

# THE FOOD , FOREST AND CARBON CHALLENGE

NATIONAL WILDLIFE FEDERATION

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TROPICAL AGRICULTURE, FORESTS AND CLIMATE PROJECT

# Report

Several people made important contributions to this report for which we are grateful.

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*The Role of Commodity Roundtables & Avoided Forest Conversion in Subnational REDD+ Agriculture, Food Security & Greenhouse Gas (GHG) Accounting*

For more details about the workshop, visit:  
[www.nwf.org/reddworkshop](http://www.nwf.org/reddworkshop)



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# Executive Summary

How does demand to use land to produce food for people and livestock contribute to deforestation, other land use conversion, and the associated release of greenhouse gases (GHGs), and how might different strategies to meet that demand for food protect forests? These questions require attention as international forest protection efforts shift from an exclusive focus on ways to reduce the “supply” of vulnerable forests, (by paying countries to protect them), toward addressing the forces that cause deforestation (often called the “drivers of deforestation”). Agriculture is the primary driver of tropical deforestation and as a result, strategies to reduce forest loss can include government and market-driven measures to boost yields on existing agricultural lands so as to reduce demand for new croplands and pastures, as well as efforts to reduce food waste to hold down demand growth overall. But researchers dispute the impacts on deforestation rates of increasing agricultural yield. Some prominent studies assume that boosts in agricultural yield, anywhere in the world, would self-evidently save forests (because demand for food could be met on existing agricultural land), while another camp argues that yield increases can actually increase deforestation in developing countries. By 2050, global demand for food and feed will likely rise by 75% or more from current levels due to population growth and growing demand for meat and other resource-intensive foods as incomes improve. This growth means it is essential to identify strategies to enhance food security without deforestation, if we are to protect forests for future generations.

This paper analyzes recent studies and some of the latest available data to address several of the major issues raised in the debate over how to reduce deforestation. It emphasizes the importance of addressing demand for land, and the limitations of forest conservation strategies which fail to address agricultural drivers of deforestation, as well as the negative impacts on other natural habitats and their carbon stocks that can result. Many studies underestimate the role of the demand for agricultural commodities in the clearing of forests and release of the carbon they store; many also miss the fact that focusing only on forests may re-direct that land pressure toward clearing other carbon-rich lands; and others fail to fully appreciate the challenges of meeting new demands for food or the potentially significant consequences of the growth of biofuels. On the other hand, strategies to boost agricultural productivity in the developing world, while extremely important to redress hunger and boost rural incomes, by themselves will not protect tropical forests and may even lead to further forest loss unless coupled with forest protection policies.

**Both demand and supply factors influence deforestation.** Inevitably, the level of deforestation will respond to both the demand to clear forest land for agriculture and the supply of that land. Demand for new agricultural land depends both on the total, global demand for agricultural products, and on the ease and cost of obtaining those additional products from existing cleared land. The supply of forest land for agriculture, which in economic terms means both its quantity and the costs of converting and using it to produce agricultural products, depends on many factors; these include distance from roads and other government infrastructure, the strength of legal restrictions and the costs of physically burning and clearing forest. In reality, these factors influence each other; for example, as agricultural demand increases the potential value of forest conversion for crops, government policy may often attempt to facilitate that conversion. Addressing demands for land for agricultural production is therefore necessary, not only to reduce the immediate economic signal to the private sector, but also to reduce pressures on governments – both honest and corrupt – to make forests available for conversion and harvest.

[Demand for land for food and animal feed has land use implications for forests and the climate that go beyond the net change in tropical forests.](#) The conventional way of estimating GHG emissions from land use change assigns virtually all emissions to tropical deforestation, and recent estimates using that approach placed annual emissions between 2000 and 2005 at 1 to 1.3 gigatons of carbon from deforestation itself, plus another 0.3 gigatons from drainage of forested peatlands in Southeast Asia. Since the vast majority of this tropical deforestation leads to agricultural land uses, that appears to implicate rising agricultural demand as the cause of all of this conversion and cap its potential contribution at 10-12% of global greenhouse gas emissions from all sources in 2005.

In fact, the true story on a global level is more complicated and implies an even larger role for agricultural demand even as other forms of demand are also important. As forests reestablish themselves on abandoned agricultural land, or regrow from logging, they absorb carbon dioxide (sequestering carbon in their living material) from the atmosphere and therefore act as carbon sinks. Deforestation due to agricultural conversion and logging releases carbon dioxide, and is a source of carbon emissions. The estimates of emissions from land use change in fact represent the balance of carbon release and new carbon sequestration from a shifting mix of land use alterations worldwide: deforestation, reforestation of abandoned agricultural lands, new logging, and re-growth from old logging. By one recent estimate, global forests sequester roughly 4 gigatons of carbon each year on a gross basis, while deforestation and logging release perhaps on the order of 2.8 gigatons (not counting peat emissions), resulting in a net forest carbon gain of perhaps 1.2 gigatons per year. In a real sense, every form of new demand for agricultural land that leads to these releases of carbon (and every demand for logs from natural forests), contributes to emissions. And when growing agricultural demand keeps land in agricultural production in countries where it would otherwise reforest (such as Europe), that expression of demand also increases the amount of carbon in the air. Overall, were it not for growing agricultural demand, the global carbon sink would be both much larger and growing faster.

[Among the reasons forest protection efforts alone cannot reduce emissions from land use change is that such efforts by themselves would re-direct agricultural production pressures into wetlands and savannas.](#) Estimates of land use change emissions have only recently started to include roughly 0.3 gigatons of carbon per year from conversion of peatlands in Southeast Asia. Wetlands and savannas are likely to become focal areas for agricultural conversion, particularly in Africa.

[Yield gains are inherently necessary to meet new food and feed demands without expanding agricultural lands.](#) An FAO projection of new cropland to meet the food demands by 2050 provides reasons for both hope and caution. By that year, the FAO projects cropland in developing countries will increase by 120 million ha, while cropland in developed countries will decline by 50 million hectares, resulting in half of the annual rate of cropland expansion of previous decades. Holding down cropland expansion to this rate seems achievable because it requires absolute yield gains at roughly two-thirds the rate of previous decades. Conversion of forest to pasture, particularly in Latin America, has also led to more than half of net tropical deforestation in recent decades, and studies have estimated high potential for pasture intensification as an alternative to additional deforestation. However, there are also reasons for less optimism, which include declining yield gain trends for wheat and rice in high-yield regions, far less water available for new irrigation, depletion of many important world aquifers, the effects of climate change itself, and above all, the need to produce more of this food in lower yielding regions where food demands will grow.

Regional deforestation highlights the importance of yield gains. In sub-Saharan Africa, the population is likely to grow by 230% by 2050, and only large yield increases can avoid large-scale expansion into forests and woody savannas. Worldwide growth in demand for beef and vegetable oil drive deforestation rates from pasture expansion in Latin America and oil palm in Southeast Asia, and are only likely to decline if forest protection efforts are coupled with large gains in pasture and palm oil yields, alongside increased production in underutilized land and strengthened market demand for deforestation-free products.

[Projected increases in bioenergy production would make it impossible to stop emissions from land use change.](#) Although food challenges suggest the importance of prudence, global goals for biofuels demand would make the FAO's limited projections of cropland expansion unrealistically low. Estimates of large bioenergy potential double count carbon and food (and to some extent, double count yield gains). For example, a target to provide 10% of world transportation fuels by 2020, roughly 2% of world energy demand, would require roughly doubling the recent rates of yield growth for cereals and soybeans, and far larger yield increases for sugar and palm oil, to avoid cropland expansion. Policies pointing toward producing 20% of world energy from bioenergy by 2050 would require roughly doubling the present quantity of biomass harvested from plants worldwide for all purposes, including not only crops but also crop residues, grass consumed by livestock and wood. That is not achievable while protecting natural areas and also meeting the greater than 70% increases expected in demand for food and timber.

[Yield gains in tropical areas are necessary but not sufficient to protect forests and by themselves may encourage more deforestation without forest protection policies.](#) Despite the importance of yield gains, researchers who have cast doubt on higher yields as a forest protection strategy are partially right. Despite some claims otherwise, yield gains are almost certain to reduce deforestation globally (known as "land-sparing"), and yield gains in temperate zones will almost certainly spare natural habitats in tropical areas and save carbon overall. However, yield gains in the tropics, such as productivity gains in using seeds, fertilizer, and labor, can easily encourage conversion of more forest to cropland locally, by making local cropping more competitive with agriculture in other world regions. That leads to a relative shift in the location of production, and helps to explain why the economic successes of agriculture in Brazil and Southeast Asia are associated with deforestation. Researchers have under-appreciated this distinction between global and local land sparing because they have underemphasized the shift in the locations of agricultural land. Even in a world with a well-functioning system for Reducing Emissions from Deforestation and Forest Degradation (REDD), tropical yield gains will increase the required level of REDD payments.

Despite this problem, ignoring the need for yield gains in the tropics is not an option. Higher yields in developing countries are absolutely critical to food security and economic development, and expanded food and feed needs will inevitably lead to deforestation and loss of savannas and wetlands if yields do not improve.

Yield gains are therefore necessary but not sufficient to reduce deforestation and other conversions of natural habitats, let alone to provide acceptable levels of food supplies. In short, although there is no perfect solution to this challenge, there are several fruitful directions to explore for policymakers, private companies and multi-stakeholder "commodity roundtables" that seek to meet food demands while protecting both carbon and natural areas.

## KEY POLICY RECOMMENDATIONS

### Policies to Promote Efficient Uses of Land

- Policies should encourage more efficient output from all land, whether that primary output is carbon sequestration, food, fiber, biological diversity or some other valuable product that requires land. For that reason, shifting a parcel of land that is already efficiently producing one of these outputs to producing another is unlikely to help achieve the dual global objectives of sufficient food and sequestering carbon, whether the shift is from food to forest or energy use or from forest to food. From a carbon perspective, policies should encourage land use change only when the productive capacity of that land has been eroded through bad management and the change in land use is the most likely way to optimize its capacity.
- Policymakers should develop more realistic goals for biofuels and only promote them where they use wastes or are likely to produce biomass at high rates on currently unproductive land.
- As part of such an effort, decision-makers need to fix an accounting error in the Kyoto Protocol and many national laws that treat all bioenergy as carbon free and thereby makes forest carbon worth more dead than alive. Other accounting errors in the Kyoto Protocol, which ignore actions that reduce growth of the forest carbon sink, should also be corrected.
- Private food companies and “sustainable commodity roundtables” should not only discourage the use of high carbon and biologically diverse lands, but should also encourage that agriculture expand only where it can achieve a high ratio of output to carbon loss. They should also encourage steady improvement in the outputs from existing agricultural lands.

### Policies to Encourage Yield Gains to Protect Forests and Other High Carbon Lands

- Policymakers should attempt to direct REDD+ compensation for forest protection toward sustainable enhancements in agricultural yields, with appropriate safeguards in place to protect forests.
- Efforts towards productivity gains should focus on boosting yields of staple foods for domestic production, on boosting production by existing farmers on existing farmland, and on boosting production, if possible, away from the forest frontier. Export agriculture in the tropics should be focused on tropical crops, preferably with high labor demands and high revenues per hectare.
- Policymakers should focus new infrastructure, where possible, on existing agricultural centers and avoid high carbon lands; and explicitly protect forests and other carbon-rich lands when new roads and ports facilitate access to such areas.





# Introduction

**For years, forest protection efforts have attempted to reduce the supply of forest for logging or agricultural conversion by establishing systems to pay countries and landowners to conserve their forests. As these systems starts to take shape, forest protection efforts have begun to focus as well on limiting the demand for forest conversion, particularly by addressing the drive of agriculture for more land. Conversion to agricultural uses is now the direct source of the vast majority of reported net emissions from land use change.**

The relationship between forests and agriculture implicates other important public goals. Along with protecting forests, the world will also need to produce roughly 75% more food by 2050 to feed a growing, selectively wealthier population, and to reduce hunger. And it needs to produce that food cheaply because billions of people are likely to remain extremely poor. To protect both biodiversity and carbon, it is not good enough just to avoid forests, as that may only shift agricultural expansion into other valuable natural areas, particularly wetlands and savannas. If protecting forests just meant more hunger and fewer wetlands and savannas, public policy would hardly be a success, and forest protection would likely lose public and political support.

Yet the relationship between forest protection and land use demands is complex, and the value to forests of demand control efforts disputed. Some scholars have argued that yield gains promoted by such efforts as the Green Revolution have saved more than a billion and a half hectares of global forests and other natural areas. Others have found

no necessary relationship between yield gains and “land sparing” and have argued that yield gains are more the consequence than the cause of land protection and sometimes even spur deforestation. In extreme versions of the argument, one side might hold that yield gains and other factors reducing demand for new land eliminate emissions from land use change wherever they occur, while another side might argue that policy should focus only on supply-side factors, such as strict controls on which lands can be converted.

This paper tries to make some initial sense of this debate by discussing the role of agricultural demand for new land in the preservation of forests and land-based carbon. In this paper, the primary focus is on demand side factors that help to meet demand for the same quantity of food on existing agricultural land or by directing new production into degraded or low productivity lands. Demand side factors may also include holding down the demand for the managed outputs of land, and this paper briefly discusses bioenergy because of the role of government policy in spurring its demand.

Population growth and diet are other factors that deserve serious emphasis but which are little discussed in this paper. Both governments and private food companies have policies, and can develop new ones, that influence the demand for land in this way.

Governments and private food companies also influence the land supply side. When food commodity roundtables, or private companies on their own, refuse to purchase food or timber produced on certain lands, their efforts could be referred to as demand controls because they are purchasing standards. But because they would work by restricting the lands that could supply these products, the logic of this paper refers to them as a form of land supply control, a private equivalent to a government regulation protecting such lands.

The land sparing debate raises some basic questions: How does the demand for land influence deforestation and other emissions from land use change? What role do yield gains play? What role can private standards and certification efforts play? To the extent demand-side efforts are valuable,

how would one structure them in light of the risks and opportunities?

This paper addresses these questions. A major theme is the important distinction between gross and net deforestation, as both net effects and the shifts of agriculture from one location to another play a critical and underappreciated role. Unpacking this inter-relationship will aid our understanding of the causes and consequences of agricultural demand and help to explain the conflicting views of “land sparing.” Shifts in the location of agricultural production are to some extent necessary and desirable, but also add greatly to deforestation and emissions related to agriculture, and they complicate the challenge of addressing agricultural demand in a way that spares forests. Ultimately, boosting yields and limiting our other demands on land for production of human goods is a necessary but not sufficient means of protecting forests and other natural areas, and policies that restrict the supply of and those that restrict demand for forest conversion need to work together.



Leonardo F. Freitas

# I. Role of Demand for Agricultural Land in Deforestation and Related Emissions from Land Use Change

## A. Some basic principles for understanding the role of agricultural demand in altering land—based carbon

Conversion of tropical forests to agricultural land is the dominant source of those land use changes cited by the IPCC as contributing to greenhouse gas emissions, and a direct satellite analysis confirmed that more than 80% of new agricultural land in the tropics in the 1980s and 1990s came physically out of forest (with the remainder mostly shrubland, and a small portion from wetlands and forest plantations) (Gibbs 2010). That does not mean that agricultural demand is the sole cause of tropical deforestation, nor that a future increase in demand for a hectare's worth of food automatically translates into a hectare of additional deforestation. The battles over biofuels have focused attention on the role of agricultural demand in causing emissions from land use change—with the different effects often obscured in the interstices of models—so it is worth setting forth a few basics.

1. *Both supply and demand factors influence forest conversion.* If there were no increase in food demand at all, but governments built good roads through rain forests and funded research improvements to improve local agricultural technology, they would reduce the costs of supplying food through forest conversion. Agriculture would expand into these forests as they out-compete some agricultural production elsewhere, and somewhat cheaper food would probably modestly trigger overall increases in consumption. For these reasons, economic development in general in tropical areas should be expected to increase forest conversion. But that does not mean that demand factors are irrelevant. Demand maintains or boosts prices, and that makes land conversion more profitable.
2. *The interaction of supply and demand is complex and it is not possible simply to add up the causal significance of each.* Although both supply and demand for land will play a role in determining conversion, they are not merely additive. Without adequate roads, growth in demand may have little consequence in a region. On the other hand, the availability of good roads may serve to amplify the power of growing food demand to trigger deforestation. A reasonable respect for political economy also highlights the relationship. When prices are high, governments are more likely to build roads and grant concessions to forest land not only because of the lobbying of powerful interests but also because of a desire to reduce food price pressures.
3. *Long-term land use responses to increased demand are almost certainly larger than short-term responses.* In the very short-term, an increase in demand can only be met through supply, by taking crops out of stocks, or by higher prices which reduces the demand. The easiest short-term new production will come from intensifying inputs or reducing fallows, as well as switching other lands (such as pastures) to crops. Over time, more land will be brought in. Unfortunately, it is very difficult to analyze long-term responses, and the great majority of economic models derive their response estimates from short-term fluctuations in price.
4. *Although the most desirable response to new agricultural demand is almost certainly an increase in yields, there is remarkably little legitimate economic evidence that demand drives yield increases.* Models that have built-in a large yield response have misinterpreted some prior lead studies, that themselves found no or little response, and that in any event used

shaky economic methods (Berry 2010). A new analysis using proper econometric methods finds remarkably little responsiveness of yield to demand in the United States (Berry 2011). One simple way to see this unresponsiveness is that long-term trends due to technology improvement and short-term weather fluctuations do an excellent job of explaining yield changes all by themselves. This result seems surprising because it just makes sense that farmers will increase not only land in use but other inputs to meet additional food demand, and therefore boost yields; but increasing demand also tends to push farmers into less ideal land and therefore depresses overall yields.

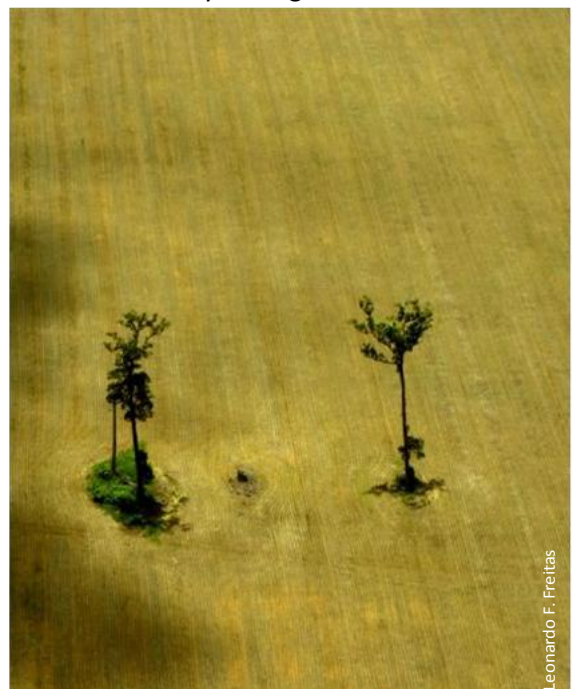
Demand may have a greater influence on yields over the long term, among other means, by pushing government policies that contribute to yield gains, but no economist can credibly demonstrate that relationship. Rising food demand may have contributed to China's economic reforms that unleashed enormous crop yield gains, but those reforms occurred as part of such larger political change that it is impossible to say which influenced which.

5. *Agricultural demand can reduce terrestrial carbon not just by leading to new deforestation but by keeping lands in agricultural use.* From 2001-2008, harvested cropland worldwide increased by 65 million hectares, by far the largest increase in any eight-year period since 1961 according to FAO data, but those increases occurred in a wide variety of countries, some with decreasing forest and some without. Most of the world's agriculturally developed countries have extensive areas of former agricultural land in different stages of transition to alternative uses. In the short-term, many of these lands are likely to be the easiest to plough up to meet a large increase in crop demand, but that does not prevent new croplands carved out of forest elsewhere from supplying the longer term response. And even by keeping land in agricultural production, demand reduces future reforestation and carbon sequestration.

6. *Demand can help fuel deforestation even without spurring net increases in agricultural land.* Land is going out of production for a wide variety of reasons. Between 2001 and 2008, Australia reported to FAO large decreases in pasture and cropland area due to drought. Brazil lost pastureland in much of the country, even as pastureland expanded by more than 12 million hectares in the Amazon (Barona 2010). One reason is that land is of very different quality and yields; thus Brazil's wetter pasturelands derived from forests produce far more food than Australia's drier grazing lands.

More fundamentally, no direct line connects declines in agricultural land in one location to increases in another. People who plough up new land do not respond to statistics they hear about declines in agricultural land elsewhere; they respond to market opportunities open to them and therefore prices. Although declining agricultural land in some regions can result in higher prices and send a market signal for expansion, so do increases in agricultural demand.

In short, although supply factors play an important role in deforestation, for basic reasons the demand for agricultural products and new agricultural land also plays an important role and influences carbon stocks more broadly throughout the world.



Leonardo F. Freitas

## B. The common reliance on net tropical deforestation as the source of greenhouse gas emissions obscures the full role of agricultural and other land use demands in causing emissions from land use change

Efforts to reduce greenhouse gas emissions from land use change have focused largely on blocking off access to tropical forests in part because scientific estimates attribute nearly all emissions from land use change to tropical deforestation. The sense seems to be that if governments better protect these forests, the problem will go away. But a fuller understanding of global land use changes suggests the importance of addressing land use demands including those for both agricultural products and timber.

Recent estimates of annual world emissions from deforestation for 2000 to 2005 or 2007 are 1.2 gigatons of carbon using the “bookkeeping” approach based primarily on reporting of forest area changes by countries directly or through FAO, and 1 gigaton of carbon from an average of satellite studies (Pan 2011; Malhi 2010). Each method has its strengths and weaknesses and the methods are not entirely measuring the same categories of emissions,<sup>1</sup> but in common both methods do attribute virtually all land use emissions to net tropical deforestation. Yet that occurs because of a particular form of netting.

Globally, according to the latest bookkeeping study, gross forest growth sequesters on the order of 4 gigatons of carbon per year (Pan 2011). (Equal to 14.5 gigatons, this gross sequestration offsets more than a third of all the carbon dioxide emitted

into the atmosphere by people each year). The growth occurs in intact forests, in part because they are responding to increased carbon dioxide in the air and nitrogen pollution, but it also occurs as forests regenerate abandoned agricultural land, particularly in the temperate zone, or as they regrow from logging activities. According to the same study, a combination of logging and physical conversion of land to cropland and pasture released 2.8 gigatons of carbon each year between 1990 to 2007. The result was a net forest carbon sink of 1.2 gigatons.

It would be appropriate to describe all of the gross land conversion and all of the logging activities as sources of emissions, offset by growth of forests on abandoned agricultural land and regrowth of forests after logging. Yet by a mostly unarticulated convention, the scientific papers showing the accounting treat all of the forest regrowth in the temperate world as offsetting the emissions from deforestation and logging in that region so they no longer report emissions from land use change in that region. The same papers typically treat the recovery of forests from old logging in the tropics as offsetting the carbon losses due to new logging there, resulting in modest net logging emissions that are treated as the emissions from tropical logging. That leaves emissions from land conversion to agriculture in the tropics as the source of the vast majority of emissions, and this way of thinking is so ingrained that the IPCC has used satellite studies of deforestation in the tropics as a basis for offering global estimates of emissions from land use change. Those emissions are important, but that exclusive focus diminishes the significance of agricultural demand in other regions as well as demand for forest products everywhere. Four implications deserve emphasis.

1. *Estimates of deforestation rates in the tropics themselves use net data and in that way probably underestimate the emissions from agricultural expansion in the tropics by ignoring the shifting of agricultural areas within the region.* Both the bookkeeping and satellite approaches typically compare net changes in forest within the tropics between one time and

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<sup>1</sup> Bookkeeping approaches, pioneered by R.E. Houghton as shown in Figure 1, estimate emissions mostly from national reports of deforestation and changes in agricultural areas, sometimes using direct national data but relying heavily on data reported through FAO. The reliance on this kind of data has been questioned because of shifting definitions, limited estimation methods in many countries, and inconsistencies with other data (Grainger 2008). Using satellite imaging has its own limitations, particularly because of the ambiguity of attributing image areas that are large enough to have a mix of uses to a single land use. Bookkeeping and satellite estimates are also not directly comparable, because of how they attribute emissions from deforestation over time (Ramankutty 2007), and whether they count logging emissions (Houghton 2010).

another.<sup>2</sup> In fact, the net loss of forest may actually result from a much larger gross conversion of forest in turn offset by substantial areas of reforestation of abandoned agricultural land. To the extent larger gross changes occur, the effective shifting of agricultural land from one location to another will generally lead to higher net emissions than estimated because the conversion of a new forest causes an immediate loss of nearly all the carbon while the reforestation of abandoned land more slowly recoups carbon.

Houghton and other analysts of global emissions are well aware of this distinction but have been limited by the data available. Estimating gross deforestation and reforestation requires far more labor-intensive satellite techniques that examine the same parcels of land in one time versus another. In one 2000 paper, for example, the authors used satellite images of the State of Maranhão in Brazil to examine both new deforestation and the reforestation of previously cleared lands from 1978 to 1998 (Houghton 2000). The authors found that reforestation occurred at two thirds the rate of deforestation from 1978-1998. The bookkeeping approach would implicitly assume one third the rate of deforestation from 1978 to 1998 in Maranhão and multiply that area by likely carbon losses while the emissions from new deforestation in this period, even after subtracting the regrowth on abandoned lands, was probably much higher.

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<sup>2</sup> The language can be confusing. Pan (2011), which is primarily a bookkeeping approach, in some parts of the paper (e.g., Fig. 1) identifies tropical gross deforestation and tropical regrowth separately. But the term “gross deforestation” is not a true gross. The gross deforestation is based on national (or semi-regional) estimates of net deforestation in any specific period. Table S2 actually shows that no attempt can be made in tropical regions to separately identify afforestation and deforestation, unlike in the temperate zones. Even in the temperate zones, however, it is not clear how countries have identified afforestation and deforestation as this author is not aware of comprehensive, statistically valid plot change studies across the reporting countries that can separately identify gross deforestation and gross afforestation or reforestation. Most likely, these countries have partial information on areas of afforestation or reforestation and report these figures to FAO.

As satellite products improve, true gross studies of forest change are only now occurring at scale and some new studies will be published soon. In some regions, gross deforestation does not appear to be higher than net deforestation, but in other regions, and therefore globally, there is a large distinction. The implication is that as agriculture expands in some parts of the tropics, it is causing more deforestation and higher net emissions than presently estimated.



2. *Netting diverts attention from forestry as a source of land use change emissions.* Logging is a massive economic activity that reduces carbon stocks, and because of that, many people find claims that emissions from land use change are almost entirely assignable to agricultural conversion implausible. Others believe that the term “land use change” as used by the IPCC and others refers only to changes from forest to another use, such as agriculture, and just does not apply to logging activities that allow forests to grow back. In fact, as the IPCC has used the term, land use change does include emissions from logging and the bookkeeping estimates account for them. (Houghton 2010) (Hurt 2006). The first intuition is also correct that logging emissions matter. But these approaches have not overestimated the role of agricultural conversion; they have downplayed logging emissions.

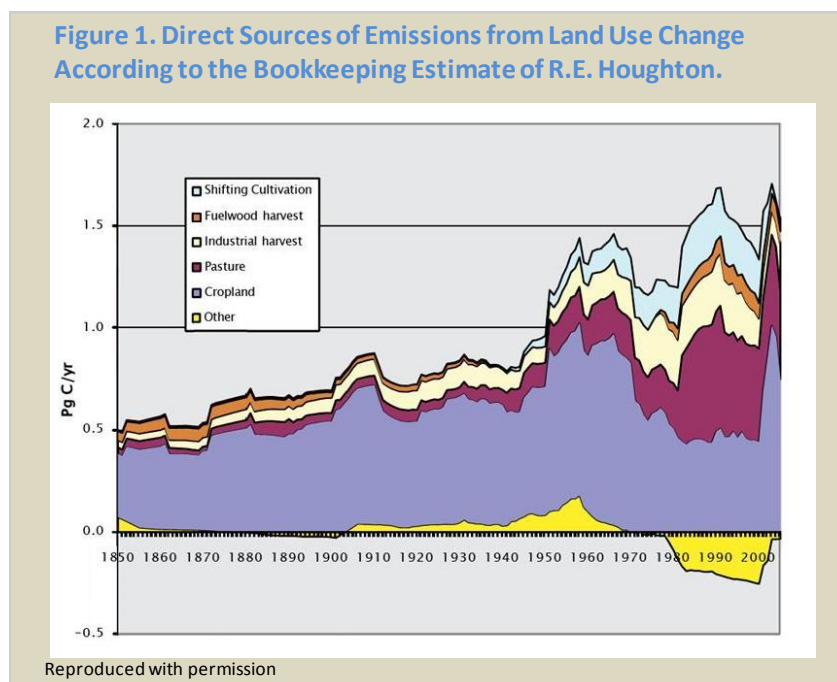
Logging emissions are downplayed because the traditional accounting treats them as partially or almost fully canceled out by the carbon accumulating in forests re-growing from prior logging. This netting approach explains why logging shows up only modestly in Houghton's estimates of emissions of land use change, as Figure 1 shows, and why logging emissions are in turn all but ignored by secondary reports, such as those of the IPCC. An alternative approach would report not only land conversion but also logging as sources of emissions, with logging adding well over 1 gigaton (deB Richter 2011; Houghton 2010). The carbon gains in forests re-growing from past logging would continue to count, but they would fall into the category of the larger "residual" carbon sink: today, only that portion of re-growth that exceeds the logging harvest elsewhere in a region becomes part of this sink. The present netting approach has policy significance because it obscures the potential significance of timber demand. The netting approach would make no difference if all the world's forests were one carefully managed plantation, so that harvest and regrowth were always balanced. However, the world's previously harvested forests will continue to re-grow regardless of whether logging continues now or in the future. Reductions in logging now and the future therefore can reduce a source of emissions without reducing this sink in re-

growth from prior logging and would therefore result in more carbon storage. Logging today will increase forest re-growth in the future – in other words, much of that carbon will grow back -- but more logging today and in the future will still lead to reductions in carbon storage for many years.

Wood removals both to industrial logging and local fuelwood appear to be growing gradually according to FAO data (FAO 2010), and are projected to grow substantially as populations grow and become wealthier (Smith 2010). Logging demand therefore merits additional focus.

### 3. Netting diverts attention from land use change in developed and transitional countries.

Developed countries alter land uses in ways that release emissions both through shifts in cropping areas that result in new deforestation or plowing up of grassland and sometimes through heavy logging. In China, Japan, South Korea and India, expansion of plantation forests may be masking substantial deforestation elsewhere (Zhao *et al.*, 2006) (Houghton, 2005). A recent satellite analysis found that temperate and boreal forests provided slightly more than half of the areas of global forest cover loss from 2000 to 2005 (Hansen 2010). The three countries experiencing the largest global forest cover loss were Canada, Russia and the United States, which lost 44 million hectares of forest,





while Brazil, Indonesia and the Democratic Republic of the Congo, the epicenters of tropical deforestation, together lost 23 million hectares. Natural fires cause some of these temperate losses, but logging and land conversion cause others.

Because of netting, however, global analyses do not point to these countries as a source of emissions. Many efforts to reduce land demands might result not only in reduced deforestation in tropical countries but reduced gross forest losses in developed countries, and both would contribute to carbon gains.

**4. Netting diverts attention from actions that reduce the forest carbon sink.** Land use activities that reduce regional net sinks anywhere in the world contribute to global warming ton for ton just the same as activities that contribute to regional net carbon emissions. Land use demands that keep agricultural land in agricultural use, instead of allowing these lands to reforest or in other cases to reestablish grasslands, will therefore also adversely affect global warming even if they do not cause additional land conversion.

Some of these netting effects are the result merely of the convention in how gross changes that increase and decrease land-based carbon are netted against each other. Others represent data limitations that can only be addressed by improved analyses using satellite photographs. Regardless of the source of the convention, it has the effect of underestimating the role of land use demands in reducing the terrestrial carbon sink, whether those demands are for agricultural products or wood, and

therefore underestimating the potential benefits from addressing those demands.

### C. Forest protection strategies that do not address agricultural demand will expose wetlands and savannas

One obvious reason forest protection efforts alone can probably not provide a solution to emissions from land use change is that agriculture can expand into wetlands and savannas, and these lands have great value too for both carbon and biodiversity.

Wetlands are the most acutely under-emphasized land use category. Only recently have global land estimates begun to add in emissions for any category of wetlands and those estimates are limited to the drained, carbon-rich peatlands of Indonesia and Malaysia. Peatlands, like other wetlands, build and preserve soil carbon because of their waterlogged conditions, and draining them releases much of this carbon either to general oxidation or through fires. The peatlands of Southeast Asia have the richest carbon deposits of any wetlands in the world, and can be meters thick. Their enormous fires in 1997 galvanized world attention, and the rapid expansion of palm plantations on drained peatlands continues to increase their emissions. One recent summary of the literature estimated that draining these peatlands on average gives off more than 86 tons of carbon dioxide equivalent per hectare per year for fifty years, an astonishing 4,300 tons per hectare in total (Page 2011). Estimates on the order of another 0.3 gigatons per year of carbon equivalent (Canadell 2007; Mahli 2010) for this region's peatlands, based on modestly lower per hectare estimates, constitute perhaps 20% of the global emissions from land use change and are probably conservative.

Global carbon estimates do not now include any other emissions from wetland drainage. Wetlands have provided much of the temperate world's best cropland because they occur in wet places whose excess water may be well-controlled by drainage and because high soil carbon creates excellent growing conditions. A recent World Bank paper, one of the few papers to focus attention on carbon from wetland drainage, calculated that net emissions from drainage of 14 deltas since human alteration have reached 3.5 gigatons of carbon, and

the drainage of 3.5 million hectares of mangrove wetlands from 1980 to 2005 will eventually result in the release of 1.5 gigatons of carbon (Crooks 2011).

Wetland drainage outside of Southeast Asia may be receiving little attention because agricultural conversion in Latin America and Africa to date does not appear to rely heavily on wetlands, which though productive are often expensive to drain. Yet Latin America and sub-Saharan Africa are both filled with wetlands, these regions are providing most of the world's new cropland, and there are reasons to believe wetlands will become a larger focus. Ethiopia has granted virtually a no-cost agricultural, rapidly exploited concession to three hundred thousand hectares of wetlands in an area previously thought of as part of the Gambela National Park, home to a migration of millions of white eared kob antelope (Pearce 2010). Kenya has begun to provide concessions for bioenergy development in its Tana Delta, another vast wetland area with enormous wildlife value. Although Africa has hundreds of millions of hectares of potential cropland, high rainfall variability provides a great barrier. Because wetlands tend to receive water in addition to their rainfall from surrounding runoff or groundwater, and their high carbon soils hold water longer, they could prove highly attractive for foreign investment in Africa.

Wetter savannas provide the other principal source of new agricultural land, which as a result of much of Brazil's *cerrado* conversion, now exist primarily in Africa. Besides the loss of biodiversity,

their conversion to cropland involves a substantial carbon loss, on the order of 50 to 100 tons of carbon per hectare (Gibbs 2008). To world modelers and planners, savannas sometimes appear as free land. One World Bank report calls for "Awakening the Sleeping Giant," which is a call to convert much of Africa's savannas to help feed the world (Byerlee 2008). One oft-cited Dutch analysis of world bioenergy potential excludes forests as environmentally unsound, and focuses instead on world savannas, many in Africa, without calculating the associated carbon costs of converting them for bioenergy production (Hoogwijk 2005). To show the potential significance, a separate, world analysis from the Potsdam Institute calculated the time it would take bioenergy crops to pay back the releases of carbon from the conversion, and most of these African savanna areas failed its ten-year payback test (Beringer 2011).

If world climate efforts focus only on forest protection, they could not merely ignore these other conversions but could even encourage them, as wetlands and savannas become the sole source of new lands for agriculture and forestry. Both carbon and wildlife impacts would remain large. These concerns motivated the thinking behind the U.K. government's Foresight Report on food challenges, to call for producing the future food and forest supplies not just without converting new forests but to concentrate on the existing footprint.



Leonardo F. Freitas

## II. The Importance of Boosting Yields and Limiting Bioenergy to Feeding the World by 2050 Without Further Land Use Change

Part of the relationship between agricultural demand and land use change is political. Political leaders, as they should, care deeply about supplying food, and even the most despotic leaders recognize that food shortages are threats to their rule. One obvious reason yield gains are important to protecting forests is that the world is unlikely to protect forests and other carbon rich lands if it cannot or will not meet food demands without using them. Analyzing the challenge of feeding the world by 2050 indicates that holding down agricultural land expansion is a credible goal but will require hard work to boost yields while also revising government expectations for bioenergy.

### A. Scenarios for Increases in the Agricultural Land Base to Meet World Food Demands By 2050

The FAO has estimated that the world needs to produce 70% more food to meet demand by 2050. That is based on a target of food availability of 3130 calories per person as a world average and a 76% increase in meat consumption per capita to meet a population of 9.1 billion (Bruinsma 2009). Food availability means the food available in the country per person, not what each person actually consumes, and a significant excess over actual consumption is needed to feed people properly. Today, food availability in Europe equals roughly 3,500 calories per person, in China roughly 3,100 calories, but in sub-Saharan Africa only 2,250 (IIASA 2011). The FAO estimate assumes that food availability almost everywhere in the world rises to 3000 calories or more, and improves in sub-Saharan Africa, but only to 2,740 calories outside of Nigeria. The United Nations population office has since revised its mid-range estimate for world population to 9.27 billion (UN 2011), and that should raise the FAO estimate of needed food increase to roughly 75%.

Can the world generate this food without expanding agricultural land? Even if technically possible, what is actually likely to happen? Modeling studies tend to focus on the second question, which to some extent makes them less useful. Studies summarized in Smith (2010) estimate increases in cropland that range from 6% to more than 30%, with some studies projecting large increases in grazing land and some projecting stable grazing lands or even declines. Unfortunately, the huge array of uncertain assumptions about developments in consumption, technology, government policies and the economic behavior of agriculture producers built into these models make it difficult to determine how outcomes are driven by different assumptions or would change because of discrete changes in policy. Because most of the models build in some increased biofuel demand, it is also hard to use the models to focus discretely on the challenges of meeting food needs.

The International Institute for Applied Systems Analysis (IIASA) has been continuing to develop its “GLOBIOM” model (the model has been described in Havlik et al. 2010), has generated a wide variety of scenarios in turn optimistic and pessimistic, and has made them available for analysis. The scenario that appears closest to a business as usual scenario similar to one developed by the FAO assumes crop yield gains consistent with historical rates, no increases in bioenergy beyond 2010 levels, constant livestock systems, and no new REDD restrictions on land use change. Under this scenario, GLOBIOM estimates a net increase of 266 million hectares of cropland by 2050 and an increase in grasslands of 121 million hectares. It also estimates a 348 million hectare decline in “unmanaged forest,” and a 168 million hectare decline of “other natural vegetation,” although a rise in plantation forest of 103 million hectares is forecast. These figures translate into net annual declines of 6 million

hectares of forest, and 4 million hectares of other natural vegetation. This model suggests no let up in agricultural pressures for land conversion.

In 2009, the FAO took a somewhat different approach and compiled an estimate on a country-specific basis, based on expert projections from available data, that FAO then aggregated for the world as a whole (Bruinsma 2009). The basic approach reasoned that farmers will find a way to meet projected food demand by providing roughly the same percentage of regional food needs as they now supply, with some deviations. In land-constrained areas, farmers will do so exclusively by increasing yields and by planting croplands more frequently, and in areas with more land, they will also use more of it. The FAO cropland projection is more optimistic than the outcome of pessimistic scenario of GLOBIOM. FAO projects an increase in cropland of only 120 million hectares in the tropics, offset by a 50 million hectare decline in temperate areas. This projection does not offer any specific projection for grazing land.

At a global level, the FAO projections seem within the range of plausible results. World crop yields have grown mostly linearly, with each hectare producing a certain additional number of kilograms more each year on average. (That is why discussion

of crop yields based on percentage compound growth, such as a 1 to 3 percent per year, is rarely helpful – the percentage growth rate decreases over time as the total level of production increases).

Table 1 shows that as a whole, to meet the FAO projections, world cereal yields have to grow in the next 44 year period at rates that vary from 48% for maize to 64% for wheat (growing at 23 kilograms per hectare per year compared to 36 kilograms per hectare per year.) The rice yield gain is adequate to avoid net rice expansion, with maize growth of 35 million hectares and wheat growth of 18 million hectares. However, only modestly higher yield growth on a worldwide basis would be necessary to achieve no net expansion for cereals. Soybean yield growth projections are more ambitious at 119% of former growth rates, and even so, soybeans need 6 million more hectares. In addition, the cropping intensity (the ratio of harvests to arable land in use) must also grow from 87% to 93%. That provides an effective increase in area harvested of 93 million hectares, which is a larger increase than the net increase in cropland, and is therefore vital to these modest estimates. Irrigation must also continue to grow, but at roughly one fifth the rate of the previous 44 years (an additional 31 million hectares in total).



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**Table 1: Yield Growth Projected by FAO and Yield Growth Needed to Avoid Net Cropland Expansion.**

Crop or Crop Category	Annual Yield Growth to 1961/63 to 2005/07 (kg/h/y)	FAO Projected Increases 2005/07 to 2050 (kg/ha/y)	FAO Projected Growth Compared to Past Growth Rate	Growth Rate Needed to Avoid Any Cropland Expansion	Growth Rate Needed to Avoid Cropland Expansion Compared to Past Growth Rate
Wheat	36	23	64%	33	93%
Rice	48	27	56%	21	43%
Maize	62	30	48%	72	116%
Barley	23	18	78%	20	89%
All Cereals	42	25	60%	27	65%
Soybeans	26	31	119%	71	275%
Pulses	6	10	167%	9	146%

Searchinger/Heimlich from FAOStat and Bruinsma (2009)



At first glance, these projections seem modest or even conservative. Indeed, growth rates for cereals at three quarters of previous growth rates would be adequate to eliminate net expansion for cereals completely. Yet there are strong reasons that yield growth rates will be lower, which help to explain FAO's thinking.

- Since roughly 1990, growth rates for rice and wheat in the highest producing areas have flattened, in particular rice in China and Korea, and wheat in northern Europe (Cassman 2011). Top yields on test plots are also stagnating for wheat and rice. Optimists can point to remaining yield gaps based on comparisons of average yields to top yields in scientific trial plots, so better field management can improve yields, but the real world pattern is disturbing. Cassman argues that there is an economic threshold of 80% of potential yields, due in part to such factors as the luck of whether the weather in a particular year accommodates decisions such as planting dates, and that could hold down future growth rates in high yield regions (Lobell 2010). Both yield growth and cropping intensity in previous decades have benefited from enormous growth in irrigation, particularly in developing countries, increasing by more than 150 million hectares. Worldwide, FAO estimates that irrigated land provides 42% of all food production, but in developing countries that percentage is 47% of all crops, and 59% of cereals (Bruinsma 2009). The

increase in irrigation has been a larger driver in world yield growth as yields on irrigated land are much higher than those of rainfed cropland. One study estimates that without irrigation, cereal production would decrease globally by 20% (Siebert 2009). Unfortunately, most of the World's major regions of irrigation, including those in China, India and the U.S., are already over-tapped. FAO therefore has sound reasons to project slower rates of irrigation growth, with resulting implications for yield growth rates. And just as irrigation in the past has come at high environmental cost, so will any increases in the future.

- Perhaps the biggest reason for reduced growth estimates results from projected shifts in agricultural production from temperate zones into the tropics and sub-tropics, which have been much lower yielding areas. The biggest growth in population and food demand is likely to come from sub-Saharan Africa, which is projected by the UN to experience a population increase of 230%. This region has the world's lowest cereal yields, only slightly more than 1 ton per hectare, compared to average world yields of 3.4 tons per hectare in 2010 (FAOStat). Even if yields grow in this area in the future, producing more of the world's food in lower yielding areas implies lower world yields. In fact, the biggest difference between the FAO scenario and the GLOBIOM "baseline" projections involves the amount of additional cropland in Africa.

The FAO did not explicitly consider two additional major sources of concern. One involves potential declines in irrigated areas that are already using water unsustainably. These include the North China Plain, the Indo-Gangetic Plains, and the Great Plains of the U.S., all of which overdraft their aquifers. A related concern is already over-drafted rivers that could face additional shortages due to climate change, including the Colorado and Indus rivers, and major rivers of China (Zongxue 2010; Gleick 2008). Although many papers discuss these challenges, there is not yet a convincing quantitative analysis of the extent to which these overdrafts of water pose threats to future food supplies. Much may depend on whether any crisis can be postponed until the second half of the 21<sup>st</sup> century, when stable or declining populations should make it easier to compensate with increased food production in other parts of the world.

The FAO analysis also did not explicitly take account of climate change. Climate change impacts on food supplies are uncertain and much debated, with general predictions, for moderate warming, of increased hardship in developing countries potentially balanced out by improved food production in northern temperate areas. Greater warming implies net harmful impacts. In general, however, more recent studies tend to show more pessimistic results, particularly from the direct effects of temperature (Searchinger 2011). Unfortunately, Africa again receives the most pessimistic prognosis despite having the greatest food needs. Impacts from changed rainfall patterns are the most uncertain and also potentially the most dramatic.

Overall, the FAO analysis used expert judgment to weigh most of the key factors, and its judgment is entitled to considerable respect. If the FAO analysis is correct, cropland in developing countries will grow at roughly half the recent rate over the next several decades, with net land expansion in developing countries at an estimated rate of 2.67 million hectares per year. On an overall basis that seems encouraging, but not wildly so, particularly because valid cases could be made for somewhat greater optimism and much greater pessimism. The more pessimistic GLOBIOM “baseline” estimate is also reasonable. One obvious implication is that yield growth in both the cropping and livestock



sectors should matter to those who wish to protect forests.

## B. The particular link of deforestation hotspots to agricultural demand

Whatever the global figures, the hotspots of deforestation show why increases in agricultural yield are necessary to protect forests in the future.

*Sub-Saharan Africa:* The population of Sub-Saharan Africa is projected to increase by 230% by 2050, and the Africans already are the world’s hungriest people with only 2,455 calories per person per day available from domestic production. Without yield gains, simply supplying the region’s people the same inadequate level of food as the population grows, while continuing to import a quarter of all consumed grain, would require cropland devoted to the region’s own food production to increase 123 percent -- from 154 million hectares to 357 million hectares (see Table 2).<sup>3</sup> The figure is even larger if Africans were to produce all their own food and to meet the FAO’s optimistic consumption estimates for them in 2050 of 2,830 calories per person, including a modest increase in meat consumption. In that case, at present yields, they would need 488 million hectares (an increase of 334 million, or 317 percent). These figures assume no growth in the use of land for exports of Africa’s high value agricultural products such as coffee, rubber and vegetables, and assume that the milk and meat now generated from grazing lands would rise proportionately with the rise in population without any expansion of grazing land.

<sup>3</sup> These calculations use food consumption balance sheets generated for Africa by FAO for 2007, and subtract North African data, <http://faostat.fao.org/site/368/default.aspx#ancor> and are explained in Searchinger 2011.

**Table 2: Yields and Cropland Needs in Sub-Saharan Africa**

	Current	2050-Current consumption Imports (2,306 kcal/person/day) & current reliance on imports	2050-FAO projection of food consumption (2,830 kcal/person/day) & self-sufficient regional production
Cropland needed at current yields for domestic food consumption (hectares)	<b>154 million</b>	<b>357 million</b>	<b>488 million</b>
Cereal yield needed to avoid new land clearing	<b>1.23 t/ha</b>	<b>2.81 t/ha</b>	<b>4.33 t/ha</b>

Searchinger/Heimlich 2011, using FAOSTAT

Flipping the numbers, one can ask how much yields would have to grow in the region to produce these levels of food without expanding cropland. Merely to maintain today’s insufficient food consumption level, yields for all food crops would have to grow 230 percent. To meet FAO’s projected level of food consumption without relying on imports—still well below the food level for transitional countries<sup>4</sup>—cereal yields would have to grow 350 percent to 4.33 tons per hectare.<sup>5</sup> Achieving the yield gains necessary to achieve the FAO food projections without adding cropland is a daunting task. For example, cereal yields on average would have to rise by an additional 72 kilograms per hectare each year, which is far higher than world average growth rates. From 1961 to 2006 China achieved an even higher growth rate of 90 additional kilograms per hectare per year, and China started from similar yields to those in Africa today. Yet cropland in China is mostly much wetter and otherwise superior, and now receives the world’s largest amounts of fertilizer, and otherwise receives its most intense management.

The FAO analysis projects cropland in sub-Saharan Africa will increase by “only” 74 million hectares, which means that more than two thirds of

<sup>4</sup> As of 2003-05, per capita, daily calorie availability in high income countries was 3,460 and 3045 in transition countries (Foresight Report 2010).

<sup>5</sup> The percentage increases of total cropland area versus cereal yield growth differ because total cropland increased reported refer to cropland for all crops, while yield gains (and land gains) needed for cereals alone are greater because of an increased proportion of cereals in the diet projected by FAO.

the new food production will result from increasing yields. Under the low-tech. scenario, the GLOBIOM model projects an increase of 182.5 million hectares (plus 29 million hectares of pasture), which means that roughly half of new food production would result from increasing yields. These different estimates essentially explain the difference between the GLOBIOM and FAO estimates at the global level, and it is unclear who is more likely right. If the GLOBIOM estimate is right, African land conversion might release more than 1.5 gigatons of carbon dioxide per year.<sup>6</sup>

These figures suggest that yield gains are critical to protect natural lands in Africa but also that continued land clearing in Africa at some level is inevitable. That in turn suggests the importance of identifying the best lands for agricultural expansion. From an environmental standpoint, those would be lands that combine high yield potential with low carbon and biodiversity. A World Bank study in a way purported to determine this by identifying all the wetter savannas of Africa as belonging in this category (World Bank 2008), but

<sup>6</sup> Gibbs (2008) op cit. estimates above ground carbon for seasonal and humid forests and savannas in Africa at 51 to 204 tons per hectare depending on whether the lands are shrub or forest, disturbed or undisturbed, with potential soil conversion losses of 10 to 19 tons/hectare, assuming that conversion loses 25% of soil carbon. At an average carbon loss rate of 100 tons/hectare, the conversion of 334 million hectares over 40 years would generate 835million tons of carbon losses per year, or 3,062 million tons of carbon dioxide, i.e., 3.06 gigatons.

this study did not consider the carbon and biodiversity values of these lands. They include wetlands and many lands that are better categorized as forest. It also treated savannas as fundamentally expendable. A more subtle analysis should evaluate where the most food can be produced at the lowest carbon and biodiversity costs, and where doing so is practicable and socially desirable.

**Latin American Conversion for Pasture:** Even if models that predict little net increase in pasture prove correct, that may be of little consolation for forests. World pasture area is an immense figure estimated sometimes as high as 4 billion hectares with enormous variation between dry and wet areas. Latin American rainforests receive high rainfall and are relatively productive. Even when Brazilians speak about “low productivity pasture” that supports only one cow per hectare, that is still orders of magnitude higher than the cattle densities in the western United States, and well managed Brazilian pastures can provide several times the forage supply as poorly managed pastures. Although supply factors play a role in pasture expansion, such as road-building, so does the demand and price for beef and milk (Barona 2010; Barreto 2011).

There is nothing in the various modeling projections that provides any reason to believe conversion rates will not remain high in this region absent effective new government policies. Even as pork and chicken claim the lion’s share of new livestock demand, beef and dairy will also expand substantially. Fortunately, the Brazilians and Costa Ricans have demonstrated enormous potential to boost pasture output and livestock yields through better management of their pastures. For reasons discussed below, boosting yields alone may not protect forests, but the opportunities to meet domestic and export food demands through more intensive management will probably play a critical role in persuading governments and private businesses to support forest protection.

**Oil Palm in Southeast Asia:** The world has a voracious and growing appetite for vegetable oil, which is being supplied primarily by expansion of palm oil and soybean oil production. Palm oil is the cheaper way of providing vegetable oil alone, but

soybeans also produce a high protein animal feed. Assuming that soy oil retains its world share, and oil palm supplies the rest, and assuming growth in palm oil yields at existing rates, one study estimates palm oil area will roughly double by 2050 (Corley 2008). That means 12 million more hectares. This figure assumes no expansion for biodiesel and allows for other industrial uses to grow, but only at their present percentage of 17% of vegetable oil use (even though their share has been rising).

As of 2008, 86% of palm oil production occurred in Indonesia and Malaysia (Donough 2009). Not only does much of the expansion displace dense rainforest, but the percentage of palm oil expansion occurring on peatlands has steadily expanded (Marelli 2010). Because already converted peatlands will continue to decay, that implies steadily rising peat emissions.

The economics of oil palm-driven forest conversion are strong, but there is also substantial potential to meet palm oil demand without this conversion. Studies have estimated that palm oil could be produced from as much as 8 million hectares of former forest in the region now overrun by imperata grasses, which burn frequently and therefore do not sequester large quantities of carbon. Even with present technology, oil palm plantations would appear capable of generating yields far higher than the 5.2 t/ha assumed by Corley for his estimate of 12 million hectares of needed palm oil plantations by 2050 (Donough 2009). Both yield gains and directing new production into imperata grasslands would appear to be critical components of any strategy to save the region’s rainforests and peatlands.



### C. The Implications of Bioenergy

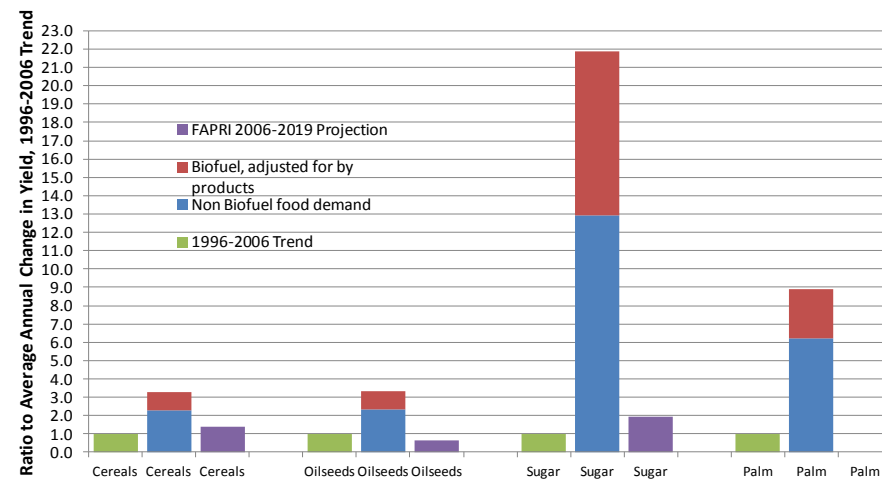
The challenge of meeting food/feed/fiber demands without continued land use change has been discussed so far by most commentators without reference to bioenergy. World government policies at this time, whether in the form of mandates, subsidies or other goals, seek roughly a 10% goal for biofuels in ground transportation fuels. Some estimates of the land needed to generate such fuels are as high as 200 or 300 million hectares. But these estimates for the most part ignore the fact that many biofuel feedstocks are produced along with by-products, which provide food and feed as well as energy. An OECD estimate of needed land from 2008 translates into 65 million hectares in high yield regions for the production of about 2% of world energy. The study deducts land attributable to by-products, and assumes a mix of biofuels comparable to the mix today (Searchinger 2009a).

Models sometimes estimate that biofuels production lead to less crop expansion than the estimates above, but that is only because they estimate other consequences of biofuels that are themselves problematic. For example, an analysis by Gunther Fischer for FAO estimates that an 8% biofuel goal from crop-based biofuels will lead to only 30 million more hectares of cropland (Fisher 2009); but it also estimates that roughly one third of

grain diverted to bioenergy will not be replaced because higher prices reduce demand. Obviously, the less food replaced, the less land use change. Other models that estimate relatively low land responses to ethanol make similar predictions, including the model used by the California Air Resources Board (Marelli 2011). One econometric estimate also implies that roughly one third of the calories in grains diverted to biofuels are not replaced in the short-term because of reduced food consumption (Roberts & Schlenker 2010). In the long run, as supply has a greater chance to respond, the reduction in food consumption is likely to be smaller and the increase in land area converted greater. If these models are accurate, however, that does not diminish the extent to which biofuels add to the competition for food and land; it means only that part of the result will be reduced food availability.

The Fischer model, like some others, also estimates a large yield response. The Berry papers discuss the limited empirical basis for these projections (Berry 2010; Berry 2011). Regardless, the capacity to boost yields is not unlimited. To the extent farmers boost yields in response to the higher prices generated by biofuels, world agriculture will find it yet harder to increase yields still more to meet food demands without new cropland. As shown in Figure 2, to meet the general

**Figure 2. Ratio of Major Crop Annual Growth Rates Needed to Meet Food and Projected Biofuels for 2020 at 10.3% of World Transport Fuels Without Cropland Expansion Compared to Trends and Projections**



Yield trends are based on world yield data from FAOSTAT for the years and crops in question. Projected biofuel crop demands are taken from an analysis by the consulting firm E4tech for the U.K. Renewable Fuels Agency projecting likely sources of biofuels to meet governmental biofuel targets in 2020 (E4tech 2008). FAPRI future yield projections are taken from FAPRI (2009). By-product adjustment for ethanol assumes that by-product distillers grains replace 35% of cereals diverted to ethanol, and soybean land demands are those solely to produce the vegetable oil generated by soybeans.

government targets of providing 10% of world transportation fuels through biofuels by 2020 without expansion of cropland, the yield growth rates of cereals and soybeans would have to roughly double, and the yield growth rates of sugarcane and oil palm would have to increase multi-fold.

Many papers treat the need for liquid biofuels in particular as a necessity because there are few alternative methods for reducing carbon emissions from transportation, and therefore it is a new demand that the world's land use will have to find a way to fit in. But this thinking is based on an accounting error, since, in fact, the capacity of biofuels to reduce greenhouse gas emissions depends precisely on their land use consequences (Searchinger 2009b). As explained in that paper, neither biofuels nor any other form of bioenergy reduces the carbon dioxide emitted from tailpipes and smokestacks. Bioenergy can reduce carbon in the air only by offsetting these emissions. Because plant growth absorbs carbon, some people believe that the growth of biomass automatically offsets emissions from burning the biomass. But like any other offset, bioenergy cannot take credit for plant growth that would occur anyway, thus counting this plant growth as an offset is double counting.

For bioenergy to reduce global warming through plant growth, it must result in additional plant growth. Alternatively, bioenergy can reduce greenhouse gas emissions by reducing other sources of emissions. For example, when bioenergy uses wastes or timber residues, it reduces emissions

from landfills and the forest floor as the biomass would otherwise decompose.

Virtually all of the large estimates of global warming reduction potential of bioenergy fail to focus only on additional plant growth or unused wastes, and instead double count biomass that would already grow or land that would otherwise supply food or sequester carbon.

- A 2001 IPCC report estimated massive bioenergy potential derived from planting bioenergy crops on unutilized, potential cropland, failing to recognize that much of what in this report was deemed to be potential cropland consists of the world's forests, wetter savannas and most productive grazing lands (Moomaw 2001).
- More recent estimates, including those of the International Energy Agency (Bauen 2009) and a new IPCC report (Chum 2011), focus heavily on the use of abandoned agricultural land, or the harvest of wood from forests that are adding biomass at rates in excess of timber production needs. These are precisely the lands whose growing carbon stocks are providing the world's terrestrial carbon sink (Pan 2011), and burning up that sink to produce energy cannot reduce global warming.
- Some studies estimate bioenergy potential from the world's woody savannas while ignoring their existing carbon storage (Hoogwijk 2005), while studies that count this carbon loss come up with much more restrictive results (Beringer 2011).



To produce bioenergy from dedicated plant production in a way that actually reduces carbon in the air, the best opportunities will be to use relatively unproductive land and make it highly productive. One way may be to grow plants like agave on dry land. Agave is reportedly capable of generating yields of 10 tons of dry matter per hectare per year even on land that receives only 200 to 400 millimeters of rainfall, and it has a high sugar content relatively easy to convert into ethanol (Yan, 2011). This land is mostly otherwise used for low intensity grazing, whose food production in absolute terms could probably be reasonably replaced on significantly less land, but taking advantage of this opportunity will require much progress in breeding and overcoming many other obstacles. Other opportunities would involve using degraded, well watered lands, like the imperata grasslands of Southeast Asia discussed below. But these lands also provide low-carbon opportunities for expanding agricultural land, and there are only so many hectares available.

The double counting of biomass has led to bioenergy plans that are grossly out of balance with the world's capacity to produce more biomass without sacrificing carbon storage or other human needs. The European Commission has required that its member countries supply 20% of their total energy use in 2020 from renewable sources, and a summary of national action plans projects that bioenergy will provide half of this renewable energy (Atanasiu 2010). In the United States, most states have adopted renewable energy standards or goals that require 10% to 30% of electricity production to come from renewable sources by similar dates, and bioenergy counts as a renewable source. There are various projections to supply 20% of world energy through bioenergy by 2050 (IEA 2008), and others with yet much larger estimates of bioenergy potential.



As of 2000, the total human harvest of plants for all purposes, including food, feed and fiber, generated roughly 230 exajoules of chemical energy (Haberl 2010).<sup>7</sup> Providing 20% of world energy by 2050 would require an additional 150 to 200 exajoules, almost a doubling of the total harvest of world plant material. These figures reflect the inefficiency of using land to generate usable energy. Producing even a small percentage of energy needs from bioenergy will significantly increase the challenge of feeding the world while protecting its forests and savannas. Attempting to provide a large proportion would make it quite unfeasible.



<sup>7</sup> Haberl (2010) uses the figure of 217 exajoules, but Haberl has subsequently estimated that this figure, which uses FAO wood harvest numbers, probably underestimates traditional wood fuel harvest, bringing the total up another perhaps 12 EJ (email communication by Haberl to author, March 7, 2011).

# III Does Boosting Yields Spare Land?

Although boosting yields appears necessary to save forests, how and when yield gains directly save forests is both controversial and complicated.

## A. The Basic Debate

By basic arithmetic, higher crop and pasture yields are necessary to provide more food without expanding agricultural area. To Norman Borlaug, the great plant breeder, this basic math made the Green Revolution one of the great environmental achievements of the century, and the land use conversion prevented by increased yields is referred to as “land sparing”. Using this kind of arithmetic, one recent study estimated that world yield gains since 1961 have prevented world cropland from more than doubling and saved 13 gigatons of carbon dioxide annually through 2005 (Burney 2010). Other papers have begun to calculate the implicit greenhouse gas savings from yield gains (Palm 2010).

Despite this basic arithmetic, economists and other researchers have questioned whether yield gains by themselves protect forests. A seminal 2001 book edited by Arid Angelsen and David Kaimowitz compiled case studies that described a wide range of different effects of intensification on tropical forests, with yield gains discouraging local deforestation in some cases and encouraging it in others. In a separate article, the authors summarized studies of whether pasture intensification saved forests, and concluded that in general it encouraged deforestation (Kaimowitz & Angelsen 2008). Rather than focusing on pasture intensification in general, they argued that policies should focus on limiting forest available for conversion and that would in turn encourage pasture intensification.

One paper in 2008 statistically analyzed the relationship on a country level between yield gains for staple croplands and agricultural land area per person and found only a weak relationship in developing countries and no relationship in developed countries (Ewer 2008). A 2009 paper found that yield gains did not spare land at the country level and declines in cropland except among countries with set-aside programs or

increasing reliance on imports (Rudel 2009). This paper also analyzed land sparing at the international level for individual crops, and found that yield gains spared land only for some crops.

Most of the individual papers brought together by Angelsen and Kaimowitz offer narratives of individual countries or regions and how forest area shrunk or increased in response to intensification of the agricultural systems over time. The overall thrust of the papers, and the conclusion of the authors, is that such a large number of factors influence the consequences of intensification on forests that it is difficult to determine if intensification will or will not spare forests. Yet, the factors raised can be grouped into a few important categories for discussion.<sup>8</sup>

*Alternative Sources of Land:* Some studies point out that even if yield gains spare land overall, they may not spare forests because some new forest areas may still be cleared, while other acres are left fallow.

*Capital Effects:* Some studies point out that when productivity increases, those who own farmland have more money and may be better able to invest in clearing more land. That is likely to be true although it is not clear if that results in larger amounts of clearing or simply changes the time of clearing.

*Socioeconomic Effects:* Some studies have alternatively claimed that productivity gains may be associated with consolidating farmland, which could displace small-scale farmers, who move into the forest, or alternatively, attract new migrants to crop areas near forest, and thus spur additional deforestation in that way (Matson 2006). Angelsen and Kaimowitz, in particular, have emphasized the displacement effect and have therefore encouraged labor-intensive forms of agriculture to avoid displacing farmers into the forest.

*Demand Effects:* The most important contention is that yield gains and other productivity gains lead to lower prices, which by then increasing demand, can actually lead to more food demand and therefore more land clearing. In a related effect, when cropland needs decline for basic

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<sup>8</sup> A good summary is provided by A. Angelsen (2010).



staples, farmers may use cropland for other crops, such as fruits and vegetables, or for non-food crops, such as rubber, which is really another way of suggesting that yield increases result in more overall production not less land use.

## B. Analyzing the Contentions – the Distinction Between Global and Local Land Sparing

At the detail level, each of the more recent papers on land sparing has limitations,<sup>9</sup> but the fundamental distinction the literature has in general failed to emphasize is the distinction between global and local land sparing.

At the global level, yield gains would only not spare land if they spurred consumption increases, by lowering prices, in the same percentage as they reduced demand for land by increasing yields. That is highly unlikely for two reasons. First, economists generally agree that the demand for food is relatively inelastic. A 1% decline in prices is therefore likely to stimulate less than a 1% increase in demand. Even if a 1% increase in yield resulted in

a 1% decline in price, demand for food would therefore increase by a lower percentage than the yield gain and overall land demand would decline. In addition, a 1% increase in yields is likely to result in far less than a 1% decline in prices because even a 1% decline in prices would only occur if land were the sole cost of producing crops.

In reality, the increase in aggregate demand for crops globally is likely to be much less than the increase in production. To determine the total demand response to lower prices, the relevant focus is on the total demand for crops not the demand for any one crop because of the substitutability of various commodities. That is rarely studied. Roberts and Schlenker (2010) estimated that a 10% decrease in the aggregate price of major commodity crops would result in less than a 1% increase in consumption. That result means that even if a 10% increase in yield resulted in a full 10% decrease in price, the total decrease in consumption would be less than 1%. Thus, when yields increase 10% and consumption only increases 1%, the net demand for land declines 9% and the opportunity for land sparing is theoretically possible.

One reason these effects may not be obvious is that a decrease in the price of a single commodity, like pineapples or palm oil, could cause a fairly large increase in demand for that crop as consumers shift from other crops, such as oranges or sunflower oil. In addition, productivity gains, such as through mechanization, could lower prices and increase demand without themselves increasing yields and therefore without sparing land.

Yet these other ways of boosting productivity and reducing prices raise an alternative question: If yield and productivity gains to some extent lower

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<sup>9</sup> The Ewer paper examined land sparing per capita, which controlled for population, but did nothing to control for other factors that would increase consumption within a country such as economic growth. In general, countries with large yield gains are also likely to have larger economic growth and therefore larger increases in consumption and demand for food. The Rudel paper defined land sparing as occurring only if the total cropland area declined in absolute terms. Because the world was experiencing large population and income growth during the 1990-2005 period analyzed, the world would likely have experienced large increases in cropland area in the absence of yield gains. The paper therefore mainly established that yield gains did not occur at a high enough level to reduce cropland area absolutely.

prices and increase consumption, is that bad? Unless land sparing is the only goal, the answer is no. So long as public goals also include decreasing hunger and increasing food available to a growing population, then the increase in consumption is also of value. Although some people may be tempted to think of expensive food as a good means of limiting agricultural impacts and curbing overconsumption by the world's affluent, expensive food at the wholesale level also has impacts on the world's poor.

Although yield gains will almost certainly spare land globally, in an integrated world agricultural market, there is no reason yield gains should spare land locally. Yield gains in one country will typically make its agricultural production more competitive and therefore more able to generate exports or more able to replace imports. As a result, although local production may be capable of meeting local demand with less land, agriculture in that country may still increase to help meet worldwide demand. That is particularly true if yield gains are associated with large-scale external sources of finance rather than through upgrading existing cropland. Even in the socially worst scenarios in which governments collude with landowners to displace traditional farmers and landholders, that is a messy process, and it is simpler for governments to provide large concessions for unclaimed land, such as forests and wetlands.

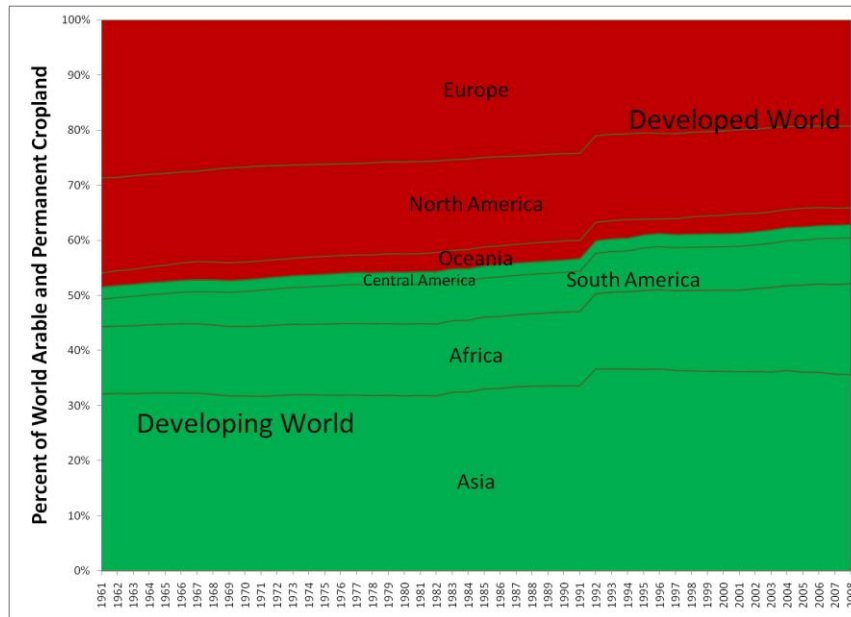
Much of the world yield gains since 1961 have occurred in developed countries, and at whatever

social cost to farmers in some developing countries, they have almost certainly helped to spare tropical forests. Yet the regions today associated with the greatest emissions from deforestation—Southeast Asia and Latin America—are precisely the regions where dramatic yield gains have led to growing export agriculture for soybeans, livestock products and palm oil, among other agricultural products. As developing nations have started to improve their agriculture, agricultural land has begun to shift more into the tropics (Figure 3). From 1990 to 2005, cropland continued to decline in Europe, North America and China, while it grew in Africa, Latin America and Indonesia (Foresight Report 2010). The FAO study projects that these shifts will continue.

These agriculture land shifts provide many economic benefits to tropical countries, but, from an environmental standpoint the shifts are a bad deal. Losing a hectare of mature forest in the tropics today sacrifices more biodiversity and more carbon storage than gained by allowing a hectare of temperate land to reforest. When measured as tons of carbon emitted from land use change per ton of food, the deal becomes even worse because yields in temperate zones are higher, and each hectare cleared and devoted to crops in the tropics releases on average roughly three-times the carbon per ton of crops as each hectare in the temperate world (West 2010).



Figure 3. Growing Percentage of Cropland in the Developing World



Source: Searchinger using data from FAOSTAT

If carbon were the only goal, world policymakers might try to keep tropical agriculture inefficient and make the southern hemisphere even more dependent on food imports from the north. But that would not be good for people and the economies of the tropics. Local food production provides more income and employment, is more reliable in countries without other strong export industries to generate foreign exchange, and helps keep food costs lower. Such a policy would of course also not be realistic. Even sub-Saharan Africa, the largest region of the world most dependent on food imports, produces 75% of its grain itself, and more than 90% of its food overall. The people should not have to suffer even greater import dependence.

Despite the benefits of becoming more food self-sufficient, the expansion of tropical agriculture runs the disturbing risk of altering the very conditions that make expansion possible. There is good reason to believe that tropical deforestation may have its own regional effects on climate change by altering albedo and water vapor levels. One study estimated that projected African deforestation would turn the rosiest world climate scenario for Africa into the equivalent of the worst

climate scenario because of those effects (Paeth 2010).

To save forests and feed people, yield gains in the developing world are vital, but the same yield gains can also contribute to deforestation. That creates an enormous challenge for climate policy and food security in tropical forest regions.



# IV A Path Forward

The comprehensive solutions to these inter-locking challenges are far from apparent, but some guiding principles and specific recommendations seem justifiable.



## A. One Guiding Central Policy – Maximize the Outputs of Land

For most of human history, land uses that did not produce harvestable plants were at most an indulgence and at worst a waste. The principle of the highest and best use of land focused just on those outputs that people harvested and used. But in an era of climate change, when carbon storage in vegetation and soils is a newly understood necessity, plant growth in all its forms is a value. Meeting our needs for more food/feed/fiber and more carbon storage therefore means taking best advantage of the characteristics of land that make it most productive for these purposes. This requires a broader definition of “highest and best use,” yet that should still be a guiding principle. (And into this mix, questions of water use, biodiversity and social considerations must obviously also play a vital role.)

This principle has concrete implications.

- High yielding production of food/feed/fiber or timber products can reduce the overall area devoted to furnishing products for human needs, thus making it more likely that land that is best for carbon storage can also be maintained through complementary policies.

That is why policies should focus on more productive use of all land, whatever its use – even land left for wildlife should be protected and enhanced as well as possible. That is also why taking land that is highly and efficiently used for food production and diverting it for bioenergy or for carbon sequestration is an idea that inherently makes little sense, and conversely why converting high carbon lands to food production is also a bad idea.

- Because of the value of immediate carbon storage, abandoned agricultural land that is merely building up sequestered carbon over time may be less valuable for carbon storage than a piece of mature forest that stores the carbon already. Nevertheless, the ongoing carbon sequestration from abandoned and/or degraded land is still valuable.
- Changes in land use do make sense from a carbon perspective when land can be used more efficiently in a new way than in its existing use. Secondary forest land that is now dominated by invasive, fire-prone grasses, for example, is not being used efficiently and could be more efficiently used for a purpose such as oil palm.

- The carbon efficiency of land use has to be judged against its likely outputs in its present or alternative use. To do that, there has to be a better way of comparing units of different kinds of foods, and comparing units of food with units of forest sequestration.

## B. Improvements to Carbon Accounting

The first step toward policies to address the demand side of land conversion is to correct errors and the resulting distortions in present international carbon accounting. Under the Kyoto Protocol today, the emissions from burning biomass for energy do not count toward a country's carbon limits regardless of the source of the biomass. That means in theory that cutting down a forest and turning it into a parking lot, and using the trees for bioenergy, counts as carbon neutral and a 100% reduction in carbon dioxide emissions when replacing fossil energy (Searchinger 2009). Biofuels generated by clearing forests and diverting crops from existing cropland also count as carbon neutral. The same accounting principle has been incorporated into Europe's directives on renewable energy and its emissions trading system, and is reflected in renewable energy policies worldwide.

This accounting error results from a misinterpretation of scientific guidance provided for national greenhouse gas reporting. In effect, that guidance recognized that when a tree is harvested for bioenergy, or when land use is changed for or as a result of bioenergy, the carbon lost from the land is counted in a land use account. As a result, that carbon does not have to be counted again when it goes up a smokestack or out an exhaust pipe. But this accounting system only works if the carbon emitted by land use and the carbon emitted by energy use are treated equally. Under the Kyoto Protocol and various national laws, carbon emitted by land use is only modestly limited in developed countries and not limited at all in developing countries; and most of the national laws on renewable energy or carbon emissions have the same fault. In effect, the flawed accounting makes forests worth more dead than alive, with huge potential consequences.

Forest accounting under the Kyoto Protocol also has other flaws. The essential problem is that countries whose forests are re-growing and gaining

carbon can, in effect, harvest wood, clear land and otherwise reduce or eliminate that carbon sink without consequences. In effect, the convention of netting land use change emissions against regrowing forests in the various papers on world land use change has carried over into law with perverse consequences. This is a harder problem to fix adequately because it is difficult to estimate what each country's future carbon sink will be; but the sensible approach would be that once any reference level is set, a country can either obtain a carbon benefit from each ton sequestered or incur a carbon cost for each ton removed from their sink.

Accounting principles drive behavior in dramatic ways, and fixing these errors is a first priority.

## C. Specific recommendations for Government Policies

*Hold Down Bioenergy and Other Additional Land Use Demands:* There may be abundant potential croplands in the world to meet food demands even if some of the worst predictions of climate change turn out to be true, but that is because there are abundant forests and other carbon-rich natural lands that are capable of producing good crop yields once converted (Bruinsma 2009). While there are reasons to believe it might be possible to produce adequate food on existing crop land, there are also strong reasons for caution and even pessimism. The mainstream estimate from FAO projects significant need for more cropland to maintain even existing—and for many parts of the world inadequate—consumption levels. By contrast, large scale production of bioenergy is a planetary game changer; and if bioenergy policies do not change, there is little chance of meeting the food and forest challenge.

*Pay Attention to Wetlands and Savannas:* Forests hold vast quantities of carbon and support abundant wildlife, but so do wetlands. Wetter savannas capable of supporting crops, which remain primarily in Africa, tend to have a little less of both, but that is only relative. REDD is focused now exclusively on forests (although the potential definitions are broad enough to reach many areas that could also be termed savannas). An exclusive

focus on forest protection would not only leave these other areas unprotected but could further encourage their conversion and exploitation.

*Safeguard the Terrestrial Carbon Sink and Therefore Pay Attention to Forestry and Land Use in the Whole World:* From a strict carbon perspective, preserving and enhancing the terrestrial carbon sink is ton for ton equivalent to reducing the emissions sources. That means that using otherwise abandoned agricultural lands is not carbon free. That also means that producing higher yields of food/feed/fiber on existing agricultural land in temperate regions has value, as it helps to maintain and enhance carbon sinks and enable the agricultural footprint to shrink.

The value of the global sink also calls for more attention to world forestry, which is causing short-term gross emissions from land use harvesting. Timber demands are growing at a rate of 1.4% per year (Smith 2010). Policy should focus on how to hold down these demands, and how to meet remaining timber demands most efficiently from a land carbon perspective. That presents a range of tricky questions in evaluating the carbon results of “sustainable forest management,” the trade-offs between reliance on plantations versus more harvesting of natural forests, the role of timber demand in preserving some forests, and the implications of time in carbon emissions and sinks.

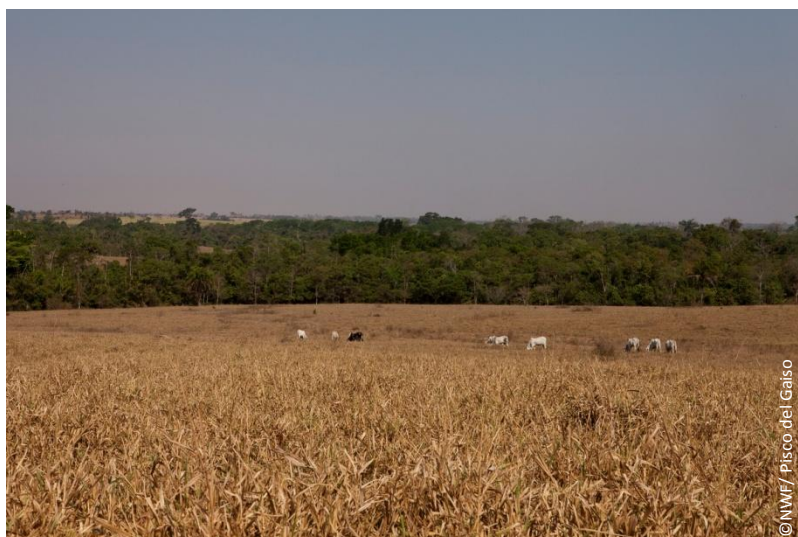
*Stop Pasture Expansion into Forests:* Although a transparent calculation is not yet available, it seems highly probable that the world’s growing

demand for milk and ruminant meat, could be plausibly supplied without any further expansion of pasture. Brazil is demonstrating enormous capacity to double or even triple forage production and livestock yield on its pastures. The feed supply for livestock in Africa already relies heavily on crop residues, which can be boosted and supplemented by agroforestry techniques.

*Focus on Africa:* Because of its high population growth rate, now inevitable because of its youthful population, and because of its existing hunger, Africa presents the greatest dilemma for the food forest challenge. Even if other continents could meet the whole world’s future food needs on existing agricultural land, the great bulk of that new food should still come from Africa itself. Yet Africans also need to protect their forests for their own reasons. Compared with Brazil and Southeast Asia, African forests receive less international attention, but it is the coming area of greatest conflict.

#### D. Policies to Help Yield Gains Spare Forests

It is possible to imagine systems of perfect governance and abundant outside resources that would both protect tropical forests and boost yields on existing land. High value agricultural opportunities will discourage countries from protecting their forests, but improved forest protection must be an overarching goal. A few thoughts on how to proceed:



**Focus Temperate Crops on Domestic and Regional Needs and Export Crops on Tropical Specialty Crops:** Tropical crops are already produced in the tropics, so yield gains are likely to reduce demand for tropical land overall. Temperate crops such as basic cereals, need to be produced in the tropics for food consumption too, but on balance, are not desirable to produce there for export. Multi-lateral investment strategies should operate accordingly and steer incentives away from such export-led development. This would mean focusing food and feed crop investments heavily on smaller and medium-sized farms, targeting research and development as well as extension efforts on boosting cereal yields from 1 to 3 tons/ha among more farmers rather than boosting yields from 3 to 7 tons/ha for a few farms, investing in proper local food processing and storage, and focusing export agriculture on tropical cash crops.

Such a vision accommodates the needs for both food/feed and export opportunities. Africa's specialty cash crops generate revenues that are valued three times higher than food imports, but use only twelve percent of Africa's existing cropland (Searchinger 2011). Their expansion generates more revenue per hectare than expansion of staple crops for export. Angelsen and Kaimowitz (2001) also point out that many tropical crops are labor intensive, so they help to accommodate the labor pool and therefore reduce deforestation attributable to migration of subsistence farmers.

**Infrastructure:** Infrastructure development to and through forests correlates closely with deforestation, but agricultural development depends on better transportation infrastructure. In Africa, that includes roads. Proposed continental road networks would put major roads directly through many of Africa's areas of intact forests containing high biodiversity (Buys 2006). To the extent practicable, road networks should be designed to avoid high carbon areas, and wide protected buffers and limits on secondary road development need to accompany the roads built through forests.

**Reduce Shifting Agriculture:** Shifting crop production in Africa plays a major role in agricultural production, such as in the Guinea Savannah region of western Africa as well as parts

of Southeast Asia. In these systems, each hectare of arable land in use therefore influences several more hectares of forest. Technically, these areas provide abundant opportunity for boosts in yields to preserve and enhance forests. They are among the primary areas in which yield gains may well preserve forests.



**Enhance Yields on Existing Cropland with Existing Farmers to the Extent Practicable:** This paper has emphasized that shifting agriculture leads to deforestation, whether from region to region or within regions, regardless even of net agricultural expansion. The relevant shifting agriculture is not limited to true swidden farmers practicing regular slash and burn rotations, but includes any land use changes that derive from degradation of existing land or from a broader range of shifts in infrastructure, agricultural technology and agricultural demands. Some shifts are inevitable and beneficial. And some shifts permit forest regrowth even as they may cause new deforestation. Even so, over reasonable time frames, shifts create additional emissions and impose additional costs to biodiversity. Governments need to work better together to understand where shifts are occurring, and their causes, and to determine when and how some should be discouraged. Agricultural development and intensification should focus heavily on making the best use of existing agricultural land.

**Integrate REDD with Agricultural Improvements:** One of the fundamental questions for REDD is who should receive compensation for forest protection. Under current proposals, payments seem likely to go from government to government, but inevitably, donor governments will

still care what happens to that money, and how it affects the actions of land holders. This discussion highlights the value of merging forest protection efforts and incentives with agricultural intensification and vice versa. The alternative is for yield intensification to lead to more deforestation and for local protection efforts to stimulate land use change elsewhere (leakage) or reduced food supplies.

*Identify and Intensify Use of the World's Underutilized Land:* The next best alternative to meeting all the world's food needs from existing agricultural land, is to increase the productivity of the world's otherwise most underutilized lands. Just producing modest amounts of food/feed/fiber on land that now holds modest carbon does not help. The key is to produce abundant food/feed/fiber on land that now holds little carbon, will sequester little carbon over the next couple of decades, and provides few other plant outputs.

*Use Brazil as a Special Case:* Brazil has already deforested as much as two hundred million hectares of land, and most is underutilized for pasture. This pasture is not as valueless as some think. Despite different climate and forage, stocking rates of one animal per hectare in Brazil still dwarf the stocking rates of the great cattle lands of the Western United States. An alternative to intensifying this land for agriculture, in theory, would be allowing it to reforest and sequester carbon. Yet, much of this land can produce crops abundantly, and Brazil is increasingly demonstrating



the capacity to intensify pasture management through a variety of creative methods. Brazil's massive strides in governance and overall development, its world-class agricultural research systems, and its large decreases in deforestation in recent years due to better enforcement of forest laws (Barreto 2010), imply that it can combine the governance and technology to serve as the world's growing food basket. Although these observations are broadly understood, the efforts in this direction should continue to be encouraged.

## E. Implications and Opportunities for Voluntary Certification and Food Roundtables

Even as government action on climate has lagged, private companies have moved to develop standards for agricultural production of some of the largest food commodities. Roundtables composed of food purchasers, producers and civil society groups have formed to establish standards for the major categories of agricultural production that have been contributing to deforestation, including soy, sugarcane, palm oil, biofuels and more recently beef. How can these efforts contribute to the solutions?

Perhaps the singular strength of these efforts is the close working relationship between the major processing and purchasing companies participating in the efforts and the farmers who supply them. This relationship gives them a capacity for collaborative action, including a capacity to work proactively, that governments can rarely imitate. Their limitation is that they inherently govern the behavior of only the better actors, and therefore only part of the market. Moreover, only a portion of new production for these commodities results from conversion of new agricultural land, while most of the world's current food production is on existing crop land which has been "grandfathered" by use of "cut-off dates" for defining recent deforestation. Thus many current producers are able to comply with even the toughest standards against land conversion for agricultural production, and they are able to sell into the "certified" supply chains, while leaving the production of commodities from land conversion to markets which don't impose such standards. Nevertheless, over time, these private efforts can work in conjunction with government

policies so that the standards ultimately influence the behavior of non-participants as well.

Much of the focus of these roundtables is reaching agreement on which lands should be off-limits for agricultural production. This effort is desirable and represents a form of forest supply control because it creates a penalty for forest conversion. The discussion in this paper suggests that roundtable and certification efforts could go beyond such supply controls and attempt to influence the demand for land conversion. The general policies recommended for governments can also animate voluntary private efforts; but there are two additional general standards that could be incorporated by food roundtables and individual companies:

*Land Standards Should Encourage Land Use Efficiency Taking Into Account All the Outputs of Land.* Barring the conversion of high-carbon lands only partially addresses the challenge of feeding the world while protecting forests. In light of consumption demands, each increment of higher production for the same or less carbon, and other environmental costs, is a positive good. For carbon purposes, ideally a food-output-to-carbon-cost standard would apply (with additional considerations for habitat values and biodiversity). Such an approach should recognize that loss of existing carbon stocks is not the only carbon cost. As the discussion of gross and net land use emissions above has tried to emphasize, foregone carbon sequestration is also a carbon cost. In addition, displacing other agricultural or timber outputs is a carbon cost, as they generally will and should be reproduced elsewhere. Roundtables can therefore not merely determine that some specific lands are off-limits but they can require that any new land conversion meet a certain ratio of output to carbon loss.

*Standards Should Encourage Improvement Not Just Discourage the Worst Practice.* This efficiency standard should be used for more than prohibition. It should encourage private companies to produce more on existing land. Companies could commit to achieve increasing levels of land use carbon efficiency over time by improving yields and supporting research and investment that leads to tangible gains in yields.

## Final Thoughts

No academic paper is complete without suggestions for further research. This paper has already suggested several useful products. One would be a far better and more specific analysis of underutilized land, particularly land in countries likely to experience agricultural expansion. In Africa, where agriculture will almost certainly have to expand into natural areas of some value, there needs to be on the ground, practical analyses of the best places for that expansion taking into account production and environmental impact.

A very different need is for an accounting system that allows a simpler way of comparing the different outputs of land, whether a yield of a certain crop or a level of carbon sequestration, to determine if the land resource is being efficiently employed in its present use. An improved index could provide a benchmark for decision-making by private food companies and roundtables.

Another useful product would build on the country-by-country analysis of likely land expansion and yield gains by the FAO, to establish benchmarks for the key parameters necessary to generate necessary food with little or no expansion into natural areas. Key factors include rates of yield growth and the types of crops grown, the types of livestock grown, their feeding efficiency and sources of feed, and pasture use efficiency. Appropriate lands for expansion should also be identified. These benchmarks can help drive specific agricultural assistance programs and influence other policies, and they can provide a means of assessing where progress is being made and where it is falling short. Such an analysis on a global level would also be useful. The key to its utility is transparency and relative simplicity, so that it is easy to understand how the key benchmarks fit together.

According to a wide variety of climate policy and economic assessments such as the Stern or Pew Reports, eliminating emissions from land use change, and in fact using land sequestration as a source of mitigation for other emissions, are supposed to be among the easier opportunities for climate change mitigation. The challenges laid out here cast doubt on that ease, but not on the need. Progress will require both commitment and a great deal of learning as we go.

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