Stimulating fuelwood consumption through public policies: an assessment of economic and resource impacts based on the French Forest Sector Model

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Abstract

Stimulating renewable energy is a crucial objective in view of tackling climate change and coping with future fossil fuel scarcity. In France, fuelwood appears to be an important source for the renewable energy mix. Using the French Forest Sector Model, our paper aims to assess the impacts of three policy options to stimulate fuelwood consumption: a consumer subsidy, a producer subsidy and a fixed-demand contract policy. We explored their impacts in terms of five groups of criteria: (1) forest resource dynamics; (2) variations in wood products prices and quantities consumed and produced; (3) trade balance; (4) budgetary costs; and (5) variations in agent surpluses. We show that no policy option is more desirable than another on the basis of all of these criteria and that trade-offs will determine which is the best policy option to be implemented.

Keywords

Climate Change, Renewable Energy, Biomass, Fuelwood, Forest Sector Modeling, Public Policies.

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1. Introduction

In 2011, renewable energy represented about 15.3% of the total production of French primary energy, i.e. about 21.2 Mtoe. The European directive 2009/28/EC has set the objective of increasing the share of renewable energy in French energy mix to 23% by 2020. In France, where forest resources are abundant — France has the fourth largest forest cover among of the 25EU countries — biomass energy is expected to play a major role in achieving this objective. As shown in Figure 1, using wood for heat production emits far less CO_2 than other energy sources for the same energy service[9]. This is mainly because carbon emissions during fuelwood combustion are compensated for by storage during forest regrowth, provided that fuelwood originates from sustainably managed forests (a condition that is met in France).

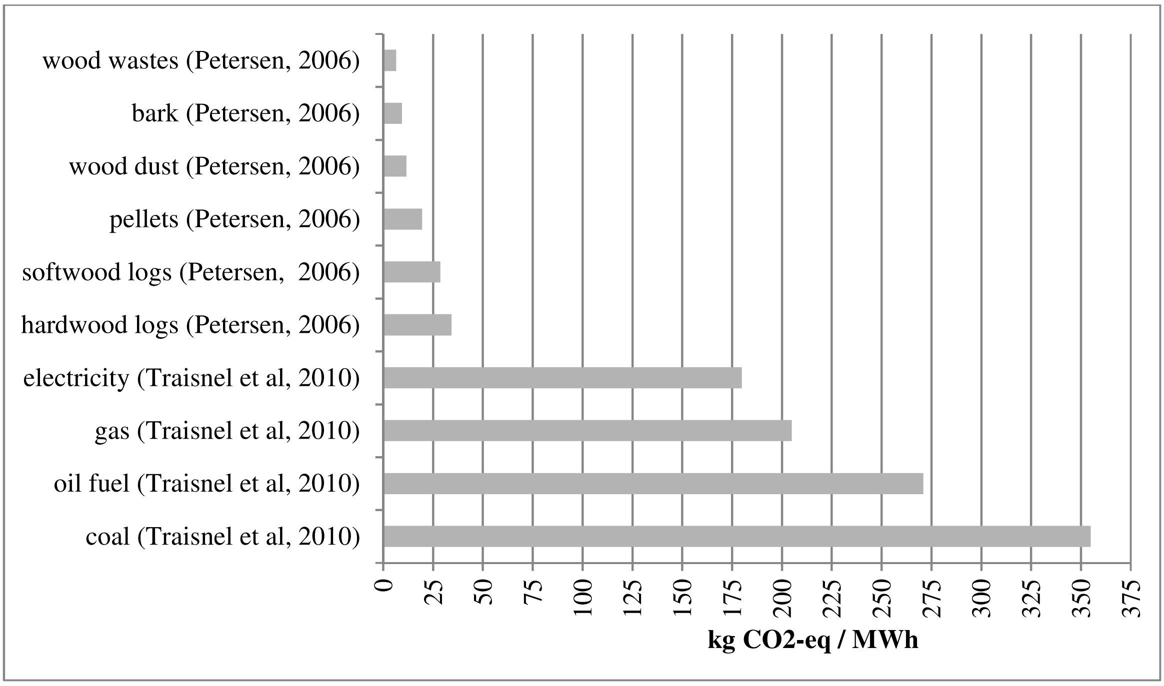

Figure 1: Comparison of CO_2 emissions from different fuel sources for heat production.

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9 This figure is based on data from Petersen (2006) for fuelwood products in Norway and data from Traisnel et al. (2010) for fossil fuels in France. Petersen (2006) accounts for all emissions from harvest, transport and the production of GHG emission other than CO_2 from the burning of wood. Even if Traisnel et al. (2010) only account for "direct emissions", i.e., those from fossil fuel combustion, we can see that emissions from fossil fuels largely exceed those of fuelwood products.

Within this context, several programs to stimulate the fuelwood sector have recently been implemented. These programs 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. These programs encompass (i) the “Plans bois-énergie” programs of the ADEME (The French Agency for the Environment and Energy) which consist in subsidizing the implementation of local collective boilers, (ii) CRE (Energy Regulation Commission) projects that consist in the implementation of biomass power plants (Chasset, 2007; Picault, 2008), (iii) the program called “1000 chaufferies pour le milieu rural”, which makes possible for rural communities to implement collective boilers and (iv) the “renewable heat funds” that allow manufacturers to invest in collective heating system projects.

The overall objective of these programs is to increase fuelwood consumption by 6 Mm^3/yr by 2020, which represent 1.38 Mtoe/yr. In 2012, France was already consuming more than 10 Mtoe/yr (40 Mm^3/yr) of fuelwood, almost exclusively for domestic heat production, of which more than 80% was exchanged through informal channels (Montagné and Niedzwiedz, 2009). The recent programs to stimulate fuelwood sector aim at increasing fuelwood consumption by about 15%, of which 66% will be used for electricity production in cogeneration plants, 28% for heat production in collective and industrial boilers and 6% for heat production in domestic boilers.

However, the impacts of these programs on the economy of the forest sector remain unclear. First, by competing for the same raw products, these projects could strengthen the competition with the pulp, panel and paper sectors and could, therefore, increase the price of these products for consumers. Second, the costs of these programs and the distribution of these costs among consumers (both fuelwood consumers and other wood products consumers), producers and the French Government are unknown. Third, while the forest sector represents the second trade balance deficit pole in France after energy, impacts of these programs on the trade balance are uncertain.

In addition, even if an additional 12Mm^3/yr harvest seems to be physically and economically possible (Colin et al., 2009; Ginisty et al., 2009), uncertainty remains regarding forest-owners’ responses to economic incentives. Indeed, in France, 70% of forests owners have a forest less than 1 ha, and forests smaller than 4 ha represent almost 70% of the whole forest area. Since small forest owners might not react to economic incentives, there is important uncertainty as to how much wood would be available for harvest in forests. In this context of uncertainty about available resources, the sustainability of the programs to stimulate fuelwood consumption must be questioned.

The aim of this paper is to clarify these debates by assessing the impacts of potential public policies designed to stimulate fuelwood consumption on (1) the economy of the sector and on (2) the forest resources. To do this, we translate the official objectives of additional fuelwood consumption into three policies to be simulated within the French Forest Sector Model (FFSM), a bio-economic model of the French forest sector (Caurla et al., 2010; Caurla, 2012b).

First, we model an exogenous increase in demand, which mimics the current policy of encouraging the development of medium- to large-scale biomass energy plants. In this case, the Government guarantees a given amount of public purchase on the market (*fixed-demand contracts*). We also consider two alternative policies to reach the same total increase in fuelwood demand: a *consumer* and a *producer subsidy*. These two subsidies represent economic incentives to change collective and domestic boilers.

We then compare these three policies by assessing their impacts on both the economy of the forest sector and the dynamics of the forest resource. On the one hand, we would expect a fuelwood policy to be sustainable, meaning that it should not lead to depletion of the forest stock. To question the sustainability of the three policies tested, we focus on the impacts of these policies on forest stock dynamics. On the other hand, we would expect a fuelwood policy to reduce the French trade balance at minimal cost and without increasing competition with other forest industries. To test this, we explore trade implications and compute the total cost of policies, differentiating between the cost for the French Government (budgetary cost) and the variations in consumer and producer surpluses. We analyze the implications of these policies over the 2012-2020 period which is short in relation to forest dynamics, but very relevant in terms of policy making. To make the comparison meaningful, the three policies were calibrated to reach the same additional +6 Mm^3/yr fuelwood consumption by 2020.

The paper is organized as follows. Section 2 presents a short literature review on the issue of forest biomass, public policies and energy. Section 3 briefly presents FFSM. Section 4 focuses on the policies to be implemented. Section 5 presents the impacts of policies on the resource, while section 6 describes their economic impacts. Section 7 provides a discussion of our results and a conclusion to our paper.

2. Forest biomass, public policies and energy: a short literature review

The impacts of fuelwood policies over the forest sector have been studied both from environmental and economic points of view.

From economic aspects, Delacote and Lecocq (2011) points out that several studies show critical interrelations between fuelwood production and other wood products such as timber and pulpwood. Using a spatial partial equilibrium model for Finland, Kallio et al., (2011) show that renewable energy targets are not realistic without considering policies that increase timber production. Using the U.S. Forest Products Module (USFPM) of the Global Forest Products Model (GFPM), Ince et al., (2011) also show that fuelwood development highly depends on the driving effects of the construction sector.

In addition, some studies insist on the potential contradictions of fuelwood policies and possibly non-targeted incentives for carbon sequestration in forest. Lecocq et al., (2011) show that combining a sequestration policy with a fuelwood policy would lead to conflicting incentives to wood suppliers. Lecocq et al., (2011) for France and Kallio et al., (2013) for Finland both show that, in the short run (2020 to 2035), sequestration incentives may perform better from an emissions reduction point of view than policies to boost fuelwood consumption. Eventually, at the global level and using GFPM, Buongiorno et al., (2011) show that reaching the level of bio-energy uses suggested by the Intergovernmental Panel for Climate Change would increase world forests depletion.

However, the question of the choice of the economic instrument to reach fuelwood consumption target in European countries has been barely studied. One exception for Norway is Sjølie et al. (2010) who compare a tax on fossil fuels with investment grants to district heating installation. They find that a tax of 60€/CO_2eq on fossil fuels could increase the annual bio-energy use in district heating by about 4 TWh while a 50% investment grants to district heating installations would also spur bio-energy use, but the effect of such subsidies would decrease rapidly if applied together with a tax. Another notable exception is Trømborg et al., (2007), still for Norway. They compare subsidies to reducie investment costs of district heating installations, deposit grants for replacement of oil burners with burners based on bio-energy and feed-in supporting energy production in district heating based on bio-energy. They show that policy incentives in terms of grants, subsidies or feed-in systems make it possible to overcome inertia in investments decisions and provide substantial increase in the supply of bio-energy.

3. The FFSM: a bio-economic model of the French Forest Sector

The French Forest Sector Model (Caurla et al., 2010; Caurla, 2012b) is a recursive simulation model of the French forest sector. As shown in Fig.2, it consists of two interrelated modules: a forest dynamics module (FD) and an economic module (E). At each period (year), given available timber resources, timber supply functions, transformation technologies and capacities, and demand functions for (first-transformed) timber products, the E module computes all market equilibriums in the forest sector (Caurla, 2012a), from which it deduces the annual harvest. Harvest then enters the FD module, which computes the available timber resource at year $t + 1$. This enters the E module, and so forth. The model is implemented under the General Algebraic Modeling System (McCarl, 2013), and runs for periods of 10-20 years[10].

[10]Since investment decisions of both wood suppliers and transformation industries are exogenous, the current version of the FFSM is ill-suited to longer-term simulations.

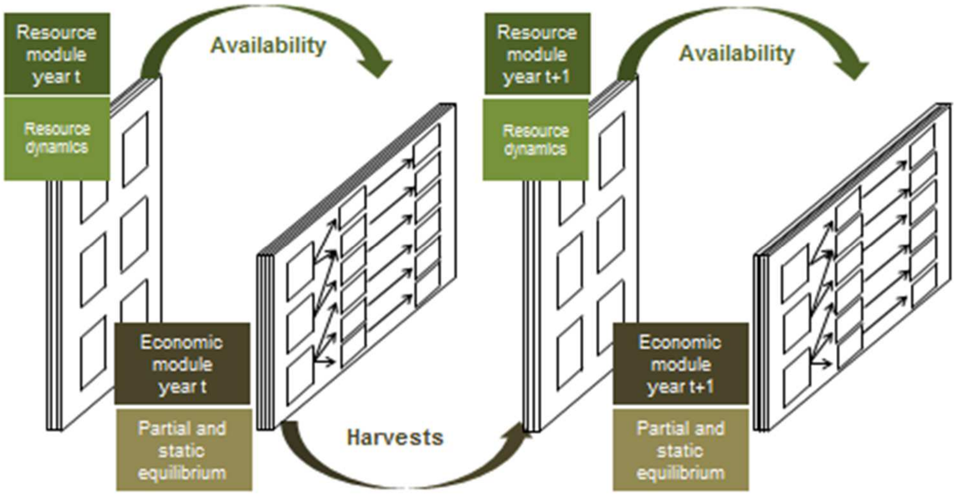

Figure 2: The FFSM is based on a recursive and modular framework.

The FD module (Wernsdörfer et al., 2011; Caurla, 2012b, pp.129-154) simulates timber stock dynamics using a diameter-class approach. Since French forests are very diverse in terms of climate, soils, species and types of management, the FD module breaks down the timber resource into 1716 cells differing by region (22 administrative regions), type of management (high forests[11], coppice, mixed), species (coniferous and broadleaved) and diameter classes (a total of 13). Resource dynamics in each cell are calibrated using data from the 2005-2007 French forest inventories (Colin and Chevalier, 2009).

The E module (see Fig.3) is a partial-equilibrium model of the French forest sector, from timber production to the consumption of first-transformation products. Four raw timber products are taken into account: fuelwood, pulpwood, hardwood and softwood roundwood, and six processed timber products: hardwood sawnwood, softwood sawnwood, plywood, pulp, fuelwood, and fiber and particle board. Three groups of agents are represented in the model: wood suppliers (either forest owners or forest managers on behalf of forest owners),

[11] High forests is a forest originated from seed or from planted seedlings. In contrast coppice forests where trees make new growth from the stump.

the transformation industry and consumers (either final consumers or second-transformation industries)[12].

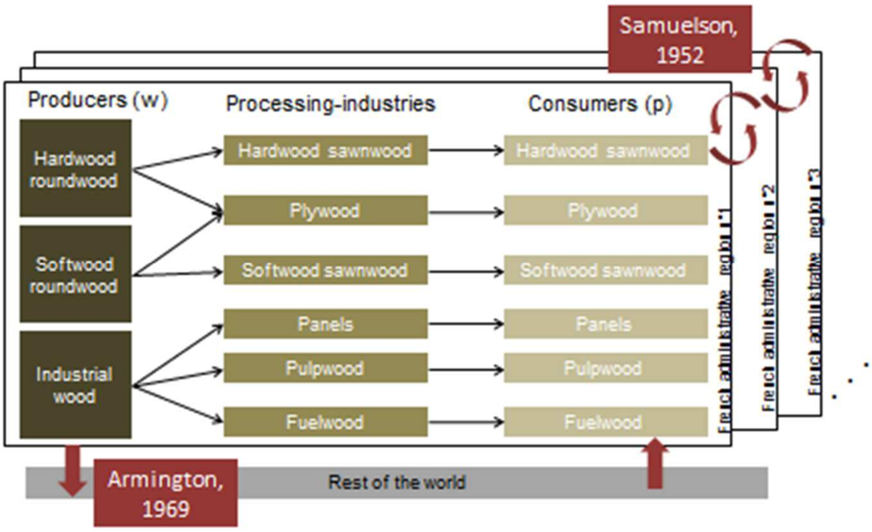

Figure 3: Description of the economic module E.

It is important to observe that, as shown in Fig.3, fuelwood demand is linked to industrial wood supply upstream and competes for the same raw industrial wood resource as pulp and panel demand downstream. This is why, in Sections 4 and 5, we also explore the impacts of fuelwood policies on the industrial wood and pulpwood sectors.

The E module distinguishes 22 administrative regions within France, and inter-regional trade is modeled assuming perfect competition and full substitutability of products across regions, according to Samuelson (1952). International trade (exports of raw products and imports of processed products) is modeled assuming imperfect substitutability within the Armington (1969) framework. The E module is calibrated using data from the literature and specific estimates, as presented in Caurla et al. (2010) and Sauquet et al. (2011).

FFSM has the same partial equilibrium structure as existing global forest sector models, such as the global forest model EFI-GTM, (Kallio et al., 2004), the Global Forest products Model GFPM (Buongiorno et al., 2003) or the Global Trade Model GTM (Kallio et al., 1987;

[12] The transformation industry is modeled using Leontief production functions. Under our assumption of perfectly competitive markets, the transformation industry makes zero profit at equilibrium (Caurla, 2012a).

Cardellichio et al., 1989), and as national forest sector models, such as the Finnish Forest sector Model SF-GTM (Ronnila, 1995; Kallio, 2010), the Norwegian Trade Model NTM and NTM II (Tromborg and Solberg, 1995; Bolkesjø, 2004). However, FFSM differs from existing models on three main aspects:

- It focuses on France: 22 metropolitan French regions (matching French administrative regions) and one aggregate "Rest of the World" region are represented.
- It models international trade using Armington (1969) theory which assumes imperfect substitution between domestic and foreign products.
- Its biological module captures French forest specificities, notably the inter- and intraregional diversity in species and silviculture practices.

4. Public policies to stimulate fuelwood consumption

We simulated public policies in the FFSM with the objective of increasing fuelwood consumption by 6 Mm^3 roundwood equivalent per year (which represents approximately 4.2 Mt of fuelwood with 25% humidity and 1,38 Mtoe). This amount represents the sum of several national programs to enhance fuelwood consumption at domestic, collective or industrial levels.

We assessed the impacts of three public policies with regard to a business-as-usual scenario (model projections with no policy implemented). The three sets of policies are implemented over the 2012-2020 period.

4.1. Fixed-demand contracts

In this first set of policies, the Government guarantees additional fuelwood consumption. The public sector implements new power plants and purchases more fuelwood energy, as in the current CRE call for tenders 1[13]. The new plants directly acquire fuelwood on the domestic final goods market, an option that we refer to as fixed-demand contracts. In other words, the new plants guarantee that they will purchase a fixed amount (at market price).

[13] CRE (Energy Regulation Commission) projects consist in the implementation of biomass powerplants.

Technically, the supplementary demand is directly introduced in the material balance Eq. 1 and into the consumer surplus for fuelwood. We also add the Government surplus ($fd_i \times P_i$) in the objective function (Caurla et al., 2010, p.15) where P_i is the domestic fuelwood price in region i. The objective function is defined as the sum of consumers, producers, processing industries and trade agents surpluses.

The supplementary demand is introduced directly into the material balance equation (Caurla et al., 2010, p.16):

$$fd_i + LD_i + \sum_j e_{i,j} = S_i + \sum_j e_{j,i} \tag{1}$$

where:

• fd_i represents the amount contracted through the fixed-demand contracts in region *i*.

• LD_i stands for the amount of fuelwood consumed in region *i*.

• $\sum_j e_{i,j}$ is the amount of fuelwood exported by region *i* to other regions.

• S_i is the production of fuelwood in region *i*.

• $\sum_j e_{j,i}$ is the amount of fuelwood imported from other regions to region *i*.

We assume fd_i is regionally computed taking into account available forest resource stock computed on a *pro rata* basis. This assumption can be seen as a simplified but not unrealistic vision of reality in which public power plants favor harvests in high forest-production areas to limit over-harvesting in low production ones.

4.2. *Consumer subsidies*

Another way to boost fuelwood consumption is to subsidize consumers to purchase fuelwood. In the FFSM, this consumer subsidy is directly implemented in the composite demand function, as shown in Eq. 2. Thus, consumer subsidies decrease the fuelwood price paid by consumers (Caurla et al., 2010, p.13). We calibrated the subsidy in order to obtain an additional +6Mm^3/yr fuelwood consumption by 2020. In addition, we assumed the subsidy is implemented in 2012 and remains constant (in relative term) until 2020.

$$D_{i,t} = D_{i,t-1}\left(\frac{\tilde{P}_{i,t}(1 - Sub_t)}{\tilde{P}_{i,t-1}(1 - Sub_{t-1})}\right)^{\sigma} \tag{2}$$

where:

• $D_{i,t}$ and $D_{i,t-1}$ represent the demand for fuelwood in region i in year t and $t-1$.

• $\tilde{P}_{i,t}$ and $\tilde{P}_{i,t-1}$ stand for composite prices of fuelwood in region i in year t and $t-1$.

• Sub_t and Sub_{t-1} are the rate of subsidies for fuelwood in year t and $t-1$.

• σ is the price elasticity of fuelwood demand.

Note that, in reality, a consumer subsidy may also represent indirect policies that reduce the price paid by consumers (implementation of fuelwood distribution facilities, for example).

4.3. Producer subsidies

A third possible way to stimulate fuelwood consumption consists in increasing the price paid by producers in order to increase their supply of industrial wood, as shown in Eq. 3. Note that, in this case and as explained in Section 2, the subsidized wood can either supply the pulpwood industry or the fuelwood industry, since it is difficult to screen supply from its destination.

$$S_{i,t} = S_{i,t-1}\left(\frac{\tilde{P}_{i,t}(1-Sub_t)}{\tilde{P}_{i,t-1}(1-Sub_{t-1})}\right)^{\sigma}\left(\frac{F_{i,t}}{F_{i,t-1}}\right)^{\beta} \quad (3)$$

where:

• $S_{i,t}$ and $S_{i,t-1}$ represent supply for industrial wood (which encompasses both fuelwood and pulpwood) in region i in year t and $t-1$.

• $\tilde{P}_{i,t}$ and $\tilde{P}_{i,t-1}$ stand for composite prices of industrial wood in region i in year t and $t-1$.

• Sub_t and Sub_{t-1} are the rate of supply subsidy for industrial wood in year t and $t-1$.

• σ is the price elasticity of fuelwood supply.

• $F_{i,t}$ and $F_{i,t-1}$ are the available amounts of timber to be potentially harvested for fuelwood in region i in year t and $t-1$.

• β stands for the elasticity of fuelwood supply to stock.

5. Impacts of the level of additional availability

As mentioned before, there is high uncertainty on the behavior of forest owners and manager, resulting in uncertainty on the level of available additional timber to be supplied on the markets. In this section, we therefore explore the impact of diverse scenarios of availability on forest resources and the economics of the forest sector.

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[14]. By resource availability, we mean the amount of timber that may eventually be harvested by timber suppliers and thus enter their supply function. However, this value may overestimate the real additional availability since French forests combine a very diverse population of forest owners and forest property rights are strongly fragmented. In particular, some small forest owners might not react to market incentives.

In order to take this uncertainty into account in the assessment of the impacts of fuelwood policies, we consider two levels of resource availability: an optimistic level that is based on the estimations of Colin et al. (2009) and Ginisty et al. (2009), and a pessimistic one, approximately 6Mm^3/yr, which assumes that small forest owners do not react to economic incentives.

5.1. Impacts on forest resources

In order to compare the impacts of policies on forest stock variation, we analyzed the rate of increment of the stock, i.e., $\frac{F_{w,i,t}-F_{w,i,t-1}}{F_{w,i,t-1}}$ (see Eq.3), in % of increment. If the biological increment exceeds the harvest volume then $\frac{F_{w,i,t}-F_{w,i,t-1}}{F_{w,i,t-1}} > 0$. On the contrary, if the harvest volume exceeds the biological increment, then $\frac{F_{w,i,t}-F_{w,i,t-1}}{F_{w,i,t-1}} < 0$ and the harvest is unsustainable.

Results in Table 1 provide four main pieces of information:

14 More precisely they estimate a raw additional availability of approximately 40 to 50Mm^3/yr from which they remove all the resource technically impossible to harvest or for which harvest would be too costly.

- First, columns 2 and 6 show that while the resource stock increases in the BAU scenario at the national level, this stock decreases in some regions. This means that, even without any fuelwood policy, FFSM simulates an over-harvesting situation in these regions. This situation, already described by Colin et al. (2009), results from the fact that these regions have a low initial stock and high consumption needs.
- Second, for a given availability case (either optimistic or pessimistic), comparisons between columns show that the impacts of the three policies on the resource are different. Overall, we can note that the three policies imply an increase in timber harvesting and, as a result, a decrease in the resource stock compared to the BAU scenario. However, a producer subsidy implies a larger stock decrease than a consumer subsidy and fixed demand contracts. This is because implementing a producer subsidy causes a windfall for all industrial woods, including those finally used in the pulpwood industries. Moreover, except for regions AQ, LI and MP, fixed-demand contracts imply smaller decreases in the resource stock than consumer subsidies. This is because consumer subsidies are homogenously implemented at the national level, while fixed-demand contracts are computed regionally on the *pro rata* of the forest resource stock. As a consequence, the contribution of regions with large forest resource, such as AQ, LI and MP, are greater in terms of scenario fd than scenario Sub_c.
- Third, comparisons between columns 3 and 7 (or between columns 4 and 8 or 5 and 9) show that, for a given policy, potential tensions over the resource are greater under the pessimistic scenario. Indeed, the French global resource stock decreases with the three policies in the case of the pessimistic scenario, while it decreases only with a producer subsidy in the optimistic scenario (see columns 3 and 7).
- Fourth, regional variability can be explained by (i) initial differences in forest stocks, and (ii) the presence of transformation industries in the region.

Table 1: Rate of increment of available forest stock per French region in 2020 (in %) for each level of availability. "BAU" refers to a scenario in which no policy is implemented during the 2012-2020 period, "fd" refers to a fixed-contract policy, "Subp" refers to producer subsidies and "Subc" refers to consumer subsidies.

	Optimistic case (+12 Mm^3)				Pessimistic case (+6 Mm^3)			
Regions	BAU	fd	sub_c	sub_p	BAu	fd	sub_c	sub_p
IF	0.7	0.4	0.2	-0.1	0.2	-0.2	-0.4	-0.9
CA	-1.1	-1.8	-2.1	-3.6	-1.9	-3.0	-3.3	-5.2
PI	-5.8	-8.3	-8.7	-23.3	-9.0	-12.0	-12.5	-35.2
HN	-1.0	-1.8	-1.6	-6.7	-1.9	-2.9	-2.8	-9.4
CE	1.4	1.0	0.9	0.1	1.0	0.5	0.3	-0.7
BN	-1.4	-2.2	-2.2	-6.2	-2.4	-3.5	-3.5	-8.7
BO	1.1	0.6	0.4	0.1	0.6	0.0	-0.2	-0.7
NP	-7.1	-9.2	-9.7	-33.4	-10.5	-13.0	-13.5	-52.9
LO	-0.7	-1.6	-1.7	-1.6	-1.5	-2.7	-2.8	-2.9
AL	-0.2	-0.8	-0.9	-1.1	-1.0	-1.7	-1.9	-2.2
FC	0.5	0.0	-0.1	0.1	0.0	-0.7	-0.8	-0.7
PL	0.9	0.5	0.3	-0.5	0.3	-0.1	-0.4	-1.6
BR	2.2	2.1	2.1	2.0	1.9	1.7	1.7	1.6
PC	2.5	2.0	1.7	1.2	2.0	1.4	1.1	0.5
AQ	-0.3	-1.7	-1.1	-0.1	-1.4	-3.3	-2.5	-1.6
MP	1.6	1.2	1.4	1.0	1.3	0.9	1.0	0.7
LI	-0.3	-1.0	-0.7	-2.3	-1.0	-2.0	-1.5	-3.6
RA	1.9	1.7	1.7	1.5	1.6	1.5	1.5	1.2
AU	1.5	1.3	1.2	1.3	1.2	0.8	0.8	0.9
LR	1.2	0.9	0.8	0.6	0.9	0.5	0.3	0.2
PA	0.5	0.2	0.1	-0.7	0.1	-0.3	-0.4	-1.4
CO	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.8
France	0.72	0.21	0.21	-0.14	0.2	-0.41	-0.41	-0.85

5.2. *Impacts on the forest sector economy*

Figure 4 shows that, without any fuelwood policy, higher constraints on wood resources imply higher pulp prices. This is because, when the stock of industrial wood decreases, forest stock $F_{i,t}$ decreases as well, which results in a reduced supply of industrial wood (see Equation 3). Therefore, competition between pulp, panels and fuelwood for industrial wood increases downstream, which tends to increase market prices. As can be seen in Figure 4, the price of pulp decreases with the level of resources available.

Since they increase harvest, we would expect fuelwood policies (1) to increase this competition, and (2) to increase this competition to a larger extent in the pessimistic case than in the optimistic case. Table 4 in appendix B gives regional variations of pulp prices for the three policies compared to the BAU scenario. We can observe from this table that downstream policies (consumer subsidies and fixed-demand contracts) unambiguously increase pulp prices whereas producer subsidies decrease them. This is because producer subsidies increase industrial wood production, regardless of its final use. However, and interestingly so, initial availability does not have much impact on pulp prices. Indeed, at the national level, pulp prices are only 5%–18% higher in the optimistic case compared to the pessimistic case (depending on policies). In comparison, the national stock is 74%–85% higher in the optimistic case compared to the pessimistic case (depending on policies). This means that tensions over the resource are not transmitted to the economic sphere with the same intensity.

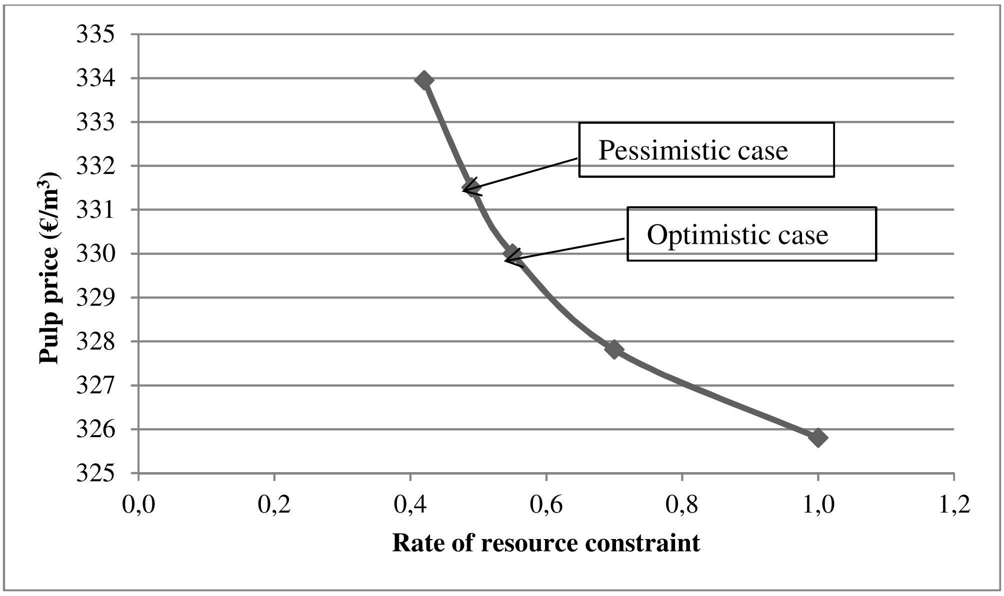

Figure 4: Pulp prices for different resource availability levels in 2020 in a scenario without fuelwood policy. These levels encompass what we defined as the optimistic and the pessimistic cases, as well as other unrealistic cases.

6. Impacts of fuelwood policies on the forest sector

In this section, simulations were made under the optimistic availability hypothesis with the aim of exploring the political feasibility of fuelwood policies. To do this, we assessed the impacts of fuelwood policies on three groups of economic indicators: (i) the variations in prices and quantities produced and consumed; (ii) the trade balance of the French forest sector; (iii) the budgetary cost and the variations in economic agent surpluses. Note that in order to understand impacts on the fuelwood sector we explored impacts on industrial wood upstream[15] and impacts on pulpwood downstream[16].

[15] Industrial wood encompass all primary wood products that can be used in the fuelwood or pulpwood sectors.

6.1. *Impacts on quantities and prices*

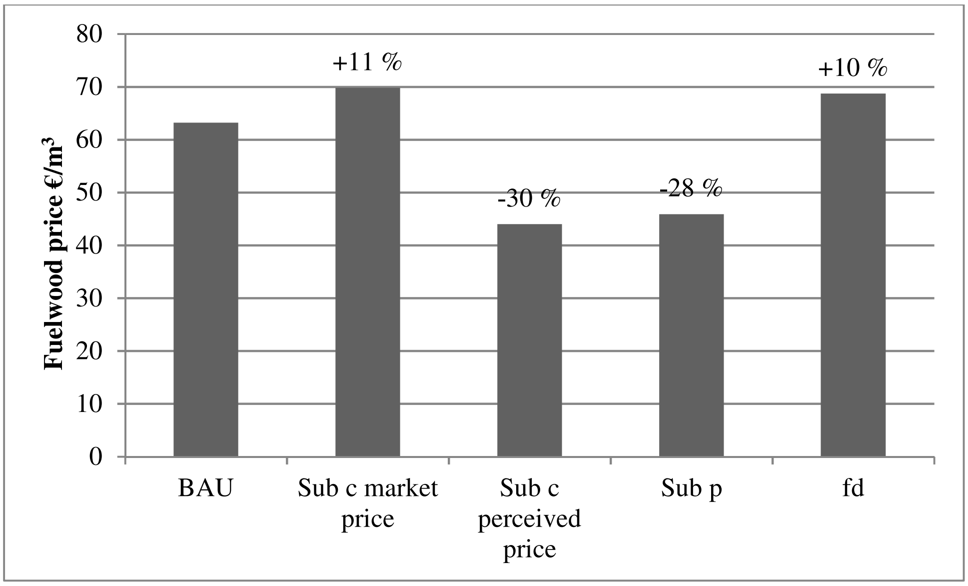

Figure 5: 2020 fuelwood price for each policy scenario and difference with the BAU scenario (in %). "Sub c" refers to consumer subsidies, "Sub p" refers to producer subsidies and "fd" refers to fixed-demand contracts.

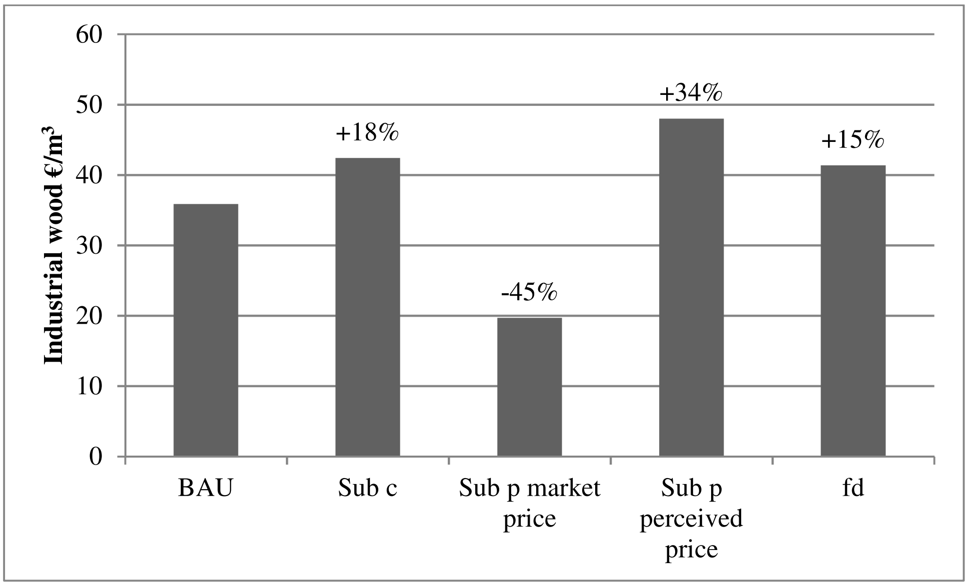

Figure 6: 2020 industrial wood price for each policy scenario and difference with the BAU scenario (in %). "Sub c" refers to consumer subsidies, "Sub p" refers to producer subsidies and "fd" refers to fixed-demand contracts.

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[16]Since pulpwood and fuelwood compete for the same raw products, it makes sense to analyze the impacts of fuelwood policies on the pulpwood sector.

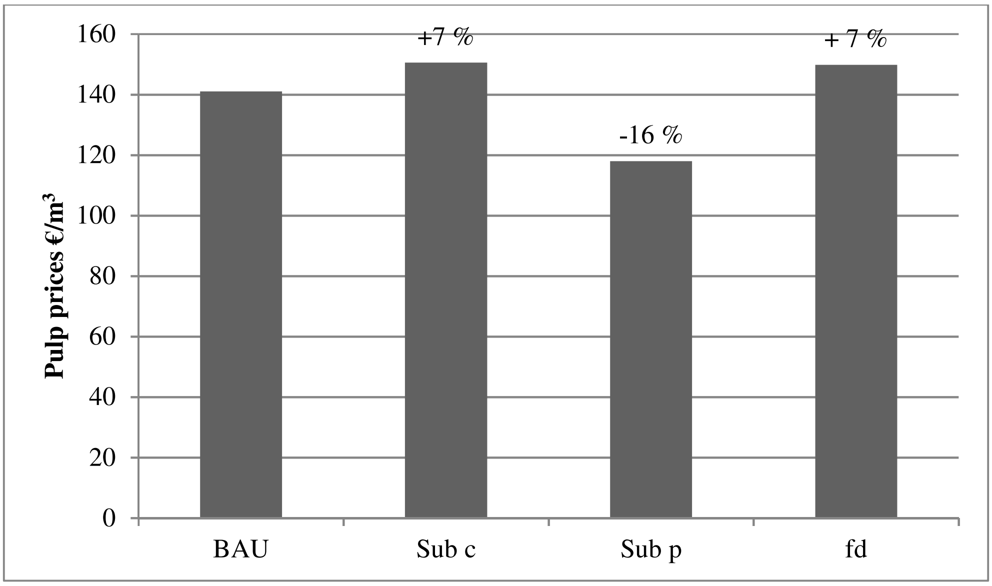

Figure 7: 2020 pulp price for each policy scenario and difference with the BAU scenario (in %). "Sub c" refers to consumer subsidies, "Sub p" refers to producer subsidies and "fd" refers to fixed-demand contracts.

First, as shown in Fig.5, the three policies have similar or opposite impacts on fuelwood prices. Under a consumer subsidy, consumers pay a lower price, but the real market price of fuelwood increases due to the increased demand. In contrast, when a producer subsidy is implemented, the fuelwood market price decreases due to the increased supply of industrial wood upstream. Eventually, when fixed-demand contracts are implemented, the market price also increases. This is because wood acquired by the French Government is withdrawn from the market. This increases scarcity and, as a result, market price. However, private consumers pay this higher market price and, thus, decrease their consumption. Therefore, the implementation of fixed-demand contracts creates a crowding-out effect on private demand due to the price increase. A policy implication is that if the objective of the Government is to reach a fuelwood consumption target, then a naive implementation of fixed-demand contracts that would not take the crowding-out effect into account may undershoot the target[17].

Second, Fig.6 shows that industrial wood prices are also affected by fuelwood policies. Under a producer subsidy, producers pay a higher price but the real market price decreases since supply increases. On the contrary, both fixed-demand contracts and consumer subsidies

[17] In the FFSM, because of this crowding-out effect, we need to calibrate the fixed-demand contract volume to +7 Mm^3 in order to reach the +6 Mm^3 target.

increase the industrial wood price since they both increase the demand for fuelwood and, therefore, for industrial wood upstream.

Third, Fig.7 shows that policies focusing on the downstream end of the sector (consumer subsidies and fixed-demand contracts) tend to increase competition with the pulpwood sector resulting in an increase in pulp price. In contrast, by stimulating the supply of industrial wood, producer subsidies decrease the pressure on the pulpwood market, thus decreasing pulpwood price. Therefore, an important policy implication is that downstream and upstream policies have opposite impacts on potential competition between the fuelwood and pulpwood sectors.

6.2. Impacts on trade balance

As shown in Fig.8, fuelwood policies have different impacts on the trade balance.

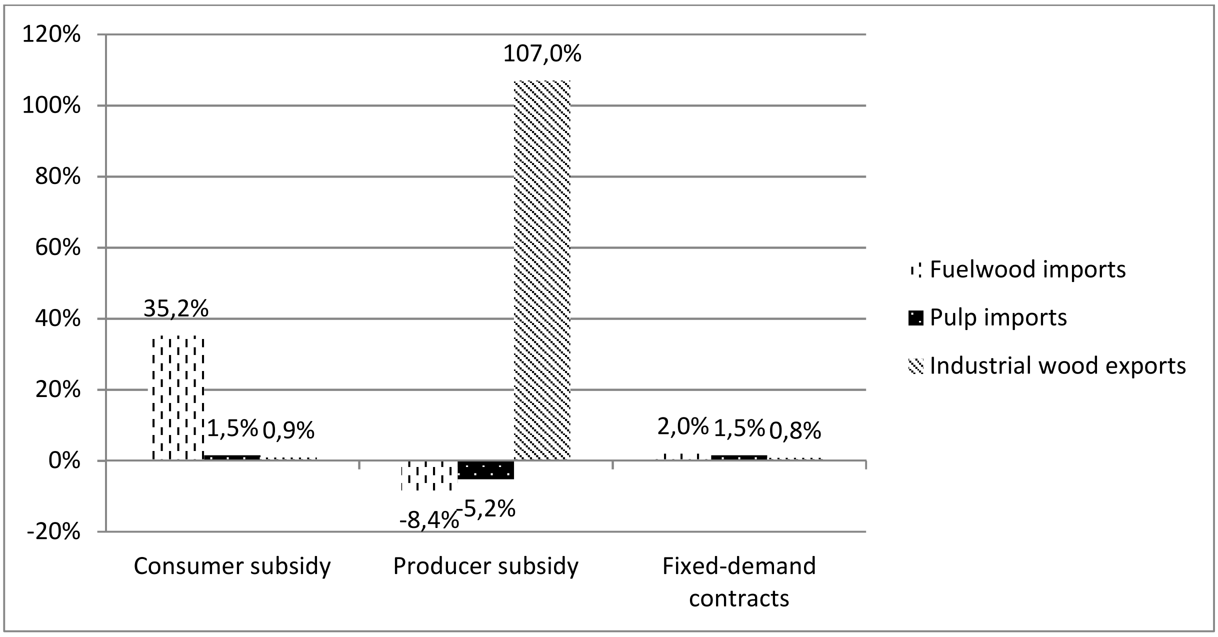

Figure 8: Impacts of policies on three indicators of wood trade balance (in % regarding the BAU scenario). "Sub c" refers to consumer subsidy, "Sub p" refers to producer subsidy and "fd" refers to fixed-demand contracts.

Upstream, producer subsidies increase industrial wood supply and thus decrease the industrial wood market price. Therefore, French industrial wood becomes more competitive compared to foreign industrial wood and industrial wood exports increase. Downstream, producer subsidies decrease the fuelwood market price, leading to a decrease in fuelwood imports. Therefore, this policy has a positive impact on the trade balance[18].

In contrast, consumer subsidies increase fuelwood demand, which consequently increases the market price of domestic fuelwood. Moreover, since all fuelwood consumed is subsidized, foreign fuelwood consumed in France is subsidized as well but does not undergo any price increase (due to our small open economy assumption). Therefore, fuelwood imports increase. Given the large trade deficit of the French forest sector (49 Mm^3 for the whole French forest sector (Puech, 2009)), this is a policy-relevant result.

In the end, fixed-demand contracts do not have much impact on the trade balance. Indeed, two opposite effects have to be considered: the fixed demand tends to increase domestic prices, which tends to decrease competitiveness and increase imports. However, the price increase creates a crowding-out effect, which decreases private demand and thus decreases imports. Overall, the price effect slightly dominates the price-ratio effect, which implies larger imports compared to the BAU scenario.

6.3. Budgetary and welfare cost of the policies

In this section, we examine the welfare implications of the three policies for three groups of agents: consumers, suppliers and the Government, relative to a BAU scenario without a policy. Key results are summarized in Table 2.

Table 2: Welfare implications of policy scenarios relative to the BAU scenario in 2020 (unit: M€) for all consumers and producers in FFSM.

	Consumer subsidy	Producer subsidy	Fixed-demand contracts
Fuelwood consumers	+596	+577	-7
Pulp consumers	-22	+95	-28
Panels consumers	-23	+61	-22
Plywood consumers	+4	+2	+1
Sawnwood consumers	+22	+25	+10
Industrial wood producers	+210	+540	+183
Roundwood producers	+10	+29	+12
Government	-818	-1211	-481

[18] Note that, due to our Armington (1969) elasticities, the impact on imports is greater than the impact on exports.

Fuelwood consumer surplus increases under both the producer and the consumer subsidies since these policies decrease fuelwood price paid by consumers. In contrast, fuelwood consumer surplus decreases under fixed-demand contracts due to the price increase and the crowding-out effect. In other words, the fixed-demand policy is the only policy that reduces fuelwood consumer surplus relative to a BAU scenario.

By increasing industrial wood production upstream, all three policies increase industrial wood producer surplus. This increase is larger in the producer subsidy case since this policy has an impact on both the pulpwood and fuelwood sectors downstream.

Industrial wood sector is linked to roundwood sector through harvesting residues supply (Caurla et al., 2010). Table 2 shows that all three policies increase the welfare of roundwood producers by increasing roundwood harvest. Therefore, tension on the sawnwood and plywood markets downstream is released, which result in a price decrease for sawnwood and plywood and a welfare increase for consumers. Conversely, as expected, only the producer subsidy increases pulp and panels consumers' welfares. The consumer subsidy and the fixed-demand contracts boost competition between fuelwood and these two products which lead to a price increase and a welfare decrease.

Eventually, the budgetary cost of subsidies is computed as the amount of the subsidy times the quantity produced or consumed. For fixed-demand contracts, the budgetary cost of the policy is calculated by multiplying the quantity of fuelwood purchased and the market price. It should, however, be noted that the cost of this policy does not take two elements into account: (1) purchasing fuelwood makes possible to reduce the purchase of other energy sources; (2) the fixed-demand policy implies the implementation of biomass power plants. Neglecting the first element tends to over-evaluate the costs of the policy, while neglecting the second one tends to under-evaluate it (nevertheless, not implementing biomass power plants implies implementing power plants from other energy sources, which mitigates the measurement error). As shown in Table 2, the producer subsidy is the most costly policy for the Government since it is implemented to subsidize the whole fuelwood-pulpwood supply. Moreover, the consumer subsidy is more costly than the fixed-demand policy. This can be explained by an important windfall effect: consumers that would have purchased fuelwood anyway (i.e., under the BAU scenario) also benefit from the subsidy (overall, the policy maker therefore has to subsidize more than 31Mm^3). To improve the cost-effectiveness of subsidies, it would be necessary to target the subsidy either in terms of additional production of fuelwood or additional consumption of fuelwood. Although such targeting may be difficult to implement in reality, one way to make it feasible would be to directly subsidize investment in new power generation capacity or in new boilers. For the producer subsidy, such a target could be feasible if the subsidy encompasses an investment in new harvest equipment (specific for fuelwood production).

Although it is the only policy that reduces the consumer surplus, the fixed-demand policy appears to be the least costly for the Government. This is mainly because such a policy does not involve any windfall effect. In times of severe constraints on public resources, this result is important to consider.

6.4. Policy mitigation costs

This analysis also provides some insights into the opportunity cost of mitigation in the forest sector.

We focus here on 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 the BAU scenario divided by carbon saved relative to BAU)[19]. The substitution coefficient that we used is 0.625 tCO_2eq/m^3. It corresponds to the amount of non-emitted CO_2 due to the use of fuelwood instead of a French composite energy mix (ADEME, 2005). Its relatively low value is due to the importance of nuclear energy in the French energy mix.

The welfare cost or "net change in social welfare" is the sum of the policy cost for the Government and of the agent's surpluses variations. The volume of CO_2 not emitted is by definition the same for the three policies (since they all have the same objective in terms of fuelwood consumption).

One limitation here is that we do not take into account the retrofitting effects due to the increase of monetary transfer over the public budget on the consumers' welfares when we

[19]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.

calculate the "net change in social welfare". From a general equilibrium framework point of view, it is very likely that an increase in public spending would result in a tax increase which would reduce consumers' welfare. Therefore, our analysis is likely to under estimate real mitigation costs.

Table 3: Mitigation costs computed for the three policies (in €/tCO_2)

	Consumer subsidy	Producer subsidy	Fixed-demand contracts
Net change in social welfare	-21	+118	-332
Mitigation costs	+5	-31	+86

Strictly speaking, table 3 shows that there are no mitigation costs for producer subsidy. More precisely, the producer subsidy results in a beneficial output for the whole society and could therefore be seen as a no-regret option (Hourcade and Robinson, 1996). This result may appear striking, as public interventions such as taxes and subsidies usually correspond to deadweight loss to the society. The change in the trade balance may explain it: since the subsidy reduces the French forest sector trade deficit, the deadweight loss related to the public policies is somehow exported to the rest of the world. However, this result must be considered cautiously since we do not take into account general equilibrium effects in FFSM, in particular the impacts of an increase in public budget over the consumers' welfare through the changes of tax rates.

Besides, we can see that fixed-demand policy has the highest average cost due to the considerable crowding-out effect that it implies (although it is the least costly in terms of public budget). The least-cost policy is the consumer subsidy since it implies a greater increase in the consumer surplus.

Interestingly, this mitigation cost for the consumer subsidy is lower than the 2009 negotiated value for a carbon tax rate (€17/tCO_2 + €2/tCO_2/yr; see Barthes et al. (2012))[20].

[20] A carbon tax was proposed in France in 2009 but it was finally killed by the French Constitutional Council in 2010.

At this point, it is important to discuss two additional important assumptions regarding the calculation of these mitigation costs.

Carbon neutrality assumption

As presented in introduction, we assume that fuelwood is carbon neutral. Indeed, in the literature most studies analyzing GHG emission impacts resulting from replacing fossil fuels with energy wood assume this energy wood is carbon neutral (Petersen, 2006; Wahlund et al., 2004; Bright and Stromman, 2009). However, Pyörälä et al. (2011) show that, in the case of Norway spruce stands in Finland, increasing the length of rotation increases the quantity of carbon sequestered in the stand. Conversely, decreasing rotation length, for example by increasing the harvest rate, is likely to decrease carbon sequestered. Therefore increasing harvest in order to produce more energy wood might change the average quantity of carbon sequestered in forest if the rules of management are modified.

Sjølie and Solberg (2011) show that carbon neutrality for energy wood can be assumed if either "time conditions" or "spatial conditions" are met.

Spatial conditions for carbon neutrality consist in two assertions: (1) "the system boundaries include the forest area from which timber is harvested" and (2) "the annual increment is at least as large as the annual harvest, i.e. the area's long term growing stock is non-declining". Matching these spatial conditions highly depends on the spatial unit used. For our analysis, spatial conditions are met for the whole French territory in all scenarios except the scenario with producer subsidy policy. Conversely, if we look at the regional scale, these conditions are never met since the annual harvest is larger than annual increment in some regions in all the scenarios (including the Business-As-Usual scenario).

Time conditions also consist in two assertions: "the system boundaries include the forest growth on the harvested area for at least as long horizon as the time needed for the forest to grow to the size when harvested" and "the discount rate is zero, implying that the points in time when carbon fluxes take place are of no importance". The first assertion refers to the rotation length which might decrease if harvest rate increases and if management rules are changed. However, it can be assumed here that most of energy wood comes from thinning.

Yet, increasing the rate of thinning releases competition between the trees (for water, nutriments, light, etc) on a specific stand which result in an increase of the rate of growth (Roberts and Harrington, 2007). Therefore, the rotation length may decrease while what Sjølie and Solberg (2011) call the "system boundaries" remains the same. The second assertion deals with discount rate. This is a crucial point which would imply a discussion on costs and damages of carbon emissions which goes beyond our initial scope.

All in all, the mitigation costs presented on Table 4 are likely to be underestimated since the carbon neutrality assumption cannot be guaranteed in our case study. This is mainly because (1) annual harvest exceeds natural increment in some regions and (2) assuming a discount rate equals to zero for a projection on a 14 years long horizon would be a too strong assumption.

Greenhouse gases (GHG) accounting

Another assumption concerns the system boundaries for GHG emissions considered. Indeed, we implicitly assumed that all three policies resulted in the same carbon saving level. Though all three policies are calibrated to reach the same additional consumption of 6 Mm^3, we may also want to take into account changes in forest carbon stocks and impacts of exports and imports on the so-called carbon leakages effects.

Lim et al., (1999) define two additional carbon accounting approaches: the stock change approach which explicitly take into account the change in forest stock and the production approach which also consider the changes in forest stock but also carbon in wood products produced in France and consumed abroad (exports). When considering both carbon sequestered in forest stock and carbon emissions avoided in the sector, all three policies lead to an increase in net emissions relative to BAU. This effect has already been described in Lecocq et al. (2011) and can be explained by (i) the relatively low substitution coefficient (0.625 tCO_2eq/m^3) for France, (ii) the fact that we do not consider emissions savings through other substitution processes[21] and (iii) the relatively short term of the time horizon. Strictly

21We only consider here substitution effect when replacing fossil fuels by energy wood but replacing steel, aluminum or plastic by wood products in the construction sector for example also results in net emission savings (Barthes et al., 2011).

speaking there is thus no mitigation and mitigation costs are not computable considering stock change and production approaches.

7. Conclusion

The aim of this paper is to explore and to compare the economic and resource impacts of three fuelwood policies on the French forest sector. To do so, we analyzed a fixed-demand contract policy, a consumer subsidy for fuelwood consumption and a producer subsidy for industrial wood production. Four key results stem from our analysis.

First, the producer subsidy leads to a larger harvest rate than the other two policies. Even in the optimistic additional resource case (+12 Mm^3/yr), this policy leads to a situation in which the volume of harvest exceeds the biological increment (over-harvesting) at the national level in 2020. Meanwhile, the two other policies lead to an over-harvesting situation at the national level only in the pessimistic additional resource case (+6 Mm^3/yr). Therefore, the producer subsidy is likely to lead to unsustainable use of the forest resource, which is not compatible with renewable energy rules.

Second, despite its negative impact on the resource, the producer subsidy is the only policy that creates a positive impact on the trade balance of the forest sector, which is of particular relevance considering the large trade deficit of the French forest sector. In contrast, consumer subsidies are likely to increase imports and to deteriorate the trade balance even more. Fixed-demand contracts have little (negative) impact on the trade balance.

Third, the fixed-demand contract policy is the lowest budgetary cost option to stimulate fuelwood consumption, which is a policy-relevant result in a context of the scarcity of public funds. Indeed, consumer subsidies imply a large and costly windfall effect on consumers. The windfall induced by producer subsidies is even larger since the whole fuelwood-pulpwood supply is subsidized (since it is difficult to distinguish the destination of the wood sold on the market). It follows that the producer subsidy is (1) the most costly for the Government, but (2) the only policy that does not increase competition with the pulpwood sector.

Fourth, in terms of welfare variation, consumers and producers both benefit from subsidies (both consumer and producer subsidies). In contrast, consumers experience a decrease in welfare when fixed-demand contracts are implemented. In fact, fuelwood prices increase, leading to a crowding-out effect on private demand. When considering both budgetary costs and welfare variations, it appears that producer subsidies are the most effective tool, being possibly a "no-regret" option, due to the positive impact on the trade balance, which allos to "export" the deadweight loss of the subsidy. In contrast, fixed-demand contracts are the least effective one (its crowding-out effect overcompensates its budgetary advantage). The consumer subsidies constitute an intermediary option in terms of effectiveness.

Overall, there is no strictly dominant policy instrument to stimulate fuelwood consumption, and the choice made by the public authority must take trade-offs between these different, and sometimes conflicting, impacts into account. If budget scarcity is the most important factor, fixed-demand contracts are likely to be favored, but they may raise some political opposition from consumers. If the trade balance is the most relevant indicator, producer subsidies are the most effective tools. However, they may experience some criticism from environmental organizations, since the forest stock would be more intensively harvested. In the case in which forests resources have to be preserved, consumer subsidies may be the tool of choice, at the cost of deteriorating the trade balance. Consumer subsidies also have the advantage of being easily accepted by public opinion (since the consumer surplus increases).

Possibly, one solution to (1) avoid competition with the pulpwood sector, and (2) reduce the trade balance deficit, while (3) preserving the forest resource would be to combine an upstream policy such as a producer subsidy and a downstream one such as fixed-demand contracts (in proportions to be determined). In addition, this solution would have the advantage of reducing budgetary costs compared to a producer subsidy alone, and increasing consumer surplus compared to a fixed-demand contracts policy alone.

Appendix A: French regions

IF: Ile-de-France

CA: Champagne-Ardennes

PI: Picardie

HN: Haute Normandie

CE: Centre

BN: Basse Normandie

BO: Bourgogne

NP: Nord-Pas-de-Calais

LO: Lorraine

AL: Alsace

FC: Franche-Comté

PL: Pays de la Loire

BR: Bretagne

PC: Poitou-Charente

AQ: Aquitaine

MP: Midi-Pyrénées

LI: Limousin

RA: Rhône-Alpes

AU: Auvergne

LR: Languedoc-Roussillon

PA: Provence-Alpes-Côte d'Azur

CO: Corse

Appendix B: Pulp prices regarding level of availability of the resource

Table 4: Impact of the initial stock availability on pulp prices. Difference between scenarios with policies and the BAU scenario (in %).

	Optimistic case			Pessimistic case		
Regions	fd	Sub_c	Sub_p	fd	Sub_c	Sub_p
IF	1.66	1.33	-8.66	2.14	1.21	-8.59
CA	1.95	2.52	-5.30	2.45	3.24	-5.59
PI	1.92	1.58	-5.46	2.50	2.94	-5.16
HN	1.91	1.61	-5.45	2.44	2.36	-4.10
CE	2.02	2.56	-4.93	2.51	3.27	-5.09
BN	2.26	2.85	-2.82	2.33	2.28	-3.62
BO	2.16	2.76	-5.26	2.67	3.52	-5.44
NP	1.70	1.40	-4.91	2.25	2.64	-4.55
LO	2.73	2.94	-5.40	3.20	3.71	-5.56
AL	2.38	2.83	-3.82	2.80	3.43	-4.17
FC	2.57	3.38	-4.29	3.42	3.98	-4.47
PL	1.91	1.47	-5.53	2.44	1.38	-4.42
BR	1.77	1.36	-8.32	2.28	1.29	-9.12
PC	2.25	3.79	-4.24	2.66	3.68	-4.88
AQ	2.94	2.30	-3.99	3.59	2.07	-5.22
MP	2.41	1.93	-4.60	2.85	1.75	-6.41
LI	2.39	1.94	-5.49	2.98	1.71	-4.37
RA	1.73	2.40	-6.34	2.40	2.88	-6.68
AU	2.53	3.38	-3.76	3.36	3.97	-4.45
LR	2.21	3.01	-5.24	2.34	3.55	-5.76
PA	1.68	1.50	-7.80	2.17	1.43	-7.65
CO	0.65	0.65	-10.96	0.01	0.01	-13.21
Average for France	2.08	2.25	-5.57	2.54	2.56	-5.84

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