon storage in standing forests (as opposed to new ones) on a regional or national scale (as opposed to individual projects).[7]

It is important to note here the voluntary nature of the policy. Timber suppliers will self-select themselves and will enter the programme only if it makes them better off. We do not introduce

[6]The current model can also be interpreted as assuming that timber suppliers have no confidence in the Government ability to sustain the subsidy, and thus react only to the current price signal, and not to the future ones.

[7]Under Article 3.4. of the Kyoto Protocol, Annex I countries may elect to account for variations in carbon storage in designated standing forests to help meet their overall obligations. To our knowledge however, no Annex I government has set up policies to pass on that incentive to individual forest owners.

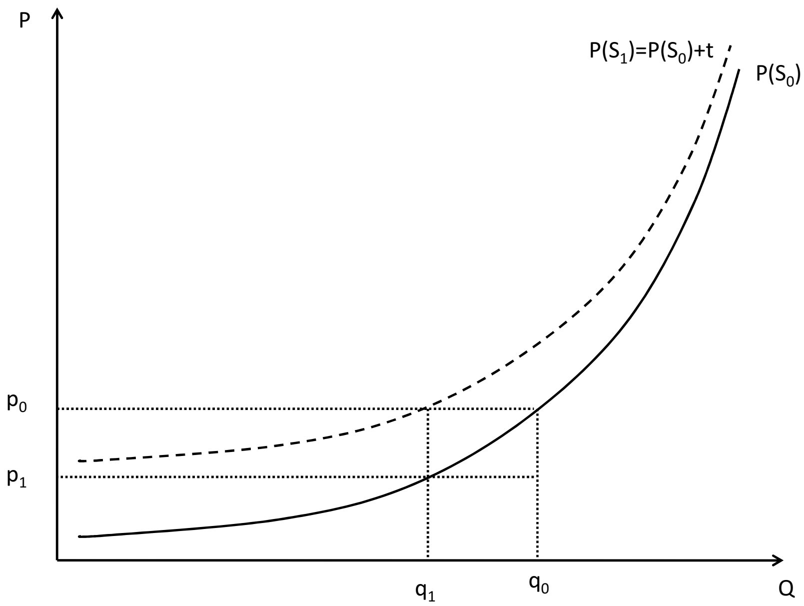


Figure 3: Effect of a tax on supplier behaviour

the participation constraint directly into the model, but instead we test *ex post* whether suppliers are better off or not.

Finally, note that the choice of the reference scenario will affect individual owners decisions to participate or not in the scheme, but not their timber supply decisions at the margin (only the annualized value of sequestration matters here). To the extent participation is constant, thus, any reference would yield the same results for timber markets (e.g., current level, "average" level over a given period of time, zero, etc.), but with very different distributional implications. In practice the choice of a reference result from a trade-off between levels of transfers, risks of non-participation, and costs of measurement of and agreement upon a reference.

3.3 Combination and BAU

Finally, we test a third scenario (S3) consisting of a combination of S1 and S2. S3 is an interesting case *per se*. On the one hand, economic theory recommends to price the carbon externality across the board. Since sequestration and substitution effects are different, it makes sense to value them jointly. On the other hand, as noted in the introduction, sequestration and substitution policies may pull forest owners in different directions, and their effects may thus cancel out, at heavy costs to society. Moreover, welfare implications for forest owners and consumers are unclear. Hence this combination scenario.

All three policy scenarios are discussed against a business-as-usual scenario (BAU). In this reference scenario, we keep base year demand functions, transformation capacity, and world market prices constant (in real terms) from 2006 to 2020. As a result, market equilibrium do not evolve markedly from 2006 to 2020. In particular, above-ground biomass stock continues to increase at high rate (+56 Mm^3 per year or +6.5% per year on average), following observed trends, and consistent with medium-term projections of the French Forest Inventory Service.

Our simulations are conducted from 2006 to 2020. We assume in each case that the policies are introduced in 2010 and sustained until 2020, with the price of carbon increasing as discussed in the previous section.

4 Policy Outcome Analysis

This section is organized as follows. First, we discuss the implications of the three policy scenarios relative to BAU in terms of GHG emissions and sequestration (environmental assessment). Next, we discuss market implications and welfare impacts for the various stakeholders in the forest sector (economic assessment).

4.1 Carbon Implications

4.1.1 Carbon in Standing Forests

The substitution policy increases demand for fuelwood by 30% or 0.80 Mm^3 relative to business-as-usual (BAU) in 2020. Though fuelwood imports increase (+43% relative to BAU in 2020), the bulk of the increment comes from increased harvesting of national forests–because fuelwood imports are a small share of consumption in the BAU. As a result, the carbon stock in standing forests decreases. It is approximately 7.1 $MtCO_2$ lower in 2020 with the substitution policy than it would have been without (see Figure 4).

Conversely, and as expected, the stock policy increases carbon storage in standing forests. The variation, however, is nearly one order of magnitude smaller (+0.9 $MtCO_2$ in 2020 relative to BAU) (see Figure 4). Thus, when the two policies are combined, the negative impact of the biomass energy subsidy on carbon in standing forests offsets the positive impact of the sequestration subsidy. In

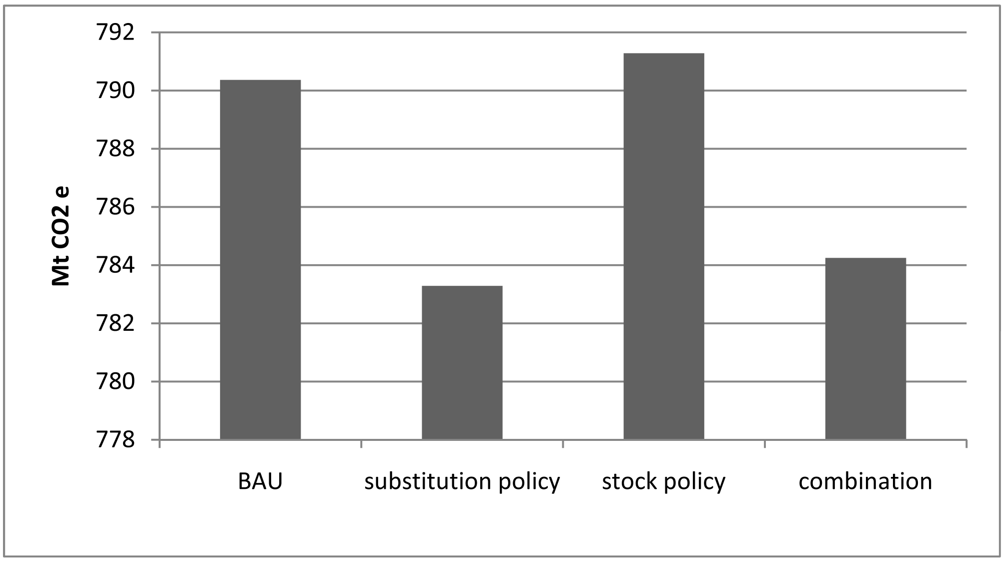


Figure 4: Carbon sequestered in standing forest between 2010 and 2020

S3, carbon stock decreases relative to BAU by nearly the same amount as in the sequestration policy (-6.1 $MtCO_2$ instead of -7.1 $MtCO_2$).

4.1.2 Substitution

Substitution is accounted for using the stock change approach to imports and exports. In particular, substitution caused by imported fuelwood is accounted for, whereas substitution generated abroad by French fuelwood export is not. We make the assumption that imported fuelwood has the same substitution coefficient than domestic fuelwood ([Brown et al., 1999], [Lim et al., 1999]).

The implications for substitution are opposite to those for carbon stock in standing forests. The substitution policy leads to higher fuelwood consumption, and thus to higher substitution gains. In cumulative terms, the fuelwood subsidy increases substitution by 3.7 $MtCO_2$ relative to BAU between 2010 and 2020 (+16%). When the price of carbon is maximal in 2020, sequestration is about +0.5 $MtCO_2$ over BAU (+30%) (Figure 5).

Conversely, the stock policy tends to limit timber supply, including (but not limited to) fuelwood supply. As a result, equilibrium demand is also lower than in BAU. However, the impact is nearly

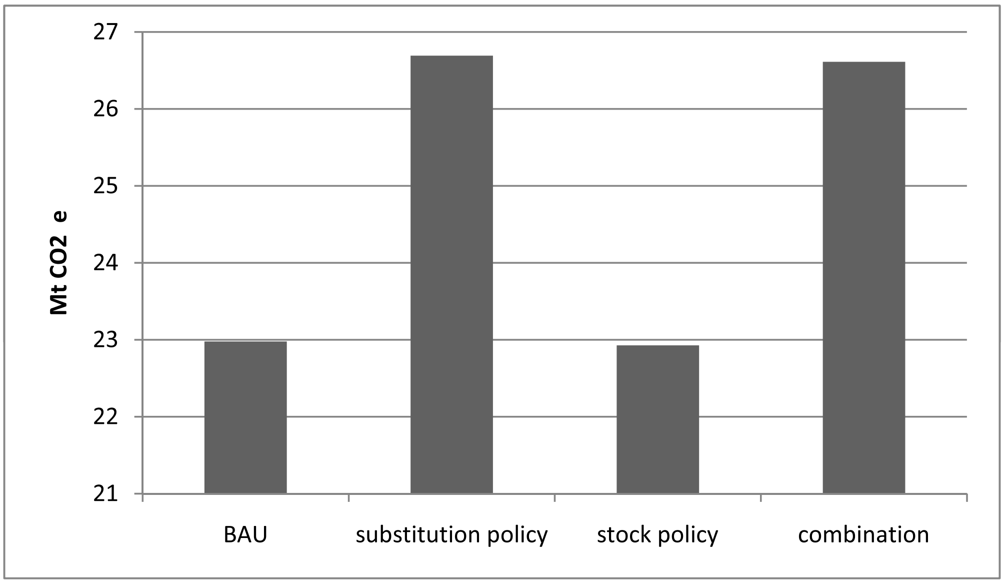


Figure 5: Cumulative CO_2 emissions savings from substitution between 2006 and 2020

two orders of magnitude smaller than the impact of the sequestration policy (-0.05 $MtCO_2$ related to BAU over the 2010-2020 period or -0.2%, -0.006 $MtCO_2$ relative to BAU in 2020). Combining the two policies has basically the same effect on substitution as the substitution policy alone.

Figure 6 summarizes the total carbon implications of the different policies. To remain consistent, we add up variations in carbon stored in standing forests with *cumulative* substitution effect over the 2010-2020 period.

Overall, the stock policy turns out to be the most beneficial in carbon terms over the 2010-2020 period. In fact, S2 is the only scenario in which total carbon increases relative to baseline (+0.9 $MtCO_2$ over 2010-2020). The sequestration policy, on the other hand, leads to a net decrease in carbon (-3.4 $MtCO_2$ over 2010-2020) because the policy drain on standing biomass is not compensated by cumulative substitution. Combining stock and flux policies does improve the environmental balance, but it remains negative (-2.5 $MtCO_2$ relative to BAU over the 2010-2020 period), as the increase in storage due to the storage subsidy is not sufficient to offset the loss due to the fuelwood subsidy.

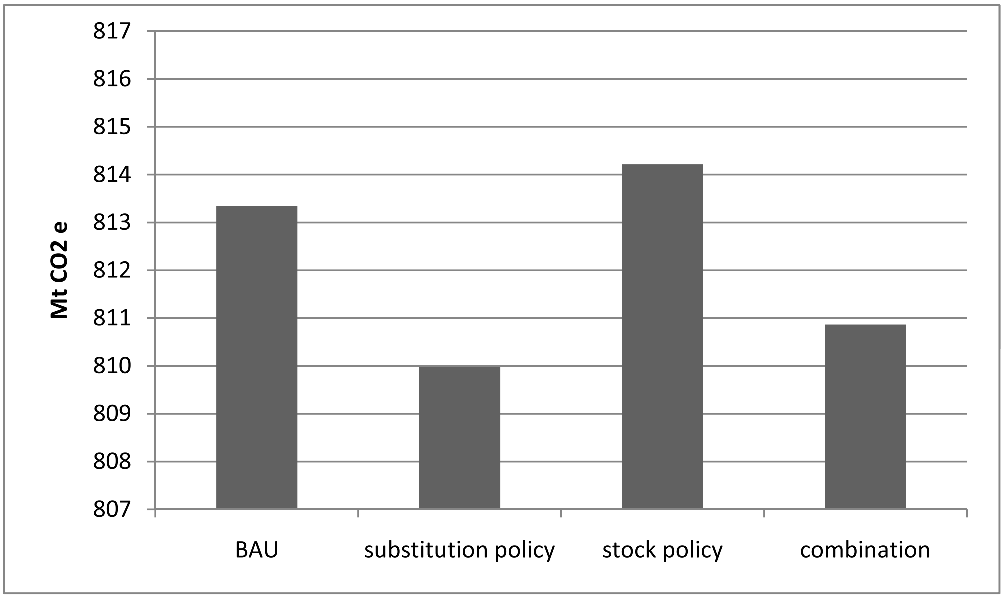


Figure 6: Total cumulative CO_2 impact (stock and substitution) between 2006 and 2020

4.1.3 Discussion

Two main comments should be made on the results above.

First, as noted above, the stock and flux policies turn out to be highly asymmetric despite being based on the *same* price of carbon. This can be explained by the fact that the stock policy compensates forest owners for one year of sequestration, whereas the substitution policy pays for the permanent substitution effect. On the demand side, the subsidy perceived by consumers in 2020 is thus $37 \times 0.625 = 23.1$€ per m^3 of fuelwood, i.e., an increase of 60% relative to BAU. Whereas on the supply side, at any given point in time, the opportunity cost of putting an additional cubic meter of timber on the market is only 1.4 €/tCO_2, or 5.3% of the average price paid to producers for fuelwood in 2020 in the BAU (and less than 3% of the average price of roundwood).

Obviously, as discussed above, the model only captures the first order impact of the stock policy on timber supply. Forward-looking forest owners may withdraw more volume from the market to take advantage of the compounded payments associated with the stock policy. Yet the situation will be very different between coppice and high forest managers. Coppice managers may react to the sequestration subsidy by increasing rotation lengths, thereby temporarily withdrawing more fuelwood from the market, until a new equilibrium is reached. High forests managers, on the other hand, may use the carbon policy to reduce harvests of low- to medium-diameter trees, thereby limiting supply in the short run, but potentially increasing supply of high-value roundwood in the longer term. Taking these dynamic effects into account would require to revise the supply function of the model and take expectations into account–a research area currently in progress. But this simulation already points to fundamental differences in stock and substitution policies.

The second important point is that we find that the stock policy dominates the substitution policy in the short run. This is consistent with previous studies (e.g., [Hofer et al., 2007]), but contingent on (i) our choice of considering biomass energy only ; and (ii) on the characteristics of the French energy system, which generates electricity with a carbon content about one fifth of KWh produced in Germany or the U.S. The ranking between the policy may change if we were to extend the simulation horizon sufficiently.

The above results also provide some insights on the costs of mitigation in France, and about the feasibility of Governmental objectives of increasing fuelwood energy consumption by *circa* 8 Mm^3 in 2020 relative to current levels. Both points are discussed in the conclusion of the paper.

4.2 Welfare Implications

In this section, we examine the welfare implications of the three policy scenarios for three groups of agents: consumers, producers and the government. The FFSM also represents the transformation industry and the transportation agents, but their profit at equilibrium is zero in all three policy scenarios as well as in the BAU. Thus, they are not considered below. This section first presents the methodology, and then discusses welfare implications. Two additional subsections deal with mitigation costs and international trade effects respectively.

4.2.1 Methodology

Consumer surplus: Consumers surplus variation under the stock policy is straightforward. Under the substitution policy, consumers demand curve shifts downward by the amount of the subsidy. As a result, market equilibrium shifts from (p_0,q_0) to (p_1,q_1). Consumer surplus variation is the grey area on Figure 7.

Producers profits: Producers profits variation under the substitution policy is straightforward.

Producers profits variation under the stock policy (and the combination policy) are more complex. There are in fact two effects.

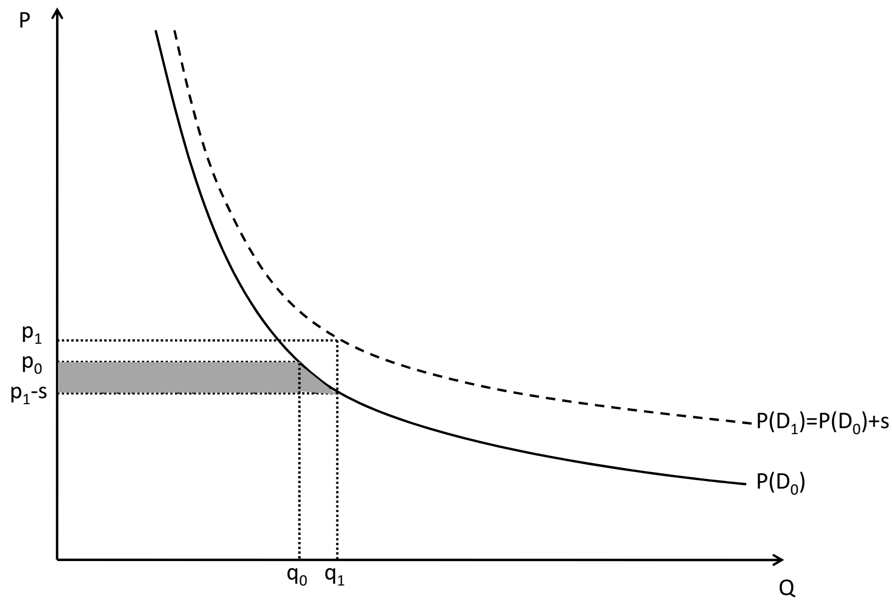


Figure 7: Consumer welfare variation when subsidy to fuelwood consumption is implemented

First, producers reaction to the payment for sequestration is to shift their supply curve upward by the amount of the subsidy. As a result, the market equilbrium shifts from (p_0,q_0) to (p_1,q_1), with a higher price and a lower quantity. The net impact on profit is the difference between the areas A and B on Figure 8, and its sign is ambiguous.

Second, producers do benefit from the payment for the tons of carbon sequestered in excess of BAU. The value of this payment is simply the price of annual carbon sequestration times the amount sequestered in excess of BAU.

Government budget: The impact of the substitution policy on the Government budget is simply the product of the subsidy rate times the amount of fuelwood consumed.

Similarly, the impact of the stock policy on the Government budget is the price of annual carbon sequestration times the difference between observed and BAU carbon stocks.

4.2.2 Welfare Impacts

Table 1 summarizes the welfare implications of the three policy scenarios relative to BAU. The substitution policy is straightforward. It amounts to large transfers to consumers and, via market

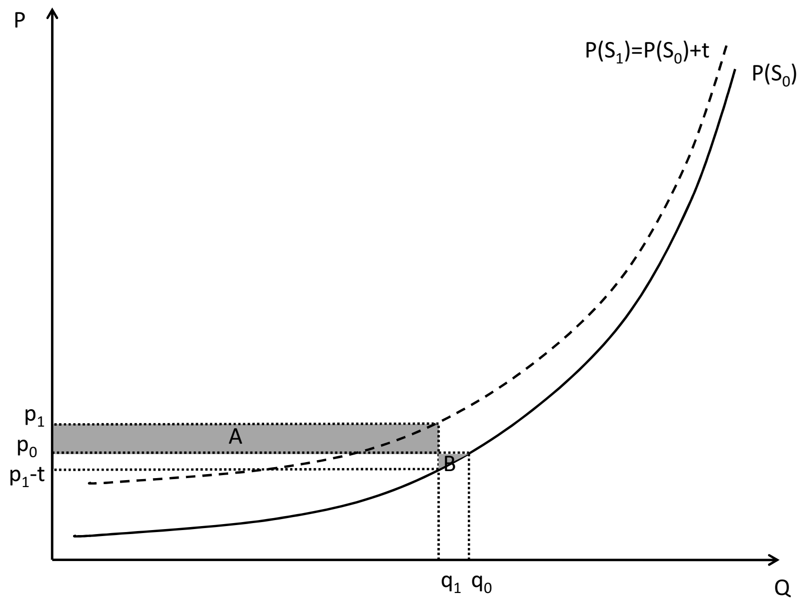


Figure 8: Producer welfare variation when tax to supply is implemented

mechanisms, to producers, with large costs for the Government and an overall deadweight loss of *circa* 18 M€ in 2020.

The stock policy has very limited impact, and therefore very limited overall effect. However, distributional implications are staringly different from the previous case, as the Government and consumers lose and producers win. It is important to note here that the about 80% of the producers welfare comes from increased prices, and not from the subsidy itself.

The figures for the combination policy (S3) look quite similar to those of the substitution policy, but there are significant differences. As noted above, the fuelwood subsidy dominates

Stakeholder	Substitution Policy (S1)	Stock Policy (S2)	Combination (S3)
Consumers	+40.85 M€	-6.28 M€	+34,87 M€
Producers	+20.8 M€	+7.37 M€	+17.53 M€
Government	-79.40 M€	-1.36 M€	-66.18 M€
Aggregate	-17.8 M€	-0.27 M€	-13.97 M€

Table 1: Aggregate Welfare Impacts of stock and substitution policies in 2020 relative to BAU

the sequestration subsidy, and producers increase harvests relative to baseline. As a result, the sequestration component of the policy turns into a net *gain* for the government as it taxes reduction in carbon storage relative to BAU. This gain is significant (+9 M€ in 2020), though not sufficient to offset the costs associated with the subsidy.

Consumer welfare: Total consumer surplus increases by +40.85 M€ when implementing the subsidy to fuelwood consumption. Since our fuelwood and roundwood markets are separated, and since resource is abundant enough for the fuel and pulp industry not to be in competition, all processed product markets are independent, and the surplus change concerns only fuelwood consumers ([Caurla et al., 2009]).

Conversely, the stock policy leads to a loss in consumer surplus by increasing the price of processed goods. All consumers are concerned, since the stock policy concerns all producers. However, this loss is relatively small: -6.28 M€ for all consumers and -0.66 M€ for fuelwood consumers.[8]

Overall, the combination of stock and substitution policies leads to an intermediary situation where consumer surplus increases, but less so than with the substitution policy alone (+34,87 M€). Thus, the substitution policy is unambiguously the most welfare improving for fuelwood consumers. In other words, the policy with the best carbon implication is also the only one which hurts consumers surplus. We come back to the policy implications of this result below.

Producers surplus: We find that the substitution policy increases fuelwood producer surplus by +20,80 M€. Indeed, by increasing processed goods market prices, this policy also increases raw materials market prices. Since both prices and quantities increase, the producer surplus unambiguously increases. As noted above, the fact that the markets be *de facto* separated explains why the surplus of non-fuelwood producers is not affected.

Interestingly, we also find that the stock policy increases suppliers' welfare (and in this case, all of them). For most producers, in fact, the limitation of supply induced by the policy (effect 1 above) results in welfare increase, as additional revenue linked to price increase more than compensates the loss of revenue due to supply reduction. When the subsidy to sequestration is added up (effect 2), the result is always positive. Overall, the subsidy to sequestration represents only 20% of total producers' surplus gain in 2020. The fact that effect 1 usually turns out positive can be explained as follows. By restricting supply without actual taxation (the "tax" is only an opportunity cost),

[8]Note that increasing the supply price elasticity, decreasing the demand price elasticity and increasing the carbon price increases this positive impact (see appendix A).

the policy can be interpreted as an incentive for producers to restrict supply relative to competitive market equilibrium, and move towards less competitive equilibrium.

When combining the two policies, the producers surplus increases in an intermediate manner (+17.23 M€). This is because timber harvested is larger in S3 than under BAU (because of the substitution policy); then the stock policy plays as a tax to forest owners. If we consider that the stock policy is voluntary, the policy maker then needs to take into account the fact that forest owners may not enter the policy in S3 (they would prefer not to enter and get the surplus from S1). This raises the question of the choice of the BAU (which is an usual question of designing payments for environmental services) and the voluntary nature of the policy. If the BAU is chosen as as situation without any policy, and if another policy (which is our case), with larger and opposite impacts (i.e the substitution policy) is implemented at the same time as the stock policy, then forest owners may choose not to enter the voluntary policy. This is represented by a trade off between the gain in producers surpluses in S3 and S1.

Government budget: The substitution policy retributes all fuelwood consumers with a subsidy that reduces perceived fuelwood price, for a total cost of 79.40 M€. Most of this total cost (75 %) is related to a *windfall effect*, which is the cost of the subsidy related to fuelwood that would have been consumed anyway (i.e., in the BAU). This raises questions of its cost effectiveness.

Conversely, because of its smaller overall impact, the stock policy is cheaper, costing only 1.36 M€. Nevertheless, because of its cumulative nature (timber not harvested today is retributed year after year), it is important to note that the cost of this policy increases one year after another.

Finally, combining the two policies has an intermediate effect. Indeed, the stock policy retributes forest owners with respect to a BAU without any policy. When combining the two policies, the effect of the substitution policy (increased harvest) is far more important than the effect of the stock policy (reducing timber supply). It follows that timber supply in S3 is larger than in BAU. Then the stock policy plays here as a tax to forest owners, since they harvest more than under BAU.

4.2.3 Implications for Mitigation Costs

The analysis also provides insights on the opportunity cost of mitigation in the forest sector.

Three notions of mitigation costs must be distinguished. Our policies are based on a *social cost of carbon*, which represents the marginal cost to society associated with the emission of one metric tonne of CO_2. This value should not be confused with the *average welfare cost* of the mitigation policy, which measures the average impact of the policy on Society (i.e., total welfare variation relative to BAU divided by carbon saved relative to BAU).[9] Finally, governments may pay particular attention to the *average budgetary costs* of mitigation (i.e., additional government expenditures relative to BAU divided by carbon saved relative to BAU), though–unlike total welfare costs–they depend on the redistribution scheme associated with the different policy scenarios.

Overall, the substitution policy (S1) leads to an increase in net carbon emissions relative to BAU. Strictly speaking, there is thus no mitigation. However, if the decrease in *in situ* carbon stock is ignored, and if only the end-use substitution effect is accounted for, the policy then results in effective mitigation, and mitigation costs can be estimated. The average welfare cost of mitigation ranges between 25 (in 2010) and 35 €/tCO_2 (in 2020). Interestingly, this average is higher than the price of carbon for most of the period, because of the indirect distortive impacts of the policy on the market add to the total costs. Of course, average budgetary cost of mitigation is much higher (*circa* 160 €/tCO_2) because of the large windfall effect of the fuelwood subsidy.

The stock policy, on the other hand, has a positive impact on total carbon. The average budgetary cost of *annual* sequestration is simply the social cost of carbon (i.e., from 0.68 €/tCO_2 to 1.48 €/tCO_2/year). On the other hand, average welfare costs of annual sequestration diminish over time (from 2.90 to 0.31 €/tCO_2/year). This might be explained by the fact that, in our simulations, available resource largely exceeds demand for fuelwood. As a result, trees that are withdrawn from harvest at year t will not restrict supply at subsequent years, and thus do not lead to additional costs to society. Hence an increasing stock of carbon but costs that remain concentrated at the margin.

4.2.4 Trade implications

Both policies, trough their price effects have an impact on international trade. As mentioned before, the substitution policy tends to increase both the raw and processed markets prices for fuelwood. It follows that French fuelwood is less competitive *vis à vis* international prices, which result in an increase in fuelwood imports (+43 %) and a decrease in fuelwood exports (-6 %).

The stock policy also leads to an increase in prices, which has the same type of trade effects. However, those effects are smaller than under a substitution policy. There is almost no impact on fuelwood imports (+0.1%), while fuelwood exports decrease by 2%.

[9]Since our model is only a partial-equilibrium model, it does not capture welfare variations for actors beyond the forest sector, and thus does not capture all the welfare impacts of our policies.

Both effects cumulate when both policies are combined. It follows that fuelwood imports increase by 43% and fuelwood exports decrease by 7%.

5 Conclusion

The aim of this paper was to explore the effects on the French forest sector of three policies to mitigate climate change: a fuelwood consumption subsidy (substitution), a payment for carbon sequestration in standing forest (stock) and a combination of the two previous instruments. Our analysis yields five key results.

First, in our simulations, the stock policy has a better impact on total net carbon emissions than a substitution policy. In fact, the stock policy is the only policy to have a positive effect on net carbon emissions in the 2010 - 2020 period. This result is consistent with previous analysis in the literature (e.g., [Hofer et al., 2007]), but it is contingent on three sets of factors: (i) The energy mix in France is far less carbon-intensive than in other European countries, thus limiting the impact of the substitution policy; (ii) The substitution policy we have tested concerns only carbon, and not other wood products which also generate substitution effects; (iii) Finally, the ranking between stock and substitution would probably change in the long-run as the impact on the standing stock levels off and the substitution effects accumulate.

Second, our simulations raise questions about the political economy of the stock policy. Unlike the substitution policy, which increases both consumers and producers surplus, the stock policy is detrimental to consumers surplus (though it increases producers surplus). It is thus politically more difficult to implement. In addition, the choice of the reference for the stock policy proves crucial. To the extent the stock policy is voluntary, it requires that forest owners be better off entering the policy than staying outside. It follows that if a voluntary stock policy is implemented jointly with a substitution policy giving large incentives to intensify harvests (scenario 3), forest owners may be better off not entering the PES scheme. Yet public budget constraints will limit governments ability to lower the reference. Finally, the reference must be easy to negociate, which in particular means transparent and easy to compute.

Third, in our simulations, combining the stock and the substitution policy is not superior to either stock or substitution alone. This is because combining the two policies leads to providing conflicting incentives to forest owners, with policies pulling in opposite directions. This result, however, is contingent on the nature of the policy that we have tested. In particular, stock and substitution policies aiming at *different* sets of producers and consumers might have synergies. In addition, complementarities may emerge in the long-run as we reach new resource equilibrium (as suggested in e.g., [Pingoud et al., 2010]).

Fourth, our results shed light on the feasibility of the French 2020 biomass consumption objectives. In fact, the report of the "Assises de la forêt" (2008) calls for harvests +21 Mm^3 higher in 2020 than in 2006. This volume would be split into +9 Mm^3 for building timber and +12 Mm^3 for fuelwood. Yet in our simulations, under realistic prices of carbon, the fuelwood subsidy we test leads to an increase in consumption of only 0.8 Mm^3 relative to 2006. Even with a carbon price increasing to 57€/tCO_2 in 2020, fuelwood consumption in 2020 would barely increase by more than +1.5 Mm^3 with respect to BAU, i.e., 7.5 Mm^3 below than the official objective (see Figure 9).

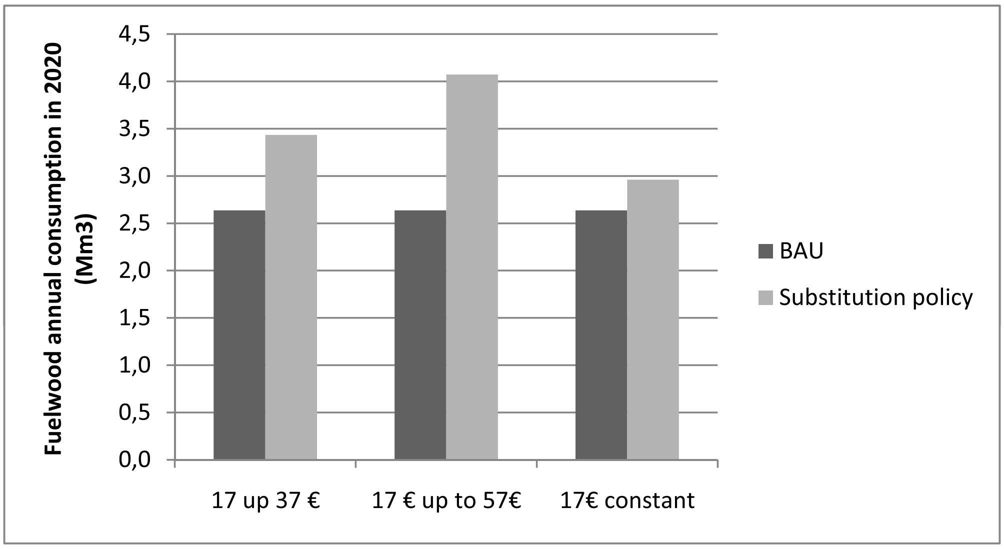


Figure 9: Growth of fuelwood consumption when retributing substitution effect with a consumer subsidy

The current version of the FFSM probably underestimates markets reactions to the substitution policy. This is because the current price elasticity of demand (-0.6) is closer to a short-run than to a long-run elasticity. This kind of demand function focuses on existing consumers, and omits new entrants. The difficulty is that the (formal) fuelwood market in France is still quite small. Thus, there is no data to estimate long-run elasticities. A direction for future research is thus to try and model investment in biomass energy generation capacity explicitly. However, very high elasticities of demand (higher than 2) are necessary to reach the Government 2020 objectives at reasonable carbon prices. Thus, in addition to a subsidy, a mechanism based on a public fixed-demand in which the government guarantees that it will purchase a fixed volume to provide public power plants could help in targeting national goals [Caurla et al., 2009].

Appendix A: Sensitivity analysis

A - 1: Price elasticities

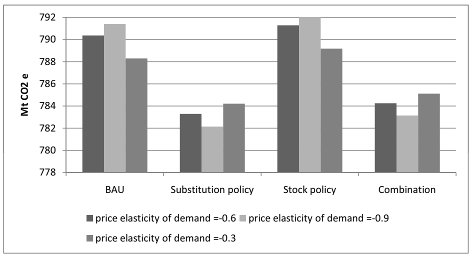
Our results are conditioned by assumptions on fuelwood price elasticity of supply (equal to 1 in our model) and fuelwood price elasticity of demand (equal to -0,6). Indeed while price elasticities are well-known for most timber products, they are more uncertain for fuelwood markets. Indeed, fuelwood markets are quite small as most fuelwood consumption is currently serviced either out of the market (via, e.g., self-production or collective timber supply at municipality level) or via informal markets. In this context, it is difficult to anticipate how would agents behave if fuelwood markets develop quickly. Thus we thus test two other demand elasticities and an other supply elasticity.

Carbon stock in standing forests: Results are shown in Figure 10a and 10b. Figure 10a shows that when demand becomes less elastic (elasticity moving closer 0), the negative impact of the substitution policy on the forest stock is lower. That can be explained by a decrease in harvest levels. The same mechanism applies for the supply elasticity: when supply becomes less elastic, harvest levels tend to decrease and the negative impact on the stock is smaller.

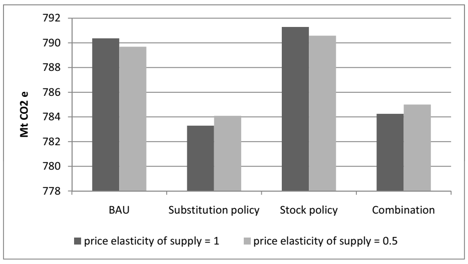
The stock policy has just the opposite implications from a change in price elasticity of demand and supply. When supply or demand become more inelastic, harvests increase and the carbon stock decreases. Indeed when the policy is implemented, raw timber supply decreases. Then raw timber prices increases, meanwhile a lower price elasticity to supply or demand means a loss in agent sensitivity to price variation.

Substitution effect: Increasing the price elasticity of supply and demand tends to increase the positive effect of the substitution policy while it increases negative effect of the stock policy (Figures 11a and 11b). Same mechanisms than the one for carbon in standing forest applies:

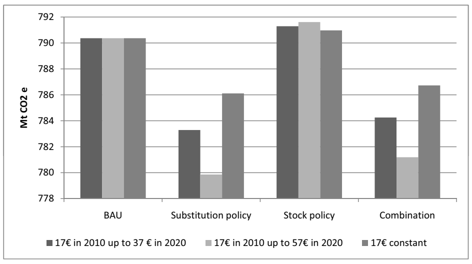
increasing elasticities of demand or supply tends to increase consumption when the substitution policy is implemented.



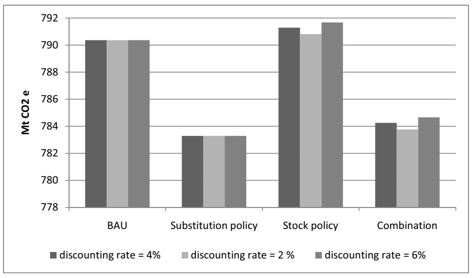
(a) Sensitivity to price elasticity of demand



(b) Sensitivity to price elasticity of supply



(c) Sensitivity to carbon price

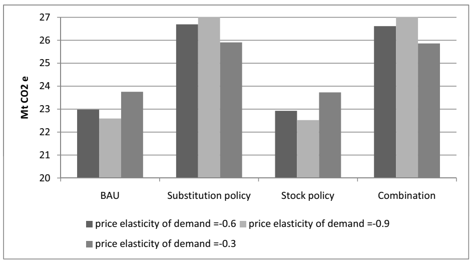


(d) Sensitivity to discounting rate

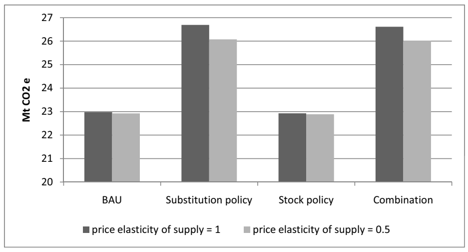
Figure 10: Carbon stock in standing forest: Sensitivity analysis

A2 - Carbon price

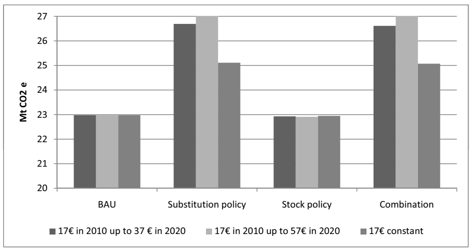
As shown in figure 10c, sensitivity to the carbon price is quite important for the substitution policy while it smaller for the stock policy, despite the fact that we consider consistent carbon prices for both policies. Indeed, our stock policy is calibrated on the value of the rent for one year of carbon sequestration while the substitution policy retributes the permanent substitution of non-emitted carbon. As shown in Figure 11c, the substitution policy is very sensitive to the carbon price trend, while, conversely, the stock policy is almost unsensitive to it.



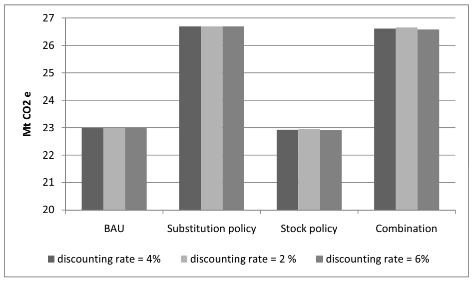
(a) Sensibility to price elasticity of demand



(b) Sensibility to price elasticity of supply



(c) Sensibility to carbon price



(d) Sensibility to discounting rate

Figure 11: Cumulative substitution in the forest industry: sensibility analysis

A3 - Discount rate

The discount rate only plays on the carbon price in the stock policy. It follows that the substitution policy is not sensitive to it. Increasing the discount rate (and thus increasing annual rent) tends to increase the effectiveness of the stock policy: increase in carbon sequestration (Figure 10d), and small decrease in carbon substitution (Figure 11d).

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