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ANALYSIS

Conflicts between biodiversity and carbon sequestration programs: economic and legal implications

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Abstract

The economic and legal implications of the interrelationship between carbon sequestration programs and biodiversity are analyzed. Firstly, the current treatment of this issue under the Framework Convention on Climate Change process is presented. Secondly, the implications of carbon incentives for existing forests are studied (basing the analysis on an extension of the Hartman model including carbon sequestration and biodiversity values). Then, the expected influence of this policy on decisions about which type of forest to use for afforestation and reforestation is discussed. An optimal control model is used to analyze the choice between two types of forests: (i) one with high timber and carbon sequestration values but lower, or negative, biodiversity values; and (ii) one with lower timber and carbon sequestration benefits, but with high biodiversity values. Finally, the relationship between the Kyoto process and the Convention on Biological Diversity is investigated, to assess whether or not the latter is expected to have any influence on the outcomes obtained in the analysis above. Results show that creating economic incentives for carbon sequestration may have negative impacts on biodiversity, especially for afforestation and reforestation programs.

Keywords: Climate change; Biodiversity; Carbon sequestration; Economics; Law

1. Introduction

At the 1992 Earth Summit in Rio de Janeiro, world leaders agreed on a comprehensive strategy for 'sustainable development', meeting our needs without compromising the ability of future generations to meet their own needs. Two key agreements adopted in Rio were the United Nation Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). The ultimate objective[1] of the UNFCCC is to achieve the 'stabilization of greenhouse gas concentration in the atmosphere ... within a time-frame sufficient to allow ecosys-

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[1] Art. 2. (UNFCC, 1992a).

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tems to adapt naturally to climate change'. The first goal[2] of the CBD is the conservation of biological diversity, understood as the variety of plants, animals, micro-organisms and ecosystems. Both conventions are thus concerned with the conservation of the existing variety of ecosystems. Additional interrelationships arise due to the fact that climate change can be seen as one of the major threats to biodiversity and that some of the actions proposed to mitigate climate change potentially imply dangers for biodiversity (ESCBD, 2000). These relationships between the two conventions should imply a high level of cooperation between them. Unfortunately, this has not always been the case[3], mainly because each refers to a specific environmental issue. They adopt a *sectorial* approach, without taking into account the significant ecological interdependence existing between global environmental problems (e.g. forests contribute to climate change mitigation as terrestrial sinks[4], but tropical forests are also the most substantial 'reservoir' of biological diversity (Pontecorvo, 1999)).

The Kyoto Protocol (UNFCCC, 1997) developed the UNFCCC and its aim is to enable the practical implementation of climate policy. Eventhough the Kyoto Protocol has not yet been enforced, its chances to do so have significantly increased since the agreements reached in Marrakech in November 2001. Therefore, the moment has come to carefully analyse the implications of the Kyoto Protocol and the Marrakech Accords (UNFCCC, 2001).

At a first glance, the UNFCCC process aims at protecting forests and complements the CBD. However, as the primary goal of the Kyoto Protocol is to reduce greenhouse gas emissions to 5% below 1990 levels, some activities proposed under the Kyoto Protocol to remove greenhouse gas emissions by sinks may have an adverse impact on biodiversity[5] (ESCBD, 2000). Thus, problems of compatibility with other international agreements related to forests, such as the CBD, may arise[6].

The aim of this paper is to study the economics and legal issues behind the interactions between biodiversity preservation and climate policy, and more precisely terrestrial sinks alternatives. Economics and law have to work together to analyze rigorously this issue, since the UNFCCC and the CBD process have reached such a high degree of complexity that modeling the expected outcomes of the signed agreements makes interdisciplinary work necessary.

We first present the treatment of carbon offsets and biodiversity in the UNFCCC process, analyzing the economic incentives and the limitations set out in the Marrakech Accords. Afterwards, we study, by means of two stylized economic models, the implications of carbon incentives for existing forests, as well as the expected influence of this policy on decisions relating to the type of forest to be used for afforestation and reforestation. We find out that negative impacts on biodiversity are not very likely with the economic incentives created for forest management, while the incentives for afforestation and reforestation may have a negative impact on biodiversity. Since the limits set out in the Marrakech Accords do not seem to be sufficient to prevent these potential negative impacts, we analyze the role that the CBD could play to mitigate these impacts. This obliges us to discuss the issue of compatibility between two international treaties, since the Marrakech Accords are a development of the UNFCCC and therefore not directly related to

[2] Art. 1. (UNFCC, 1992b).

[3] Nevertheless, these relations have shown up in official documents (e.g. FCCC/SBSTA/2001/INF.3 or FCCC/SBSTA/2001/L.14).

[4] Plants absorb CO_2 from the atmosphere through photosynthesis. A portion of this CO_2 is released again, but a part is used by plants to build up their biomass, liberating oxygen. This implies a reduction in atmospheric CO_2, but its effect is constrained by the life-cycle of the biomass, since the carbon stored is finally released through oxidation.

[5] See FOEI et al. (2000) for an overview of these potential negative impacts and their real-world implications.

[6] Other related instruments are (non exhaustive list): the Forests Principles, Agenda 21 (section II, chapter 11), the United Nations Convention to Combat Desertification, the International Tropic Timber Agreement, the Washington Convention on International Trade of Endangered Species of Wild Flora and Fauna, or the RAMSAR Convention on Wetlands of International Importance especially as Waterfowl Habitat.

the CBD. We finish our discussion by exploring approaches to overcome potential conflicts between these two international treaties.

2. The Marrakech Accords

Sinks were one of the major concerns that resulted in the failure to reach an agreement at the Sixth Conference of the Parties (COP6) in The Hague (November 2000). In the interest of consensus, the opposition of the European Union and other 'sink-skeptics' in Bonn (COP6.bis) and Marrakech (COP7) was significantly reduced (Müller, 2001). This led to an agreement with 'generous' rules in regard to sinks. Nevertheless, some limitations were raised and some references to biodiversity were included in the Marrakech Accords[7] (UNFCCC, 2001).

2.1. Limitations[8]

Forest management carbon credits or debits[9] can be accounted, firstly[10], up to the amount of debits resulting from article 3.3 of the Kyoto Protocol (i.e. afforestation, reforestation and deforestation), with a maximum amount of 9.0 megatons of carbon times five[11] (enabling thus to compensate deforestation by forest management). Additional credits for forest management can be issued[12] up to the particular cap established[13] for each Annex I country (OECD and economies in transition), including credits earned for forest management by means of Joint implementation[14] in other Annex I countries.

The cap[15] set to the clean development mechanism[16] (CDM) requires that credits earned by a Party through eligible land use, land use change and forestry (LULUCF) activities under the CDM shall not exceed 1% of base year emissions of that Party times five. This cap has to be understood in conjunction with the limitation[17] of the CDM to afforestation and reforestation, implying hence a cap to these activities.

All caps can be seen as absolute limits. This feature is highly relevant for our analysis, as shown below. It is also worthwhile to remark that caps do only refer to *forest management* and to *afforestation and reforestation while undertaken as CDM* (not when they are carried out inside an Annex I country, directly or via joint implementation). Other LULUCF activities[18] are free of limitations (i.e. 'cropland management', 'grazing land management' and 'revegetation'). Hence, no cap on 'sinks' was decided in Bonn–Marrakech.

2.2. Biodiversity

Some direct references to biodiversity can be found in the Marrakech Accords. Parties[19] affirm as one of the principles that govern LULUCF

[7] If no special reference is made all decisions and draft decisions mentioned hereafter can be found in UNFCCC (2001).

[8] Caps were set in Bonn (COP6.bis) in Decision 5/CP6 (FCCC/CP/2001/L.7) and incorporated, with some modifications, in the Marrakech Accords (UNFCCC, 2001). Hereafter the paragraphs (§) will refer to the Marrakech Accords. Nevertheless, in most cases, the formal decision remains the Bonn agreement, since several paragraphs have been included in the Marrakech Accords in the draft decision -/CMP.1 *Land use, land-use change and forestry* (from now on DD-/CMP1), which is not yet formally adopted (this is a draft proposed for adoption in the first Meeting of the Parties to the Kyoto Protocol).

[9] 'Credits' is used where removals are larger that emissions on a unit of land and 'debit' when the opposite is true.

[10] §10 of the Annex DD-/CMP1.

[11] The commitment period is 5 years long. In Bonn, the limit was set at 8.2 MtC (D5/CP6; FCCC/CP/2001/L.7).

[12] §11 Annex DD-/CMP1.

[13] Appendix to the Annex DD-/CMP1. The limit for Russia was raised from 17.63 to 33 MtC in Marrakech (D12/CP7).

[14] Joint implementation (art. 6 Kyoto Protocol) is the name given to the flexible mechanism that enables to account in one Annex I country (OECD and economies in transition) the reduction of emissions achieved in another Annex I country.

[15] §14 Annex DD-/CMP1.

[16] The clean development mechanism (art. 12 Kyoto Protocol) is the flexible mechanism that enables to account in one Annex I country emission reductions achieved in Non-Annex I countries.

[17] §13 Annex DD-/CMP1.

[18] Parties themselves decide which of these activities are applied during the first commitment period (§6 and 7 Annex DD-/CMP1).

activities 'that the implementation of LULUCF activities *contributes* to the conservation of biodiversity and sustainable use of natural resource' (emphasis added). Parties[20] also 'request the subsidiary body for scientific and technological advice (SBSTA) to develop definitions and modalities for including afforestation and reforestation projects under the CDM in the first commitment period, *taking into account* ... environmental impacts on biodiversity and natural ecosystems'. Neither *contributes* nor *taking into account* can be understood as concrete limitations, especially not the latter, so that biodiversity conservation has not been included as a clear constraint to LULUCF activities (see Section 5 for a discussion of the possibility to see the CBD as such a constraint).

In addition, a direct reference to biodiversity is included in the definition[21] of forest management. However, including biodiversity only in the definition of forest management and not in the definitions of other activities, such as afforestation or reforestation, has the dangerous interpretation that biodiversity conservation is only necessary in the case of forest management. Nevertheless, article 2 of the Kyoto Protocol balances this assertion by referring to sustainable management practices in relation to afforestation, reforestation and deforestation as a policy of protection and enhancement of sinks[22]. However, the interpretation of what sustainable management covers is left to the Parties.

Finally, the SBSTA is required to investigate the application of biome-specific forest definitions for the next commitment periods[23]. Here, the elaboration of the definition and modalities for sinks projects under the CDM seems to adopt the concern of bio-diversity protection, but this is just a wish for the future.

[19] §1 of the DD/-CMP.1.
[20] §2 (e) of D11/CP7.
[21] §1(f) in Annex DD-/CMP1.
[22] Art. 2.1(a)(iii) Kyoto Protocol (UNFCCC, 1997).
[23] §2 (b) D11/CP7.

3. Forest management

If the Kyoto Protocol finally comes into force, Parties will earn credits for LULUCF activities. Therefore, Parties will probably establish incentive schemes to increase the amount of carbon units issued by means of these activities. We now turn to analyze the expected outcomes of these incentives, focusing on forest management and on afforestation and reforestation (since these are the activities expected to account for the lion's share).

In this heading we assume the existence of a forest, that the type of forest is not going to be changed and that no real risk of disappearance exists. These are realistic assumptions in contexts where deforestation is no longer relevant and where forests are protected by effective laws. In this scenario, the main[24] decision of the agent is the harvesting age (the rotation). Bringing this scenario to the Kyoto framework, we are examining a forest management alternative that could be incorporated by means of article 3.4 of the Kyoto Protocol.

If the forest type is changed (i.e. changing the species), the analysis is closer to the situation described in the next section. This possibility has not been explicitly ruled out by the definition of forest management proposed in the Marrakech Accords. Nevertheless, and as stated above, the definition of forest management includes a direct reference to biodiversity, so that aggressive strategies should be ruled out[25].

In the following sub-headings we discuss the different objective functions of the agent if he: (i) takes into account timber values exclusively; (ii) incorporates carbon sequestration values; and (iii) integrates also biodiversity values.

[24] An alternative forest management strategy to increase sequestration is to use fertilisation products. Fertilisation can have negative impacts on biodiversity (ESCBD, 2000), but we do not consider it in this study (it supposes a change in growth functions).
[25] In addition, credits for forest management can only be earned inside Annex-I countries (OCDE and economies in transition).

3.1. Timber

It is well known that the correct objective function to maximize timber values is the Faustmann formula, which maximizes the infinite flow of net revenues (Samuelson, 1976). The Faustmann objective function can be written in a simple form as (assuming clear-cutting):

$$PV_{\mathrm{W}} = G(T)\,\mathrm{e}^{-rT}\cdot[1+\mathrm{e}^{-rT}+\mathrm{e}^{-2rT}+\cdots] = \frac{G(T)\mathrm{e}^{-rT}}{1-\mathrm{e}^{-rT}} \qquad (1)$$

where PV_{W} is the present value of timber; G, the timber net value function[26]; r, the discount rate; and T, the rotation period. The typical form of the timber value function increases with age up to a point where timber is too old for most commercial uses and its value decreases with age, mainly due to the influence of diseases and malformations (we assume $G'(T) > 0$ in the first stages and $G''(T) < 0$, assuming that $G'(T) \leq 0$ is possible for long rotations).

3.2. Carbon sequestration

Englin and Callaway (1993) and Van Kooten et al. (1995) proposed, independently, very similar approaches to modify the Faustmann formula in order to incorporate carbon sequestration values. Basically, their proposal consists in valuating each ton of carbon sequestered with a given price P_{c}, which is paid to the forest owner when carbon is sequestered and is paid by the owner when carbon is released. The first question that arises is whether this approach is adequate to model the expected outcomes of the Marrakech Accords. According to the Marrakech Accords, and for units issued by means of article 3.4 of the Kyoto Protocol, carbon sequestered in a given year is added to total allowances (added to the assigned amount of the Party, neglecting any temporality issue) and carbon liberated is considered as an emission[27] (subtracted from the assigned amount). Hence, if incentives are established to maximize national sequestration through forest management, the schema described above is appropriate[28].

Concentrating only on carbon related terms, the objective function can be written as follows (the overall objective function for the agent would be formed summing up Eqs. (1) and (2)):

$$PV_{\mathrm{c}} = \frac{\int_0^T P_{\mathrm{c}}\cdot g'(t)\cdot \mathrm{e}^{-rt}\,\mathrm{d}t + \int_T^\infty P_{\mathrm{c}}\cdot h'(t)\cdot \mathrm{e}^{-rt}\,\mathrm{d}t}{1-\mathrm{e}^{-rT}} \qquad (2)$$

where PV_{c} is the present value of carbon sequestration; P_{c}, the carbon price; $g(t)$, the carbon sequestered at each moment during the growth of the trees (incorporating above-ground biomass and below-ground biomass in the terminology of the Marrakech Accords[29]); $h(t)$ is the carbon sequestered in deposits after harvesting (including litter, dead wood and soil organic carbon[30]); and t is time.

As it occurs for timber in the first stages, the rate of carbon sequestration is positive and decreases with the age. However, the total amount of carbon in the forest does not necessarily decrease, as it occurs for the value of timber in old forests. Diseases and malformations influence the commercial value of timber but they do not significantly reduce the carbon content of the biomass. Hence, we assume[31] $g'(t) \geq 0$ and $g''(t) < 0$. Since

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[26] $G(T)$ is used, instead of $P_{\mathrm{w}}W(T)$ with P_{w} constant, as in the following heading, to allow for the influence of age on timber price.

[27] §17 Annex DD-/CMP1.

[28] However, the cap imposed on forest management (see previous section) implies that incentives are only necessary if the cap is not surpassed without additional measures. If no incentive measures are established no negative impacts for biodiversity will occur by definition (since we only consider distortions not present in the current situation).

[29] §21 Annex DD-/CMP.1.

[30] idem.

[31] $g''(t) < 0$ might not be true for the first years, but it is an adequate assumption for the ages where the rotation is decided.

the liberation of carbon is gradual, through oxidation, $h(t)$ is a decreasing function (with $h' \leq 0$ and $h'' < 0$, indicating that carbon liberation occurs mainly in the first moments after cutting). This last function is not applicable if Harvested Wood Products[32] are finally not taken into account, since this option is equivalent to assuming instantaneous liberation of the sequestered carbon (the decision on Harvested Wood Products has been left for further negotiation rounds[33]).

3.3. Biodiversity

As it is known, a standing forest can have other values apart from timber and carbon sequestration. The theoretical incorporation of these values was proposed by Hartman (1976), using recreational values as an example (biodiversity is another example of a value of a standing forest). The Hartman objective function can be written (showing again only the non-timber part of the equation):

$$PV_B = \frac{\int_0^T P_b B(t) \cdot e^{-rt}\, dt}{1 - e^{-rT}} \tag{3}$$

where PV_B is the present value for biodiversity values; B, the biodiversity function; and P_b, the biodiversity shadow price. The biodiversity value function typically increases monotonically with age (in general no reasons exist to expect it ever to decrease; thus, we assume $B'(t) \geq 0$).

The aggregate objective function (PV_S) is constructed summing up the different objective functions (Eqs. (1)–(3)) (Englin and Callaway (1995) analyze numerically a similar equation and Caparrós et al. (2003) present an application with recreation):

$$PV_s = \frac{G(T)e^{-rT} + \int_0^T P_c g'(t) \cdot e^{-rt}\, dt + \int_T^\infty P_c \cdot h'(t) \cdot e^{-rt}\, dt + \int_0^T P_b B(t) e^{-rt}\, dt}{1 - e^{-rT}} \tag{4}$$

First order conditions can be shown to be (after differentiating with respect to T, setting it equal to zero and rearranging):

$$[G'(T) + P_c \cdot (g'(T) - h'(T)) + P_b B(T)] = \frac{r}{1 - e^{-rT}} \times \left[G(T) + P_c \left(\int_0^T g'(t) \cdot e^{-rt}\, dt + \int_T^\infty h'(T) \cdot e^{-rt}\, dt \right) + P_b \times \int_0^T B(t)\, e^{-rt}\, dt \right] \tag{5a}$$

Interpretation of this formula follows conventional lines, weighting the value of waiting an additional year (left hand side) against the interest forgone by not investing the future monetary stream associated to felling at T (right hand side). The first term of the left hand side accounts for the increase in the value of timber, the second (in brackets) for the increase in carbon sequestered and the third for the value of biodiversity. The first term of the right hand side accounts for the interest rate on the numerator and for the multiple rotation aspect of any version of the Faustman formula on the denominator. The second term incorporates the monetary stream associated to future rotations for each of the three benefits considered.

That is the outcome if the agent internalizes carbon sequestration as well as biodiversity. If this is the case, its decision will lead to the social optimum (we assume that the society's objective function is Eq. (4)). The problem is that currently only $G(T)$ is internalized by private agents and that the implementation of the Kyoto Protocol will only internalize carbon values, leaving biodi-

[32] It refers to the accounting of the carbon stored in wood products after harvesting.

[33] FCCC/SBSTA/2001/L.12.

versity out of the market and therefore out of the decision process. To correct this deviation, the conventional approach is to estimate P_b in order to establish an incentive to ensure that the agent's strategy coincides with the social optimum. The problem arises from the difficulty to estimate P_b and B (especially P_b), which will probably imply that biodiversity will remain outside of the markets.

The influence of partial internalization of external costs and benefits on optimal management is not easy to establish regardless of the particular form of the different valuation functions involved and of the discount rate applied by the agent. However, a more detailed discussion of Eq. (5a) enables to determine which are the overall tendencies. For this purpose it may be useful to use a less simplified version (Eq. (5b)):

$$[G'(T) + P_c \cdot (g'(T) - h'(T)) + P_b B(T)] = (1 + e^{-rT} + e^{-2rT} + \cdots) \times \left[rG(T) + rP_c \left(\int_0^T g'(t) \cdot e^{-rt}\, dt + \int_T^\infty h'(T) \cdot e^{-rt}\, dt \right) + rP_b \int_0^T B(t) e^{-rt}\, dt \right] \tag{5b}$$

Setting $P_c = P_b = 0$ in Eq. (5b) or Eq. (5a) the original Faustman formula is recovered. The left hand side of Eq. (5b) simplifies to $G'(T)$, which declines with age. This is weighted up, on the right hand side of Eq. (5b), with a non-discounted value ($rG(T)$), and a set of discounted values (accounting for the future rotations). Contrary to the rest of the benefits analyzed below, the timber part of the function offers a positive undiscounted value at the moment of felling. This usually implies that the timber part of Eq. (5b) holds for relatively short rotations, especially with high discount rates as used by private agents (since $rG(T)$ is not discounted for the current rotation, it increases together with the discount rate r).

Setting $G(T) = P_b = 0$ the carbon part of Eq. (5b) is isolated. The left hand side, waiting one additional year, has two positive terms which only slightly decline with age (recall $h' < 0$). On the right hand side of Eq. (5b), all future benefits are discounted since they are associated with the growth of the next generations, while costs also appear (the integral of $h'(t)$ is negative since $h'(t) < 0$, in addition, since $h''(t) < 0$ the costs are close to the time of felling). This enables us to expect that, at least for high discount rates, the optimal rotation focusing on carbon sequestration will be reached at an older age than for the commercial benefits (if it is at all optimal to cut at any moment in time). This is especially true if gradual payment associated to carbon liberation is substituted by an instant payment for all the carbon contained in the timber felled, as is the case if Harvested Wood Products are not considered (this would imply an undiscounted cost associated with felling).

Finally, setting $G(t) = P_c = 0$, Eq. (5b) focuses on biodiversity. The comparison is now between the full value for biodiversity in the year (left hand side)—not only the increase in this value—versus a discounted value representing the future benefits of biodiversity associated with the growth of the next generation of trees after felling (right hand side). In addition, since the value of biodiversity does not generally decrease with age ($B'(t) \geq 0$) the left hand side of Eq. (5b) increases with time (contrary to the case described for timber above). The right hand side also increases, but at a lower rate (due to the influence of the discount rate), so that the two sides will in general never equalize. Hence, the expected outcome is that the optimal strategy, from a biodiversity point of view, would be to never cut (once more, this is especially true for high discount rates).

To sum up, the expected outcome if only carbon is internalized—in addition to the commercial values already provided—is that the optimal rotation age would increase; since the new terms incorporated in Eq. (5b) tend to raise this rotation. But this increase is expected to be lower than the one that would occur if biodiversity were also internalized. Thus, providing incentives to private agents to take into account carbon sequestration when setting the rotation period of a managed forest should have positive effects for climate change and positive impacts on biodiversity (or at least no major negative impacts). Empirical studies confirm these expectations. Englin and Callaway (1993), Van Kooten et al. (1995), Romero et al. (1998) and Campos and Caparrós (1999) have shown that incorporating carbon sequestration in the objective function of the agent implies longer rotation periods, at least for high discount rates. Englin and Callaway (1995) analyzed numerically the environmental impacts of carbon sequestration maximization regimes, finding that, for high discount rates, the externalities associated with old forests are enhanced in regard to timber maximization strategies.

4. Afforestation and reforestation

Under this heading the choice between two types of forests, when reforesting[34] agricultural land, will be formalized and analyzed (Van Kooten (2000) analyses the reforestation with one species, leaving biodiversity out). According to the Marrakech Accords, Parties can issue credits through afforestation and reforestation by means of article 3.3 of the Kyoto Protocol if the land is located in an Annex I country that ratifies the Protocol (or eventually via article 6 and Joint implementation) and by means of article 12 (clean development mechanism) if the land is located in any non-Annex I Party. Thus, and as discussed in the previous section, incentives will probably be created to get forest managers to take carbon sequestration into account. For afforestation and reforestation undertaken inside an Annex-I country the incentive schema will be probably similar to the one described in the previous section (associating payments with the actual carbon budget). On the contrary, for credits earned by projects (CDM) several methods have been proposed, but not in all of them payments are strictly related to the carbon budget. The decision on which method to use has not been taken yet. Nevertheless, the model proposed in this heading covers all of them and the results obtained are not influenced by the method finally adopted.

It is usually accepted that biodiversity increases when degraded and agricultural lands are converted into forests (IPCC, 2000). However, this is only true in regard to indigenous forests and not when the 'reforestation' is actually the setting up of rapidly growing alien species plantations. It is also not true where pre-existing land uses have high biodiversity values (IPCC, 2000). Matthews et al. (2002) have quantified bird biodiversity associated to reforestations in the US and have found further evidence of the potential negative impacts of reforestation regimes.

To formalise the decision process, we will assume that the agent can choose between two types of forest and that type 1 has a greater carbon sequestration potential while type 2 has greater biodiversity values ($C_1 > C_2$ and $B_1 < B_2$; using the notation introduced below). A typical example of this situation is when reforestation with a fast growing alien species[35] (forest, or plantation, type 1) is compared with a natural indigenous species alternative (forest type 2).

Define: L = total land available for reforestation; $a(t)$ = agricultural land at t (state variable); $f_1(t)$ = reforested land of forest type 1 (state variable); $f_2(t)$ = reforested land of forest type 2 ($f_2(t)$ can be eliminated from the model as state variable, since $f_2(t) = L - a(t)\ f_1(t)$); $u_i(t)$ = total area reforested at time t of forest type i ($i = 1, 2$) (control variables); $k_i(u_i)$ = reforestation cost of type i (function of the amount of land reforested in a given year); r = discount rate; $A(x)$: a space-related function describing annual net revenues associated to present agricultural uses (this variable includes commercial as well as non-commercial values).

Define further $F_i(x)$ as a space-related function for the annual net revenues of forest land type i

[34] Afforestation and reforestation will be treated as synonyms, official definitions can be found in §1(f) Annex DD-/CMP1.

[35] Fast growing species do not always yield higher carbon sequestration per hectare when mature, but since sequestration occurs faster the present value for these species of the sequestration is generally higher, due to the effect of the discount rate.

$(i=1,2)$. These functions are supposed to have three terms: $F_i(x)=P_\mathrm{w}W_i(x)+P_\mathrm{c}C_i(x)+P_\mathrm{b}B_i(x)$, where $W_i(x)$, $C_i(x)$ and $B_i(x)$ represent physical quantities associated with timber, carbon sequestration and biodiversity, respectively and P_w, P_c and P_b the prices, real or shadow ones, associated with these three components. Forest-related data are strongly time-related but, for modeling reasons, it is interesting to annualize them, ensuring that investment incentives are not changed[36]. This has the additional advantage, already mentioned, that the model works regardless of the final method adopted to internalize carbon sequestration for project-related units (as for the CDM).

The objective function if the agent incorporates all benefits can be written:

$$\max\ V_2=\int_0^\infty \Pi(t)\cdot \mathrm{e}^{-rt}\ \mathrm{d}t \tag{6a}$$

$$\Pi(t)=\int_0^{a(t)} A(x)\ \mathrm{d}x+\int_0^{f_1} F_1(x)\ \mathrm{d}x-k_1(u_1)\cdot u_1(t) + \int_0^{L-a-f_1} F_2(x)\ \mathrm{d}x-k_2(u_2)\cdot u_2(t) \tag{6b}$$

and first order conditions for the optimal control model can be shown to be (see Appendix A):

$$\frac{F_2(L-a-f_1)}{r}-k_2(0)=\frac{A(a)}{r} \tag{7a}$$

$$\frac{F_2(L-a-f_1)}{r}-k_2(0)=\frac{F_1(f_1)}{r}-k_1(0) \tag{7b}$$

Taking Eq. (7a) and Eq. (7b) together and writing them out:

$$\frac{P_\mathrm{w}W_2(L-a-f_1)+P_\mathrm{c}C_2(L-a-f_1)+P_\mathrm{b}B_2(L-a-f_1)}{r}-k_2(0)=\frac{P_\mathrm{w}W_1(f_1)+P_\mathrm{c}C_1(f_1)+P_\mathrm{b}B_1(f_1)}{r}-k_1(0)=\frac{A(a)}{r} \tag{8}$$

The interpretation of Eq. (8) once more follows conventional lines. In the steady-state equilibrium the revenues of reforesting one additional hectare of forest type 2 have to be equal to the revenues associated to one additional hectare reforested of forest type 1, and to the revenues associated to the agricultural use of that hectare.

The problem hidden in Eq. (8) is again that only P_w and the commercial part of A are actually provided by existing markets and that the proposed market for carbon will internalize only $P_\mathrm{c}C$. However, if this is carried out regardless of the influence on $P_\mathrm{b}B$, the social optimum will be reached only by coincidence. The issue is more relevant since C and B will generally go in opposite directions, so that an alternative established in order to maximize C would reduce B, or even make it negative. If only $P_\mathrm{c}C$ is internalized, and with the assumptions made for forests types 1 and 2, the expected outcome is a suboptimal overplantation of forest type 1. That is, in equilibrium the agent will equalize Eq. (8) regardless of the biodiversity term, and since $P_\mathrm{b}B_1<P_\mathrm{b}B_2$ the last unit would have gone to reforest with forest type 2 if all benefits were considered. Depending on the form of the carbon and biodiversity functions, exclusive internalization of carbon would lead to an even worse situation from the point of view of society than the current one (if the loss in biodiversity is higher than the gain due to the increase in carbon sequestration).

As stated in the previous section, the conventional solution to this deviation requires the economic valuation of biodiversity, with the problems already mentioned. An alternative approach is to work with the imposed constraints, to assess whether or not this could bring the agent's strategy closer to social optimality (the possibility to see the CBD as such a constraint is discussed in the next section).

As described above, the Marrakech Accords have set an absolute cap for afforestation and

[36] Calling $z(t)$ to the real flow of net benefits associated to any of the values described above ($z(t)$ could also be decomposed in quantity times price), the present value of the investment is: $PV_\mathrm{z}=\int_0^\infty z(t)\ \mathrm{e}^{-rt}\ \mathrm{d}t$ and the annualised value Z which assures equal investment incentives is: $PV_\mathrm{z}=\frac{Z}{r}$; $Z=rPV_\mathrm{z}=r\int_0^\infty z(t)\mathrm{e}^{-rt}\ \mathrm{d}t$.

reforestation in the CDM (not for afforestation and reforestation in Annex I countries). However, this alternative provides no incentive to favor forest type 2. This kind of restriction implies that the choice between species is done regardless of the constraint until it becomes binding, favoring therefore forest type 1. Once the restriction becomes effective, no additional forestation occurs at all.

Another alternative would be to limit the total amount of carbon sequestration per unit of land to which an economic value may be given. This is a straightforward strategy to reduce or remove the influence of the different amounts of carbon sequestered by the two types of forests. If the maximum amount of carbon per unit of land taken into account (C_m) is set such that $C_m = C_2$, the differences in carbon sequestration between the two species disappear and the agent will choose the type of forest to set up focusing on timber (since biodiversity is not internalized). Nevertheless, both types of forest would be favored compared to agricultural land due to the internalization of carbon sequestration, so that the total area reforested would increase (maintaining the current proportions between forest type 1 and 2). This kind of restriction is justified as long as the difference in biodiversity values is higher than the values internalized by the market and therefore considered by the private agent (timber and carbon sequestration). Returning to the legal texts, in the Kyoto-Marrakech Protocol no per hectare cap was included. This option was timidly proposed by the IPCC, acknowledging at the same time the difficulties to incorporate non-carbon environmental and social concerns into quantitative limits on carbon credits (IPCC, 2000). Nevertheless, a conservative value for the major types of regions could reduce the incentives to plant fast-growing alien species.

5. Interrelations between the Convention on Climate Change and the Convention on Biological Diversity

As seen above, some forest practices with the view to enhance carbon sinks may have an adverse impact on biodiversity. Such a result may conflict with the aims of the Biodiversity Convention or other international norms related to forests. The question that arises is, which instrument should prevail when two overlapping conventions differ with regard to their objectives or the actions to be undertaken.

5.1. An overview of the Convention on Biological Diversity

The Convention on Biodiversity (CBD) aims at the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising from the utilization of genetic resources[37]. The convention (Wolfrum, 1996) applies to all processes and activities which have or are likely to have a significant impact on the conservation and sustainable use of biological diversity undertaken within Parties' jurisdiction or control[38]. The CBD calls upon Parties to adopt national policies consistent with the conservation and sustainable use of biological diversity[39]. It requires Parties to: (i) regulate or manage biological resources relevant to the conservation of biological diversity; (ii) promote the protection of ecosystems; (iii) rehabilitate and restore degraded ecosystems; and (iv) prevent or eradicate alien species, which threaten ecosystems. In addition, it requires identifying, monitoring and regulating processes and activities likely to have a significant adverse impact on biodiversity[40].

Unfortunately, the wording used by the CBD to attain these objectives is rather weak[41]. Therefore, the CDB fails to provide strong binding rules and its implementation only relies on the good faith of the States (as long as they have sovereign rights over their own biological resources). The CBD

[37] Art. 1 CBD (UNFCC, 1992b).
[38] Art. 4 CBD.
[39] Art.6 CBD.
[40] Art. 8 c), 8 d), 8 f), 8 h), & 7 c) CBD.
[41] '*Each Contracting party shall in accordance with its particular conditions and particularities...*' or, '*Each Contracting Party shall, as far as possible and as appropriate...*' is used in art. 7 & 8 CBD. See Swanson (1999).

also lacks of any real financial incentives, which could have balanced the economic benefits resulting from timber and carbon sequestration maximization strategies (Wolfrum, 1996; Bothe, 1996; Swanson, 1999). In terms of the models presented above, P_b will be zero in the maximization problems faced by private agents.

Nevertheless, the CBD has recognized biodiversity loss as a global environmental problem and has promoted its conservation to being a global concern for humankind. As well, the CBD has established a quasi-universal regime, encompassing an ecosystem approach[42]. Furthermore, the Third Conference of the Parties to the CBD recognized forests as playing a crucial role in maintaining global biological diversity[43].

5.2. The compatibility issues of two overlapping treaties and the international law of the treaties

It is commonly admitted that there is no hierarchical structure to international law and that treaties are equally binding, with the exception of treaties endorsing rules of *jus cogens* that produce an *erga omnes* effect (Nguyen et al., 1987). Neither the CBD nor the Kyoto Protocol contains such a rule. Therefore, if the Kyoto Protocol finally enters into force, the Kyoto Protocol and the CBD will be on equal standing.

In the case of conflict between these two international agreements, article 30 of the 1969 Vienna Convention on the Law of the Treaties (1969 Vienna Convention), which regulates such situations, seems rather inappropriate[44].

Firstly, the *lex posterior* principle applies only to successive treaties that govern the same subject matter[45]. The CBD and the Kyoto Protocol do not govern the same environmental matter, they merely overlap on one issue, while their primary aims are different. This feature also excludes the application of the *lex specialis* principle[46].

Secondly, the Kyoto Protocol lacks a conflict clause, which would prevent conflicts of obligation by establishing a precedence of those instruments adopted before the respective treaty (Wolfrum and Matz, 2000). In contrast, the CBD contains such a clause (article 22.1), which allows for the precedence to a certain extent of rights and obligation that bind the contracting Parties at the time of ratification. However, this exemption applies to obligations and rights that existed before the CBD was ratified. Further, this exemption is strictly limited to the extent that the exercise of these rights will not threaten biological diversity, leading to the *de facto* precedence of the CBD in relation to other agreements (Wolfrum and Matz, 2000).

A conflict between the Kyoto Protocol and the CBD would appear if the former would impose any obligation to violate the rules of the latter. As the use of sinks in the Kyoto Protocol is voluntary, such a conflict will probably not occur. Nevertheless, the Kyoto Protocol may provide incentives that could violate the CBD, and these incentives could be seen as a source of conflict between the two Conventions. A good example for such a situation is the introduction of alien species: (i) as we have shown in the section on afforestation and reforestation, the Kyoto Protocol provides incentives for afforestation and reforestation practices with fast growing species, generally alien species; and (ii) the CBD bans the introduction of alien species which threaten ecosystems. In principle, the limitations included in the CBD should be sufficient to avoid the use of alien species in LULUCF activities[47]. However, the lack of concrete and stringent rules in the CBD and the vague language used implies that this provision cannot

[42] In October 2001, the CBD had 183 parties (www.biodiv.org). Concerning the ecosystem approach, see Decision V/6, UNEP/CBD/5/23.

[43] UNEP/CBD/COP/3/16, 12 September 1996.

[44] The 1969 Vienna Convention on the Law of the Treaties applies to written agreements governed by international law concluded between States (art. 1). (Nguyen et al., 1987).

[45] If all parties to the later agreement are also parties to the earlier, the earlier is only applicable as far as it is consistent with the later (art. 30.3 1969 Vienna Convention).

[46] In the case of two treaties governing the same subject matter, the more specialised rules prevail.

[47] In this regard, the CBD could be seen as an additional limitation only applicable to their Parties, so that Parties to the Kyoto Protocol not included in the CBD could have a comparative advantage (however, almost all countries have signed the CBD).

be seen as a real limitation to the market forces invoked by the Kyoto Protocol. That is, the respect of biodiversity may not be seen as a constraint in the maximization problem faced by the private agents which was discussed above (in addition, and as already stated, P_b will be perceived as being equal to zero by these agents).

5.3. A reconciliation approach at the state level

From the principle of international law *pacta sunt servanda*[48], parties to an international agreement are required to fulfill their commitments in good faith, without violating existing obligations from previous international instruments. Starting from this assumption, some authors (Pontecorvo, 1999) argue that States, in implementing potentially-conflicting international obligations, must adopt a 'harmonizing approach', taking into account pre-existing commitments. Furthermore, instruments such as the CBD and the Kyoto Protocol are 'common interest treaties'[49], which implies that Parties to both agreements are under the 'moral obligation' to reconcile the provisions of these treaties in the light of a 'common interest clause'[50]. This approach seems to be endorsed by the Kyoto Protocol, which contains such a 'common interest clause' in article 2.1: 'taking into account its commitment under relevant international environmental agreements'[51]. However, the fact that States try to avoid a binding regime for forests, delaying the adoption of a biodiversity forestry regime under the CBD, shows that States reject to be bound by international stringent standards for the sustainable use of forestry (Tarasofsky, 1996; Henne and Fakir, 1999). Thus, they define themselves, in good faith with relevant international environmental agreements, national criteria for a sustainable use of forest.

5.4. An integrated approach through inter-institutional co-operation

Article 5 of the CBD invites Parties to cooperate where appropriate through competent international organisations on matters of mutual interest for the conservation and sustainable use of biodiversity. Such co-operation should enhance the implementation of coordinated measures on common areas of action such as forestry. This approach was endorsed by the Secretariat of the CBD, when issuing a note that was addressed at the Sixth Conference of the Parties of the Climate Change Convention. The note distinguishes two groups of collaboration activities[52]: (i) one is concerned with the analysis of the impacts of climate change on biological diversity and possible response measures; and (ii) the other group explores the possibility of using Kyoto Protocol incentive measures as a vehicle to integrate biodiversity concerns.

In principle, the UNFCCC process seems favorable to such integration. In the Marrakech Ministerial Declaration, Parties decided to explore such synergy between the two conventions[53] and, as stated above, the Marrakech Accords include several references to biodiversity. However, this concern is rather vague (see Section 2). Further, the Marrakech Accords finally only require from Annex I Parties to list their national laws on LULUCF activities which contribute to the protection of biodiversity and sustainable use of natural resources (the requirement to report on actual measures and results for biodiversity protection was finally set aside during the negotiations). In addition, compliance with reporting requirements for LULUCF activities is not an eligibility criterion for the use of the flexible mechanisms anymore (such as emission trading). Therefore, the Marrakech Accords rely mainly on

[48] Pacts have to be honoured (art. 26 of the 1969 Vienna Convention).

[49] Because they deal with global environmental problems, establish general regimes, principles and specific standards.

[50] Moreover, the interpretation by States of sinks-related provisions should encompass non-legally binding instruments relevant to forests, such as the Forest Principles, as they express the *opinio juris* (Tarasofsky, 1996).

[51] This interpretation is coherent with the historical elaboration of this article (Depledge, 2000). On the contrary, this article is too generic to be considered a conciliation clause in the sense discussed in the previous sub-heading.

[52] UNEP/CBD/SBSTTA/6/11.

[53] § 3 D1/CP7.

the good faith of the Parties to define and to implement nationally the notion of sustainable use and the preservation of biological diversity.

6. Conclusion

This paper has shown that putting an economic value on carbon sequestered by means of *forest management* is not expected to have a great negative influence on biodiversity. On the contrary, creating economic incentives for carbon sequestration by *afforestation and reforestation* is expected to yield a sub-optimal over-plantation of fast growing alien species with a potential negative impact on biodiversity. The possibility to avoid this threat with the regulations adopted in the Marrakech Accords and in the Convention on Biodiversity has been investigated.

The limits to land use, land use change and forestry activities set in the Marrakech Accords are mainly overall caps in terms of quantity of carbon, with almost no influence on the situation discussed above (an alternative quantitative per hectare cap could reduce the sub-optimal incentives created to establish fast growing plantations). Direct references to biodiversity have also been included in the Marrakech Accords, but they are general guidelines and cannot be seen as effective limitations.

The Convention on Biological Diversity lacks economic incentives which could ensure that agents will follow the optimal social strategy, whereas the Kyoto Protocol creates such economic incentives. In addition, the Convention on Biodiversity does not provide stringent enough rules to make the conservation of biodiversity a real constraint. However, the Convention on Biodiversity provides rules relevant to forestry which should be considered while further elaborating the rules under the Kyoto Protocol. In particular, attention should be paid to limitations on the use of alien species in order to avoid conflicts between the Conventions and to ensure that no incentive measures will result in a violation of the Convention on Biodiversity. An integrated approach, using the synergy of both regimes at an institutional level, offers an opportunity to enforce biodiversity concerns together with greenhouse gas mitigation.

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Appendix A: The objective function

The objective function can be written:

$$\max V_2 = \int_0^{\infty} \Pi(t) \cdot \mathrm{e}^{-rt}\, \mathrm{d}t \tag{A1}$$

$$\Pi_2(t) = \int_0^{a(t)} A(x)\, \mathrm{d}x + \int_0^{f_1} F_1(x)\, \mathrm{d}x - k_1(u_1) \cdot u_1(t) + \int_0^{L-a-f_1} F_2(x)\, \mathrm{d}x - k_2(u_2) \cdot u_2(t) \tag{A2}$$

and the optimal control problem is:

$$\max H_c = \Pi_2 + \lambda_1(-u_1 - u_2) + \lambda_2 u_1 \tag{A3}$$

$$\text{s.t.: } \dot{a} = -u_1 - u_2 \tag{A4}$$

$$\dot{f}_1 = u_1 \tag{A5}$$

$$\dot{\lambda}_1 = r\lambda_1 - \frac{\partial H_c}{\partial a} = r\lambda_1 - [A(a) - F_2(L-a-f_1)] \quad \text{(A6)}$$

$$\dot{\lambda}_2 = r\lambda_2 - \frac{\partial H_c}{\partial a} = r\lambda_2 - [F_1(f_1) - F_2(L-a-f_1)] \quad \text{(A7)}$$

Initial condition: $a(0) = L$ (A8)

Assuming interior solutions:

$$\frac{\partial H_c}{\partial u_1} = -k_1(u_1) - k_1'(u_1)u_1 - \lambda_1 + \lambda_2 \quad \text{(A9)}$$

$$\frac{\partial H_c}{\partial u_2} = -k_2(u_2) - k_2'(u_2)u_2 - \lambda_1 \quad \text{(A10)}$$

Solving Eq. (A10) for λ_1 and substituting it in Eq. (A9), λ_1 and λ_2 can be written:

$$\lambda_1 = -k_2 - k_2'u_2 \quad \text{(A11)}$$

$$\lambda_2 = k_1 + k_1'u_1 - k_2 - k_2'u_2 \quad \text{(A12)}$$

In equilibrium no additional reforestation occurs and since the transversality condition for infinite horizon problems is $\lim_{t\to\infty} = \lambda(t) = 0$, in the steady-state: $\dot{\lambda}_1 = \dot{\lambda}_2 = u_1 = u_2 = 0$.

Hence, substituting Eq. (A11) in Eq. (A6) gives, after rearranging:

$$\frac{F_2(L-a-f_1)}{r} - k_2(0) = \frac{A(a)}{r} \quad \text{(A13)}$$

and substituting Eq. (A12) in Eq. (A7) gives, again after rearranging:

$$\frac{F_2(L-a-f_1)}{r} - k_2(0) = \frac{F_1(f_1)}{r} - k_1(0) \quad \text{(A14)}$$

Taking Eq. (A13) and Eq. (A14) together:

$$\frac{F_2(L-a-f_1)}{r} - k_2(0) = \frac{F_1(f_1)}{r} - k_1(0) = \frac{A(a)}{r} \quad \text{(A15)}$$

or writing F_i out:

$$\frac{P_w W_2(L-a-f_1) + P_c C_2(L-a-f_1) + P_b B_2(L-a-f_1)}{r} - k_2(0) = \frac{P_w W_1(f_1) + P_c C_1(f_1) + P_b B_1(f_1)}{r} - k_1(0) = \frac{A(a)}{r} \quad \text{(A16)}$$

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