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Carbon credits and the forest sector

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Abstract
In the context of Kyoto Protocol, forests can be used to create carbon credits. Contrary to the energetic sector where emissions reductions are considered as definitive, managing forests to mitigate climate change has been crticised because of the risks of reversibility. Biological carbon sinks are said to be non permanent. So, how can we compare carbon emissions reductions to carbon sequestration by sinks? What is the value of the carbon credits issued from forestry?
In this study, we consider the debate surrounding carbon credits attribution. As a first step, we recall methods that have been suggested. Results of a case study dealing with a forest located in southwestern France are presented in the second part of the paper. In a final discussion, we wonder about financial impact of different geopolitical strategies.

Keywords: Biological sinks, sequestration non permanence, carbon sinks valuation.

Introduction
Climate change is a crucial environnemental problem faced by human kind. Temperature on Earth's surface could rise in an important way if nothing is made to reduce GHG emissions. Kyoto Protocol lays down sigantories countries to not exceed some limits on their greenhouse gases emissions. To meet their commitments at a lower cost, three types of tools can be used:
exchange of carbon credits between Annex I countries. Carbon credits are obtained by countries that emit less than the amount that was imposed on them by Kyoto Protocol (KP); those carbon credits can be sold to countries wanting to emit more GHG than the amount fixed in KP;

Joint Implementation allows Annex I countries to obtain credits trough investments in carbon emissions reductions projects in another Annex I country;
Clean Development Mechanism allows Annex I contries to obtain credits trough investments in carbon carbon emissions reductions projects in a developping country.

Energetic and industrial activities are mainly concerned by those tools. But, considering the part played by forests in the carbon cycle, forestry is concerned by attempts to mitigate climate change. Under UNFCCC, countries must inventory carbon emissions by sources and carbon sequestration by sinks. Under article 3-3 of KP, countries can obtain carbon credits trough activities of afforestation or reforestation (plantation on lands that were not forested on december 31st, 1989 (debits are created for deforestation; clear cutting implying a land use change). For France, those activities imply some debits (Petroula, 2002). To compensate, countries can use forest management activities under article 3-4. We imagine that intentional management activities (longer rotations, light thinning regimes etc.) could be implemented. In the two cases, countries must prove that activities have been undertaken under human control, since 1990. Contrary to energetic sector where emissions reductions are considered as definitive, carbon sequestration by biological sinks is non permanent. Actually, forests can become Co2 sources, because of natural risks or human actions. This non permanence characteristic is one of the most heavy criticism against the use of forest resources to mitigate climate change. In this paper, we consider the debate surrounding carbon crediting methods in the context of forestry activities. With those methods, we try to compare carbon credits obtained trough forestry activities with carbon credits due to emissions reductions in energetic or industrial sector. In the first part of the paper, we recall methods that have been considered. In the second part of the paper, we present the results of a case study involving a maritime pine forest, located in Southwestern France. Even if France has decided to not subsidy forestry activities in the context of climate change management, this study should contribute to put an economic value on carbon sequestration. In an increasing number of countries, foresters and landowners are paid for environmental services provided by their forests, especially for carbon sequestration ().

1. A survey of carbon crediting methods for forestry

We present successively four carbon crediting methods. Due to some problems to their implementation, the two first methods, ton year and average stock, have been abandonned. Stock change approach will be used for verifying Annex I countries' commitments and temporary credits approach will serve to value carbon credits in the context of Clean Development Mechanism.

1.1: The average stock approach

This method has been considered for projects we can anticipate successive harvesting replanting cycles (Gabus, 2001; Phillips, 2002; Schlamadinger, 2002). Establishing carbon credits on the average of stored quantities allows avoiding numerous transfers between credits and debits. Forest owner does not have to buy credits when he decides to cut the stand.

Credits are given annually according to carbon stocks increases. When the average stock is reached, let us call this moment *X*, carbon crediting stops. The Net Present Value of the income received by the forest owner over one rotation is

$$Y = p_c \int_0^X s'(t) e^{-rt} dt$$

with p_c the carbon price, $s'(t)$ the marginal flow of carbon at instant t and r the interest rate. The main advantage of this method is that it permits compensating losses due to forest management by biomass growth without having to credit carbon stocks changes each year. But credits obtained with this method depend strongly of the duration chosen for the project (Gabus, 2001; Phillips, 2002; Schlamadinger, 2002). If this duration is too short, the quantity of carbon credits is important, reducing environmental credibility of the system. On the opposite, if this duration is too long, financial attractiveness of projects will be reduced and forestry to mitigate climate change will not be an interesting option for landowners. Because of the impossibility of choosing an acceptable duration for the projects, this method has been abandoned.

1.2: The ton year approach:

A ton of carbon emitted does not result in a permanent increase in atmospheric Co2. Carbon dioxyde concentration in the atmopshere decreases trough time as carbon is naturally absorbed by the oceans and the biosphere. This lenght defines the global warming potential of carbon dioxyde; its environmental impact. Considering this element, we can define the time a ton of carbon must be sequestered to reach the environmental impact of an emission reduction of one ton. This lenght is called the equivalence factor(Gabus, 2001; Herzog and al., 2003; Marland and al., 2001; Sedjo and Marland, 2003; Philips, 2002; Schlamadinger and al., 2002). If the equivalence factor is 100, this means that to reach the environmental impact of a non emission, carbon must be sequestered during one century. Litterature on the subject indicates some important disparities, the factor could vary between 42 and 150. As for the preceeding method, the choice of an equivalence factor is very controversial. A high level of the equivalence factor could reduce financial attractiveness of the projects (Marland and al., 2001). On the opposite, if this factor is too small, the quantity of carbon credits should be very important, reducing environmental credibility of the project. Numerous uncertainties about the carbon cycle and interactions between GHG in the atmosphere have driven to renounce to this approach. Another important matter rising with this type of approach is liability issue. At the end of the project, no one is held liable if carbon goes back to the atmosphere; the forest owner can sell new carbon credits (or even change land use) and the initial emitter has paid for his emissions.

1.3: The stock change approach:

This approach concerns Annex I Countries having to face a limit on their GHG emissions. Carbon credits are attributed when carbon stocks increase and debits must be paid when carbon stocks decrease. The income received by the forest owner over one rotation is

$$F(T) = \int_0^T p_c(0)e^{\beta t}s'(t)e^{-rt}dt - p_c(0)e^{\beta t}s(T)e^{-rT}$$

where $s(T)$ is carbon stock constituted in the forest at time T and T is the end of the rotation. If we consider forest owner is liable for wood products (so, emissions are weighted by wood product length life), the income is

$$F(T) = p_c\left[\int_0^T s'(t)e^{-rt}dt - \int_T^{T+D} s'(a)e^{-ra}da\right]$$

where D is the moment when wood products are destroyed. As

$$s(T)e^{-rT} > \int_T^{T+D} s'(a)e^{-ra}da$$

the income received by the forest owner is superior with this second approach.

Those results are consistent with constant carbon prices. As numerous studies have shown, the introduction of such a carbon crediting method in the objective function of forest owners should increase rotation lenghts. But authors generally do not consider carbon prices changes, that could alter economic viability of projects.

$$F(T) = \int_0^T p_c(0)e^{\beta t}s'(t)e^{-rt}dt - p_c(0)e^{\beta t}s(T)e^{-rT}$$

If we consider carbon price is not constant, the first equation is written as

$$F(T) = \int_0^T p_c(t)s'(t)e^{-rt}dt - p_c(T)s(T)e^{-rT}$$

If $p_c(0)$ is carbon price at time *0* and β its growth rate (when we suppose it is known),

$$F(T) = \int_0^T p_c(0)e^{\beta t}s'(t)e^{-rt}dt - p_c(0)e^{\beta t}s(T)e^{-rT}$$

Rearranging, we have

$$F(T) = p_c(0)\left[\int_0^T s'(t)e^{(-r+\beta)t}dt - s(T)e^{(-r+\beta)T}\right]$$

We can underline the following results concerning financial viability of projects.

If $\beta = r$,

$$p_c(0)\int_0^T s'(t)e^{(-r+\beta)t}dt = p_c(0)S(T)e^{(-r+\beta)T}$$

because $e^{(-r+\beta)t} = 1$ and

$$\theta(T) = \frac{e^0 T}{1}$$

So, $F(T) = 0$. From a financial point of view, carbon sequestration is a neutral operation.

If $\beta > r$,

$$p_c(0)\int_0^T s'(t)e^{(-r+\beta)t}dt < p_c(0)S(T)e^{(-r+\beta)T}$$

When *t=0, F(T)=0*. The derivative of F(T) with respect to time is equal to

$$-(-r+\beta)S(T)e^{(-r+\beta)T}$$

and is negative in the case where $\beta = r$. So, subsidies increase at a smaller rate than the tax as *T* increases. Consequently, $F(T) < 0$. In this context, carbon sequestration is not viable.

If $\beta < r$,

$$p_c(0)\int_0^T s'(t)e^{(-r+\beta)t}dt > p_c(0)S(T)e^{(-r+\beta)T}$$

Actually, the derivative of *F(T)* with respect to time is positive in this case. So subsidies increase at a more important rate than the tax. Consequently, $F(T) > 0$.

Externalities related to the contribution of forests to carbon cycle are fully internalised but this approach presents several limits:

it implies numerous transfers between debits and credits;

The area is dedicated to forestry and if the landowner decides to cut his forest stand, he is liable for carbon losses; so it implies a permanence of forest cover. At the scale of countries, it has been described as a constraint upon their sovereignty and a threat to their food security (see Blanco and Forner, 2000, quoted by Marland et al., 2001).

Permanence in this context is insured, because accounting for credits on an area involves following future events modifying carbon stocks on this area (Schlamadinger and al., 2002; Gabus, 2001).

1.4: The temporary credit approach:

Another way to credit carbon sequestration activities could consist in temporary crediting. This method will be used for valuing carbon credits issued from forest plantations in the context of Clean Development Mechanism. Forest owners sell to carbon emitters a temporary permit to emit GHG. At the end of the contract, Co2 emitters must reduce their emissions, or buy a permanent credit on the market, or renew the temporary contract. This allows an intertemporal arbitration to Co2 emitters, according to carbon prices changes and technological developments. Carbon sequestration is viewed as a temporary solution allowing to buy time, before buying for example a new technology. The fundamental difference comparing to the stock change approach is that liability for Co2 emissions is the Co2 emitters' one, not the forester's.

Because forestry is an alternative to Co2 emitters, we focus now on their behaviour; and the conditions that create a demand for temporary credits issued from forestry. When an emitter is faced to a constraint on his GHG emissions, he has three options:

- reducing GHG emissions;
- buying a permit on the market (said as a permanent credit);
- buying a temporary credit issued from forestry (

The first option is a technological solution. Co2 emitters can replace current technology by a less carbon intensive technology. But specific conditions can make of this option an unattractive solution, for example, if new technologies are expensive. In this case, he can think of the two other solutions.

The second and third solutions are market solutions. In the second case, Co2 emitter buys a carbon credit to other emitter that emits less than his quota. Co2 emitter buys the right to emit. Because emissions reductions are considered as definitive, these carbon credits are said to be permanent. But the price of these permanent credits could be prohibitive. In this case, Co2 emitter can buy a temporary credit to a forest owner, knowing that he will have to replace it by a permanent credit at the end of the contract. In this case, Co2 emitter gives his liability to the forest owner during the length of a contract. At the end of the contract, liability for carbon emissions comes back to the initial emitter, and he has to choose once again between the three options (he can too renew temporary contracts). Forest owner can freely choose future land use. He is only temporarily liable for carbon storage. Environmental integrity of the system is due to liability for carbon emissions that goes back to the initial emitter at the end of the contract. The third option consists so in buying a temporary credit now and a permanent credit in the future. A rational Co2 emitter will choose this option if it is less costly than for example, buying a permanent credit. The value of a temporary credit can be expressed as the delay obtained by the Co2 emitter faced to a limit on his GHG emissions. The willingness to pays of a Co2 emitter for a temporary credit is the maximum price he will accept to pay for a temporary credit. When this price is at a maximum, Co2 emitter is indifferent between the three options.

To obtain a non arbitrary condition, the following identity must be satisfied (when we suppose there are no transaction costs). Buying a temporary credit now and a permanent credit in the future must cost the same amount as buying a permanent credit now (Subak, 2003).

$$p_{\max} + \frac{pc_T}{(1+r)^T} = pc_0$$

$$p_{\max} = pc_0 - \frac{pc_T}{(1+r)^T}$$

where $p_{\max}$ is the willingness to pay of a Co2 emitter for a temporary credit, pc_0 is the current price of permanent credits, pc_T is the anticipated price (at time *T*) of permanent credits, r is the discount rate.

If we suppose that the carbon price rises at a rate β , we can write pc_T as

$$pc_T = pc_0(1+\beta)^T$$

and the willingness to pay of a Co2 emitter is written as

$$p_{\max} = pc_0 - pc_0\frac{(1+\beta)^T}{(1+r)^T}$$

$$p_{\max} = pc_0\left[1 - \frac{(1+\beta)^T}{(1+r)^T}\right]$$

We are faced to four situations;
carbon price rises faster than the discount rate ;
carbon price rises slower than the discount rate;
carbon price rises at the discount rate;
carbon price decreases to zero.

In situation (1), it is not interesting for a Co2 emitter to buy a temporary credit. His willingness to pay is negative ($p_{\max} < 0$). Buying a temporary credit now and a permanent credit in the future will cost him more than buying a permanent credit now. One can expect to this type of situation when technological developments are still experimental, or when more severe climatic policies are anticipated.

In situation (2), it is interesting for a Co2 emitter to buy a temporary credit. The cost of buying a temporary credit and a permanent credit *T* years after is smaller than the cost of buying a permanent credit. One can expect to this situation in the case of low carbon intensive technologies running inexpensive, or in the case of climatic policies becoming less severe.

In situation (3), $p_{\max}$ is equal to zero. Buying a temporary credit now and a permanent credit *T* years after is the same amount as buying a permanent credit now; the Co2 emitter is indifferent.

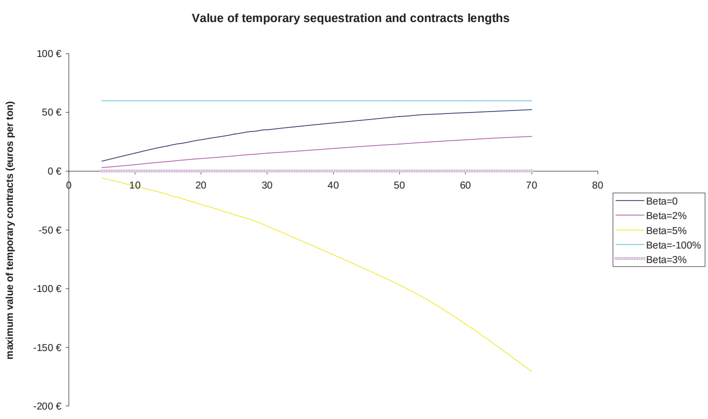
In situation (4), carbon price decrease to zero; it could happen if international regulation on carbon use would fail and stop in a few years; in this case, buying a temporary credit (and so, no permanent credit *T* years after) is the same thing as buying a permanent credit.

To summarise, willingness to pay of Co2 emitters for buying temporary carbon credits depends on anticipations concerning carbon prices and the discount rate.

An example of the value of temporary credits
Table 1 and Graph 1 present some examples of the value of temporary credits

Table 1: In this table, we show willingness to pay of Co2 emitters according to several assumptions of carbon price growth rate and lengths of contracts. Carbon price is assumed to be 60 euros per ton of carbon.

		Lengths of contracts (years)						
Discount rate	***Beta***	***5***	***10***	***25***	***30***	***50***	***60***	***70***
3%	0	8	15	31	35	46	50	52
3%	2%	3	6	13	15	23	27	30
3%	3%	0	0	0	0	0	0	0
3%	5%	-6	-13	-37	-47	-97	-130	-171
3%	-100%	60	60	60	60	60	60	60



Graph 1: We can see that increasing lengths of contract make increase Co2 emitter's willingness to pay for temporary credits (the upper limit is the price of permanent credits, as the length of contracts increases).

2. The case study:The afforestation project:

We suppose the stand is the result of a new forest (additional). The stand is harvested when it is 45 years old. Five thinning are planned during the rotation. This corresponds to a classical silviculture of maritime pines. Volumes and carbon stocks are obtained with software

OptimFor©, developed for maritime pine silviculture in SouthWestern France. The general approach funding the building of this software is dynamic programming, based on Bellman's algorithm. It permits to optimise forest management according to different criterions (economic, biologic etc.), assess biological and economic impacts of management options or of exogenous events (storms, forest fires etc.). Parameters that describe growth of trees are those of Lemoine's model.

Carbon stocks are directly linked to wood volumes. We determine it as follows: an expansion factor gives total wood volume starting from marketable wood. As a second step, we must calculate dry weight of the trees. As a third step, we need to know the carbon content of the dry weight of trees. The equation and coefficients used in this study are, following Malfait et al. (2003):

$$Sc(t) = v(t).E.D.Car \quad (6)$$

Where *Sc(t)* is the carbon stock at age *t*, *E* is the expansion factor; *D* is the part of the dry weight of trees and *Car* is the carbon content of dry weight. The values of parameters are: *E=1,6; D=0,5; Car=0,43.*

We suppose carbon price is 60 euros per ton, discount rate is 3%; and we deal only with the present value of carbon storage incomes. We comment results for each method presented in the first part of the paper. I

2.1: The average stock approach:

Credits are attributed marginally according to fluxes (annual fluxes). When average stock is reached, carbon crediting stops. In this example, average stock is 62 tons of carbon, and is reached when the stand is 23 years old. According to this approach, income of one rotation is 2 405 euros per hectare.

2.2: The ton year approach:

We suppose an equivalence factor equal to 100. This equivalence factor has been chosen in KP to define equivalence between climatic effects of different greenhouse gases. Carbon credits are attributed annually, and incomes weighted by the equivalence factor. The income received by the forest owner is 657 euros per hectare during one rotation. Incomes obtained with this method depend strongly of the equivalence factor and are inversely proportional. For example, if the equivalence factor is 50[1], income doubles (1314 euros).

2.3: The stock change approach:

Carbon credits are attributed according to stocks changes observed during the rotation. Income obtained by a forest owner is 4 126 euros per hectare. If we consider clear cutting of the stand (verification is made at year 46), the income is 1 828 euros per hectare

2.4: The temporary credit approach:

We suppose the length of contracts is 10 years, and prices of permanent credits are constant. Value of temporary credits is 15.35 euros per ton of carbon. Credits are attributed as follows: During the first ten years, credits are given according to stocks changes. The first contract finishes at year 10. At the end of this contract, a new contract begins and new credits are given according to stocks changes. But as long as the stand continues to sequester carbon, credits of the first contract are renewed and this process follows for the other contracts. The income obtained by the forest owner is 2 205 euros per hectare.

[1] This means that to obtain the climatic effect of an emission reduction of one ton, less effort is required ; carbon needs to be sequestered during only 50 years to reach the environmental impact of an emission reduction.

Discussion

In this analysis, we assume carbon price is constant during the rotation. In a real environment, carbon price would be subject to long term trends. Technological developments, international regulations, political strategies influence carbon prices. In the following analysis, we suppose carbon credit prices will be influenced by technological development and demand of carbon credits coming from large emitters countries as China, India, Brazil and USA. Currently, those countries are not constrained by KP[2]. If they come into the process, they will demand carbon credits and carbon price will rise.

in a first case, we could imagine that technological developments as hydrogen will arrive in a few years and that USA, China, India and Brazil stay outside KP. We would expect to a relatively small and decreasing carbon price. From the point of view of a forest owner, stock change approach would give positive financial results as shown in the first part of the paper. Concerning the demand for temporary credits, it would be positive too, if we assume that carbon price grows at a smaller rate than the discount rate;

in a second case, we assume that technological development will arrive in a moment that exceeds the horizon of human life (and economic calculations);and that China, India, Brazil and USA come into Kyoto process. Carbon price would increase because of the important demand for credits. The stock change approach would give negative results while the demand for temporary would be negative. Carbon sequestration would not be an output of forestry activities.

Even if France has decided to not subsidy carbon sequestration activities, forests represent an important point in the "Plan National de Lutte Contre les Changements Climatiques". This plan insists on afforestation strategies, use of wood as building material, or as a substitute to fossil fuel combustion and forest management (article 3-4) should be used to reach France's Kyoto commitments. As the greatest artificial forest area of Europe, this forest could contribute to help France meeting her goal.

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[2] China, India, Brazil are Annex II countries while the US have not ratified KP.

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