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Preserving the World's Tropical Forests—A Price on Carbon May Not Do

U. MARTIN PERSSON* AND
CHRISTIAN AZAR
Physical Resource Theory, Department of Energy & Environment, Chalmers University of Technology, S-412 96 Göteborg, Sweden

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Climate policy will create both disincentives and incentives for tropical deforestation. Disincentives if the carbon emissions from forest clearing are priced, as is currently being discussed within the United Nations Framework Convention on Climate Change (UNFCCC); incentives as a price on carbon will increase the demand for carbon-neutral energy sources, including bioenergy, making deforestation for biomass cultivation increasingly profitable. The question is whether the increased cost for forest clearing, through the price on carbon emissions, will be enough to counter-balance the increased profitability of deforestation through the escalating value of agricultural land. In an attempt to answer this question we analyze the profitability of tropical deforestation and subsequent bioenergy production, taking oil palm plantations as an illustrative example. We estimate that deforesting for palm oil bioenergy production is likely to remain highly profitable, even in the face of a price on the carbon emissions from forest clearing. Current efforts to include carbon emissions from tropical deforestation in a future international climate regime, while a step in the right direction, may therefore not suffice as protection for the world's tropical forests. Additional, and stronger, protection measures for the world's tropical forests will still be needed.

1. Introduction

During the United Nations Framework Convention on Climate Change (UNFCCC) negotiations in Bali, December 2007, the first small steps were taken toward including carbon emissions from tropical deforestation in a future climate regime. With annual emissions in the order of 1.0−2.2 GtC/yr (*1*) (in parity with the global carbon dioxide (CO_2) emissions from transportation), slashing tropical deforestation could be an important source for emission reductions, while at the same time having significant cobenefits in terms of biodiversity, and soil and water conservation (*2*). The increased interest in reduced deforestation as a tool for climate mitigation also stems from the fact that it is seen as a low-cost carbon abatement option (*3*). Both the IPCC (*2*) and the Stern Review (*4*) point to *reduced emissions from deforestation and degradation* (REDD) as one of the least expensive abatement options available.

Climate policy in the form of a carbon tax or a cap-and-trade system will also augment the profitability of biomass plantations through higher prices on fossil fuels, raising the willingness to pay for biofuels. This, in turn, would increase the value of land (*5*, *6*), making preservation more difficult and emission reductions from reduced tropical deforestation more costly than currently assumed (e.g., *7*−*11*).

Existing biofuels policies in Europe and the United States may already have caused increased rates of deforestation in the tropics, both directly (*12*) through forest clearing, for example for palm oil plantations, and indirectly (*13*) through increased demand for land pushing up world crop prices in the period 2006−2008 (*14*). If we are to meet stringent global climate targets, global demand for bioenergy is likely to be dramatically scaled up from today's modest levels, as this is one of the cheaper mitigation options available (*5*). Most of the studies in the meta-analysis of Berndes et al. (*15*) find bioenergy use in the range of 100−300 EJ/yr by the end of the century, with corresponding increases in bioenergy plantations between 300−900 Mha.

The additional pressure such a development would put on the world's remaining tropical forests forms a strong rationale for broadening today's climate policy regime to also include a REDD component. If tropical countries are compensated for reducing emissions from forest clearing—be it, as is currently discussed, through a market or fund based system—the international climate regime will not only offer an incentive for increased bioenergy use—pushing up the demand for land and hence land prices—but also create an incentive for forest conservation.

A key question is whether this will provide sufficient economic incentives to protect the world's tropical forests. Even in a world where all CO_2 emissions (including those from deforestation) are priced at a uniform rate, climate policy will act as a double-edged sword, creating both disincentives and incentives for continued deforestation. The question is whether the increased cost of forest clearing, due to CO_2 pricing, will be enough to counter-balance the increased profitability of deforestation caused by the escalating value of agricultural land. In an attempt to shed light on this question we analyze the profitability of oil palm cultivation for liquid and solid bioenergy in a future carbon-constrained world. While two recent papers (*16*, *17*) have analyzed the effectiveness of REDD payments in preventing deforestation for palm oil plantations—with mixed results—neither accounts for the fact that carbon pricing will likely lead to enhanced palm oil prices. Hence, both studies likely underestimate future revenues from forest clearing.

2. Method

Oil palms are the world's highest yielding oil crop, producing both crude palm oil that can be used for biodiesel production and bioenergy residues that can be used to substitute fossil energy. With a global planted area of just under 11 Mha, primarily in Southeast Asia (Indonesia and Malaysia currently supply over 85% of global demand), and an annual yield of close to 40 million tons, palm oil is the world's leading vegetable oil (*18*).

The fact that oil palms have such high bioenergy yields per hectare, are so well adapted to tropical conditions, and already have been identified as a major culprit behind tropical deforestation in Southeast Asia (*19*, *20*), implies that oil palm plantations could become a key driver of deforestation in a future when tightening climate policies push up the demand for bioenergy and biofuels even further. The FAO and IIASA (*21*) estimate that over a third of the land currently under forest in the countries harboring the world's tropical rain-

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* Corresponding author e-mail: mpersson@chalmers.se; phone: +46-31 772 3453; fax +46-31 772 3150.

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forests could be suitable to some degree for rain-fed oil palm cultivation, with the major potential for expansion being in the Congo and Amazon river basins (see Table S1).

We assume that the land use decision facing a forest owner—be it private or public—is whether to clear the forest and establish a palm oil bioenergy plantation, or let the forest stand. If the net present value of clearing, paying the carbon price for the associated carbon emissions—be it through a carbon tax or a cap-and-trade system—and producing bioenergy is positive the land owner will chose to deforest (i.e., we assume that the revenues for the land-owner of forest conservation are zero). The net present value of deforestation is given by

$$\mathrm{NPV}(t) = -\Delta S_{\mathrm{C}} \cdot P_{\mathrm{C}}(t) + R - c_{\mathrm{c\&e}} + \sum_{\bar{t}=t}^{\infty} \left[\left(\sum_{i} [Y_i(\bar{t}) \cdot p_i(\bar{t})] - c_{\mathrm{p}}(\bar{t}) \right) / (1+r)^{\bar{t}-t} \right] \quad (1)$$

where ΔS_{C} is the difference in carbon stock between the forest and the time and space average for the plantation, $P_{\mathrm{C}}(t)$ is the carbon price at time t, R is the revenues from the sales of timber (here for simplicity assumed to be constant over time), $c_{\mathrm{c\&e}}$ is the cost of clearing the forest and establishing the bioenergy plantation, $Y_i(\bar{t})$ is the net bioenergy yield each year, for the different types, i, of biomass produced (i.e., palm oil biodiesel and biomass residues), $p_i(\bar{t})$ is the price paid for the different types of bioenergy, $c_{\mathrm{p}}(\bar{t})$ is the annual cost of cultivation and biodiesel production including the cost for greenhouse gas emissions associated with these activities, and r is the discount rate. The latter is set to 10% in the base case. The time frame for the analysis here is mid- to long-term (up until year 2050), implying that we assume that there is an international agreement in place establishing a global price on carbon for all emission sources.

Note that while we in eq 1 have assumed that deforesting incurs a cost, this is equivalent to a case where the land owner receives a payment for preserving the forest based on the prevailing carbon price, in which case $P_{\mathrm{C}}(t)$ would be reinterpreted as the opportunity cost, or forgone earnings, of cutting the forest.

We consider oil palm cultivation on mineral soils and assume two cases: *Good practice* and *Optimized system*. The assumptions regarding oil palm yields, energy and greenhouse gas balances of cultivation and bioenergy production, as well as the associated costs, for each of these cases are presented in detail in Table S2. Data on oil palm fresh fruit bunch constituents, energy contents, and annual yields used in the analysis are displayed in Table S3. The yield profile is taken as the average of several profiles given in the literature, see Figure S2.

Based on these assumptions, one can calculate average net annual yield of biodiesel and bioenergy residues, the cost for the palm oil produced, and annual greenhouse gas balance for the palm oil cultivation, for the two yield/cost scenarios. These results are displayed in table 1.

As can be seen in Table 1 the greenhouse gas balance for the palm oil bioenergy system turns positive within 27–45 years in the *Optimized system* and the *Good practice* cases, respectively, which is similar, or even above, the results from other studies (e.g., *12, 23*).

However, some studies have estimated the carbon payback time of deforestation for palm oil biodiesel to be in the range of 70–90 years (*24–26*). There are two main reasons for the much longer payback times found in these studies compared with those estimated here and in refs *12* and *23*; first, they assume lower palm oil yields and, second, they do not account for the climate benefits of using residues and byproduct (i.e., palm kernel oil, PKO) for energy purposes, substituting fossil fuel. We argue that while the studies showing longer payback times may reasonably well depict the state of current *average* palm oil biodiesel production conditions they say less about current *good* or *best practices*, let alone about *future performance* of palm oil bioenergy in a carbon-constrained world, where higher land and energy prices create even stronger incentives for intensified cultivation and exploitation of agricultural residues.

TABLE 1. Greenhouse Gas Balance, Biodiesel and Bioenergy Yields (Average over a 25-Year Planting Cycle), and Palm Oil Production Cost Using the Assumptions Given in Tables S2 and S3

		scenario	
	unit	good practice	optimized system
plantation performance			
crude palm oil (CPO) yield	(tCPO/ha/yr)	4	5
palm oil biodiesel yield	(GJ/ha/yr)	172	210
	(l/ha/yr)[a]	4940	6030
residue bioenergy yield	(GJ/ha/yr)	59	146
palm oil production cost[b]	(US$/tCPO)	340	240
greenhouse gas balance			
GHG offsets - biodiesel[c]	(tC/ha/yr)	3.2	4.0
GHG offsets - residues[c]	(tC/ha/yr)	1.1	2.8
emissions from cultivation and production[d]	(tC-eq./ha/yr)	0.9	1.0
net reduction in GHG emissions[e]	(tC-eq./ha/yr)	3.5	5.7
GHG payback time			
carbon content forest	(tC/ha)	206	206
carbon content plantation	(tC/ha)	50	50
pay back time	(yrs)	45	27

[a] Assuming a biodiesel density of 0.87 kg/L. Note that we also assume that the palm kernel oil is utilized for biodiesel production. In reality this oil is used as feedstock in the oleochemical industry replacing petroleum products, giving similar greenhouse gas benefits as using it for biodiesel production. [b] Costs given for year 2000. The production costs rise over time, as the price for fertilizers increases due to increased natural gas feedstock prices. These costs are roughly in line with the current costs for palm oil production in Indonesia and Malaysia, being around US$200–250/tCPO. [c] Here it is assumed that the biodiesel and the biomass residues produced replaces fossil fuels with a carbon content of 18.9 gC/MJ, equal to that of fossil diesel (*22*). [d] This number includes CO_2 emissions from diesel use in palm oil cultivation and transportation, natural gas use in fertilizer production, natural gas use (for methanol feedstock) in biodiesel production, as well as N_2O emissions from cultivation. [e] Numbers do not add up due to rounding.

The yields assumed here—4 and 5 tons crude palm oil (CPO) per hectare and year (averaged over the 25-year rotation cycle, see Figure S2) in the *Good practice* and *Optimized system* cases, respectively—are somewhat higher than the current Malaysian and Indonesian *national averages*, which reached 3.9 and 3.4 tCPO/ha, respectively, in 2006 (*27*) (yields per hectare *harvested*, i.e., mature fields, averaged 4.4 and 3.9 tCPO in Malaysia and Indonesia, respectively, but this is adjusted downward to take into account the fact that in the first three years of the 25–30 year plantation cycle yields are zero).

These national averages are held back by smallholders having a low level of agricultural inputs (mainly Indonesia), a high proportion of overmature plantations with low yields (mainly Malaysia), and inefficient management systems (*28–30*). Intensively managed commercial estates already achieve yields of 5–7 tCPO/ha/yr, and even higher yields—up to 10–15 tCPO/ha/yr—have been reported (*30–32*).

We also account for the use of residues from cultivation for energy purposes, substituting fossil fuels in heat and electricity production. Cogeneration (albeit at low efficiencies) from some cultivation residues (shells and fiber) are already the main energy input to palm oil mills (*33*), and increasing the use of residues (e.g., by also utilizing empty fruit bunches) has already been shown to be profitable (*33, 34*).

We assume a residue utilization rate of 59−146 GJ/ha/yr, where the former is equivalent to using the shell, fiber, and kernel cake, in line with current good practice, while the latter implies using all residues but the fronds. In a carbon-constrained world, residues will become increasingly valuable and incentives to utilize them effectively will grow stronger (in fact, there are already CDM projects along these lines being implemented).

To derive a consistent set of prices for carbon, bioenergy, and fossil fuels under different climate stabilization scenarios we use a global energy systems model, GET 5.0 (see refs *35* and *36* for a full description of the model). The GET-model is a linear programming model that is globally aggregated and has three end-use sectors: electricity, transportation fuels, and heat (which includes low and high temperature heat for the residential, service, agricultural, and industrial sectors). Primary energy supply options include coal, oil, natural gas, nuclear power, hydro, biomass, wind, and solar energy. Conversion plants exist that may convert the primary energy supplies into secondary energy carriers (e.g., hydrogen, methanol, heat, electricity, natural gas for vehicles, and gasoline/diesel). The model also includes exogenously set maximum expansion rates for different primary energy supplies and energy technologies.

The GET model is set up to meet an exogenously given energy demand while meeting a specific atmospheric concentration target by the year 2100 at the lowest energy system cost (NPV costs over the period 2000−2300). Optimization is intertemporal and the capital stock declines exponentially with a lifetime of 30 years. For this analysis the model is run with a carbon price that increases by 5% per year in the base case and where the initial level is adjusted so as to meet two different CO_2-concentration targets: 350 and 550 ppm at the year 2100. The discount rate in the model is set equal to that used in the NPV calculations for palm oil cultivation (see eq 1). Figure 1 displays the modeled carbon and fuel prices for the two CO_2 concentration stabilization scenarios for the base case assumptions, up until year 2075.

3. Results

Under the assumptions made here we find that in almost all cases forest clearing for oil palm plantations is profitable even in the face of a carbon price on the emissions resulting from deforestation, see Figure 1. The profitability is of course largest for the *Optimized system* case, the NPV of forest clearing and subsequent oil palm cultivation reaching US $22,000 and US $29,000 by midcentury, in the 350 ppm and 550 ppm cases, respectively. In the *Best practice,* 550 ppm case deforestation is also highly profitable. Solely in the *Best practice*, 350 ppm case does the carbon price make deforestation unprofitable, and only then after year 2041.

Rephrased, our results indicate that forests suitable for palm oil plantations may not be worth preserving solely on the basis of their carbon content; from a climate protection perspective clearing forests for high-yielding bioenergy crops may indeed make economic sense. This result rests fundamentally on the fact that the greenhouse gas balance for bioenergy system studied here turns positive within 27−45 years.

While greenhouse gas balances may give indications of which alternative fuels are preferable in a future carbon-constrained world, these are not the sole determinants of which fuels will enter a market with carbon prices. For example, the profitability of palm oil biodiesel will also be affected by the world market price for oil, since this (together with the carbon price) determines the willingness to pay for alternative fuels. The GET model assumes a competitive oil market with oil prices below those prevailing in a world where some producers (i.e., the OPEC countries) wield market power. With more realistic oil prices we would find even higher profitability of palm oil cultivation.

As already is the case, countries may also—out of other concerns such as competitiveness or energy security—introduce policies that specifically push for the use of renewables or reducing the GHG specifically in the transport sector. In effect this will differentiate the carbon price between sectors, in turn increasing the incentive for forest clearing as the GHG emissions from deforestation would implicitly face a lower price than those from the transport sector (though, one could of course also envisage another scenario, where due to concerns like these voiced here, the CO_2 emissions from deforestation are priced higher than other emissions).

Note that the results shown here do not hinge on carbon prices not being high enough. Apart from the fact that carbon prices in our model—at least in the 350 ppm case—are substantial, the positive NPV is a result of carbon prices rising over time, implying that landowners can profit from paying a low, in relative terms, price for the emissions from forest clearing and then reaping the benefits of higher carbon prices over time, raising the willingness to pay for bioenergy. Simply increasing the level of the carbon price will not reverse the results regarding the profitability of deforesting for biofuels production—since it will not only increase the cost of forest clearing but also the revenues from it—as long as it does not reach a level where it makes backstop technologies in the transport sector, like hydrogen from solar energy, profitable, limiting the willingness to pay for palm oil biodiesel.

The latter implies that technological advances and choices in the transport sector will affect the profitability of deforesting for agricultural land. If, e.g, solar-based hydrogen or algae-based biofuels, both being far from commercialization today, becomes available at a much lower cost than what is currently believed, and at a scale that allows it to set the price for transportation fuel in the world, this will of course limit the profitability of palm oil biodiesel. Electrification of the transport sector, through the deployment of plug-in hybrids or electric vehicles, may also affect the willingness to pay for liquid biofuels, but likely to a lesser extent. The reason for this is that a large share of the transportation demand, that coming from long-range transport (both personal and freight) and aviation is extremely hard to electrify and is likely to remain liquid fuel based. In the GET model the latter two—aviation and freight transport—comprise about two-thirds of the total transport demand in year 2100.

3.1. Sensitivity Analysis. In addition to the factors discussed and analyzed above (i.e., climate target, the palm oil yield and economics, the oil price, and technological choices in the transport sector) the estimated profitability of deforesting for palm oil bioenergy plantations is dependent on, *inter alia*, the discount rate, the carbon price trajectory, and the carbon content of the forest. Here we explore and discuss the sensitivity of our results to these parameters.

The carbon content of tropical rainforests varies on a regional, national, and local level, with the IPCC giving a range from around 80 tC/ha (lower bound in Africa, America, and continental Asia) up to 440 tC/ha (upper bound in continental Asia). If this spatial variability is accounted for in climate policies, the NPV of deforesting for palm oil will differ from plot to plot. The effect of adopting a higher or lower biomass content will of course be stronger the higher the carbon price, i.e., the further into the future one looks. Still, it takes a carbon content of 350 tC/ha to make the NPV

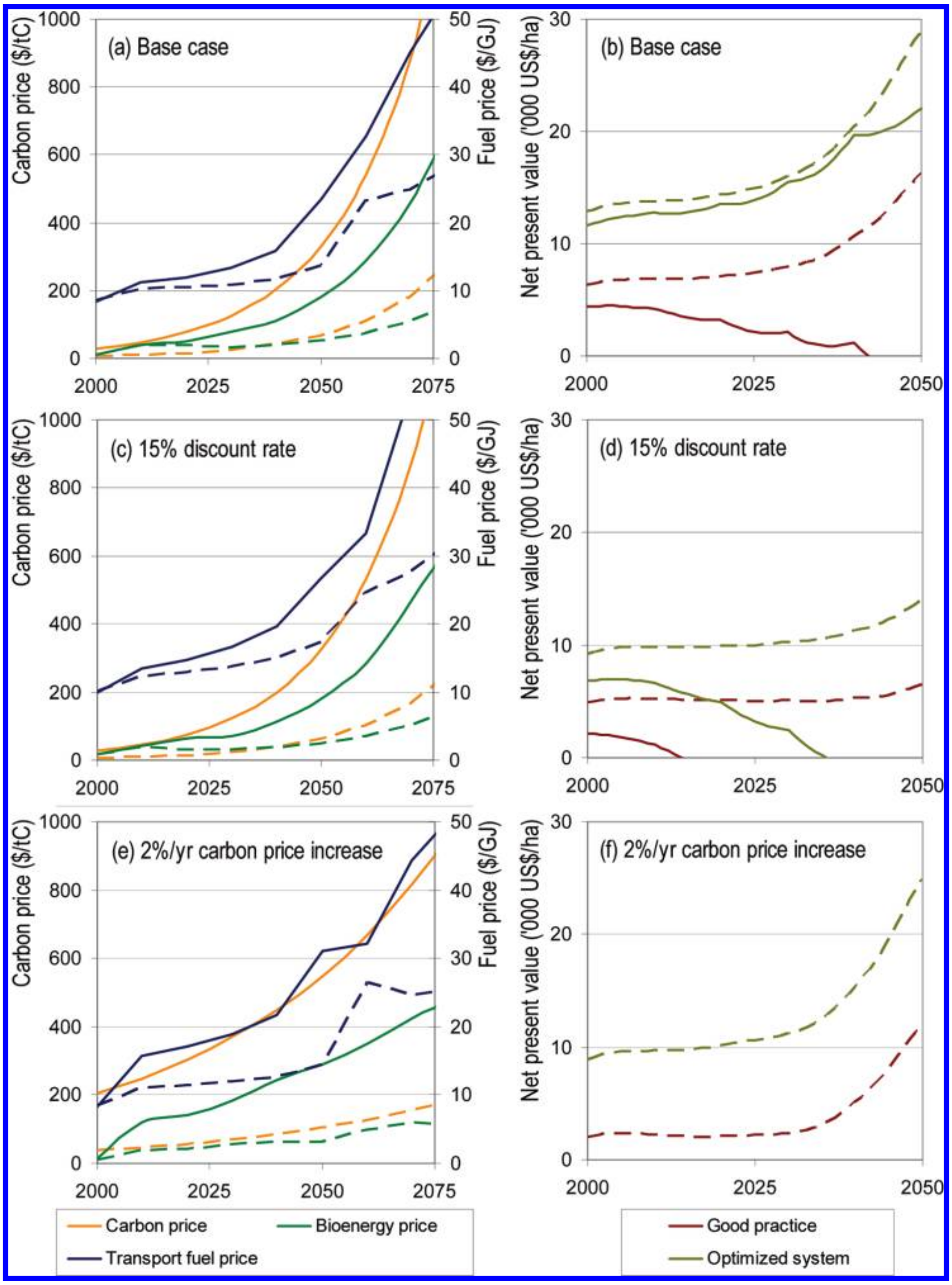

FIGURE 1. Carbon and energy prices from the GET5.0 model (left panels) used to calculate the net present value of forest clearing and subsequent palm oil production for solid and liquid bioenergy (right panels). Results are shown for two CO_2 concentration targets: 350 ppm (solid lines) and 550 ppm (dashed lines) in year 2100; for two sets of assumptions regarding the discount rate: 10%/yr (panels a-b, e-f) and 15%/yr (panels c-d), and the carbon price trajectory: increasing at 5%/yr (panels a-d) and 2%/yr (panels e-f).

in the least profitable scenario (the 350 ppm, *Good practices* case) negative at all times up to year 2050. In the 550 ppm scenario, the NPV of deforesting for palm oil plantations remains positive throughout the time period—though only slightly so for the *Good practices* case—even for the IPCC upper bound of 440 tC/ha.

The NPV of deforestation and palm oil cultivation should be expected to fall if the discount rate is higher—shifting the balance between the current costs and future benefit of clearing—or if the carbon price rises less rapidly. Figure 1 therefore shows the results also for a higher discount rate, 15%/yr, and an alternative carbon price trajectory, where the costs for GHG emissions increase by 2%/yr.

Raising the discount rate does indeed lower the NPV, but only in the 350 ppm stabilization scenario does it shift the incentive from one of deforestation to one of preservation, after year 2015 and 2036 for the *Good practice* and *Optimized system* cases, respectively. This is partly explained by the high profitability of well-performing palm oil plantations even in a carbon-constrained world, but it is also due to the fact that a higher discount rate implies an increasing willingness to pay for biofuels—as can also be seen by comparing panels (a) and (c) in Figure 1. The reason for the latter is that a higher discount rate will increase the cost for highly capital intensive solar energy more than the cost for biomass and since solar energy sets the prices for transportation fuel in the long run (beyond 2050) it will increase the profitability of biomass.

Similarly, reducing the growth rate of the carbon price to 2% per annum results in a negative NPV of forest clearing and subsequent palm oil cultivation in two cases, again the two 350 ppm target scenarios. However, the combination of a slowly increasing carbon price and a stringent climate target is less likely to materialize in reality, since it implies that initially carbon prices have to be very high (note, though, that it is not the high carbon price *per se* that reverses the result, but the fact that it rises more slowly over time, shifting the balance between present costs—the carbon price—and future revenues—incomes from selling bioenergy). In the GET model, realizing a 350 ppm stabilization target with a carbon price increasing at 2%/yr demands a global carbon price in year 2010 in the order of US \$250/tC, see Figure 1.

4. Discussion

Our conclusions are at odds with earlier assessments finding that tropical deforestation can be substantially reduced already at very low carbon prices. For example, the Stern Review finds that deforestation in eight countries responsible for almost half of the world's deforestation can be completely halted at a carbon price of below US \$5/tCO_2 (*10*). The IPCC (*7*) suggests that emissions from tropical deforestation can be reduced by more than 0.5 GtC/yr by year 2030 at a price below US \$20/tCO_2, and by 1 GtC/yr at a carbon price of US \$100/tCO_2. Similar conclusions can be found elsewhere (*8, 9*).

These studies are right in pointing out that pricing carbon emissions through an international climate agreement could potentially make many of the current proximate causes of deforestation unprofitable (e.g., extensive cattle ranching, small-scale slash-and-burn agriculture and woodfuel use *10, 11*), though actually getting the incentive through to the local level and overcoming institutional barriers may prove difficult (*4*−*7, 37*).

However, our analysis points to an important mechanism that these studies miss. As climate policy is progressively strengthened, and carbon and energy prices rise, so does the value of land. This implies that increasing the carbon price, so as to penalize deforestation even more, will not suffice to change the profitability of deforestation and bioenergy cultivation, since a higher carbon price will not only increase the cost of forest clearing but also the revenues from doing so (up to the point when carbon prices make back-stop technologies like solar hydrogen become competitive, limiting the willingness to pay for biofuels). Reduced deforestation through the price on CO_2 emissions therefore becomes an evasive goal.

The mechanism of climate-policy-induced competition over land between forest conservation and bioenergy production has in fact been studied in some integrated assessment models, with mixed results. A recent study (*38*) finds that a uniform carbon price, covering the emissions from land use change, prevents the expansion of bioenergy plantations onto forested land. The main reason for the conflicting conclusions between their and our study is most likely that the model used in the former assumes a generic bioenergy system with a notably lower yield and biofuel conversion efficiency than the palm oil biodiesel system analyzed here.

There are other models that do find an extensive expansion of biofuels into tropical forests, even in the case that all carbon emissions are priced ((*39*); see also discussion on results from the IMAGE model in ref *40*). Interestingly, the IPCC, although arguing that REDD is one of the cheapest mitigation options available, notes that "forest sector emissions may actually increase in mitigation scenarios as a result of net deforestation due to bioenergy production ((*40*), p 241). Thus, even though modeling results in line with those obtained here have been presented before, the implications this may have for the costs of reducing deforestation—and the efficacy of carbon pricing in doing so—has generally not been acknowledged.

What a carbon price will do is change the relative profitability of clearing and cultivating old-growth forests compared to lands with lower carbon content, e.g., formerly deforested and abandoned land, wastelands, etc. However, since some of these lands may give lower yields and, most importantly, since they will not be able to quench the enormous demand for land induced by stringent climate policies, they will not take the full pressure off natural forest lands.

Note, also, that plantations established on peat lands in South East Asia, where carbon emissions following drainage are in the order of 20 tC/ha/yr (*20*), would have a negative annual greenhouse gas balance for over 100 years (*41*), leading to very long carbon payback times, and consequently a negative NPV even for fairly low carbon prices. But, as noted in the introduction, the largest potential for oil palm expansion lies not in South East Asia, but in the Amazon and Congo river basins (see Table S1) where peat soils are not prevalent.

The results presented here should not be interpreted as an argument in favor of keeping tropical deforestation out of future international climate regimes. That would only make matters worse. But, it implies that *in addition* to a price on carbon emissions from deforestation, other protection measures will be needed. These can be either in the form of supplemental payment schemes for ecosystem services other than carbon retention, or by more traditional regulatory instruments, e.g., large-scale conservation through parks and reserves, sustainable forest management, and strong governance of agricultural frontiers (*42*). There is also a need to improve institutional capacity both for monitoring and enforcement of forest policies.

Certification, the most widely discussed remedy in response to the fears that imports of bioenergy and biofuels could incur deforestation, may on the other hand have limited effect, as it is the overall demand for agricultural land that matters. Even if one can ensure that *no* biofuels are produced on newly deforested lands, the increased demand for cultivable land that follows from a biofuels expansion—and the subsequent rise in land prices—is likely to increase the pressure on natural forests, leading to deforestation.

To illustrate this, consider the increased use of corn for ethanol production in the United States, which in 2007 induced American farmers to switch away from growing soy. As global demand for soy products did not diminished this shortfall in supply from the U.S. was partly filled with soy expansion in Brazil, contributing to deforestation in the Amazon (*13*). Similarly, with more than half of the European rapeseed harvest today going into biodiesel production, the EU palm oil imports have doubled, again likely contributing to deforestation elsewhere, this time in Southeast Asia.

In the end, what is needed if we are to come to grips with the deforestation crises is either to reduce the pressure on forests (by decreasing the overall demand for timber products and agricultural land) and/or to enhance the protection of the forests through international, national, and regional policies. Still, certification might be a positive step in coming to grips with other problems associated with bioenergy plantations, e.g., local environmental effects and labor conditions.

Finally, there is an ongoing international discussion about who should bear the costs for the preservation of tropical forests—the countries that host them or the global community as a whole. Our analysis suggests that the opportunity cost of preserving them will rise substantially under stringent climate policies, and that this will raise the stakes even further in forthcoming international negotiations on these matters.

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Supporting Information Available

Detailed account of assumptions and data on oil palm yield, clearing, cultivation, and biodiesel production costs, used in the NPV calculations, as well as the input used to calculate the GHG balance of the bioenergy system. This material is available free of charge via the Internet at http://pubs.acs.org.

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