The Root of the Matter

Carbon Sequestration in Forests and Peatlands

Dominick Spracklen, Gil Yaron, Tara Singh,
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policy exchange

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Executive Summary

In tackling climate change, policy makers often overlook the role of the natural world in regulating greenhouse gases in the atmosphere: specifically, the unique role that forests and peatlands have to play in the battle against rising emissions. Changing approach would significantly reduce the cost of tackling climate change and deliver a variety of other benefits.

As forests grow, carbon dioxide is taken out of the air. However, this carbon is released during deforestation. Similarly, peatlands have accumulated carbon from plant matter over millennia and when they dry out – often as a result of deforestation – release vast quantities of carbon. In other words, living forests and peatlands can sequester carbon emissions, whilst dying ones release previously stored carbon.

In this report, we argue that preventing deforestation, promoting afforestation/reforestation and stopping peatland destruction are some of the cheapest and most effective ways of reducing global greenhouse gas (GHG) emissions. We propose the introduction of market mechanisms that can ensure investment is directed into these areas and a strategy to make this happen as quickly as possible.

Every year the destruction of forests and peatlands generates more than the entire GHG emissions from the global transport sector or a similar amount to that emitted by the United States or China. Stopping their destruction can be done comparatively quickly and cheaply. The prevention of deforestation and peatland destruction requires no technological development and little capital investment. This method of reducing GHG emissions is dramatically cheaper than all other mitigation technologies currently available–as low as US$0.1 per tonne of CO_2. The table and graph overleaf set out the relative costs of the different mitigation options.

The economics is startling – if developed countries spent the same amount of money on preventing deforestation and the destruction of peatlands as they do on biofuel subsidies (US$15 billion), this would halve the total costs of tackling climate change. In addition to this, the protection of these habitats yields a plethora of valuable eco-system services, particularly in the poorest countries.

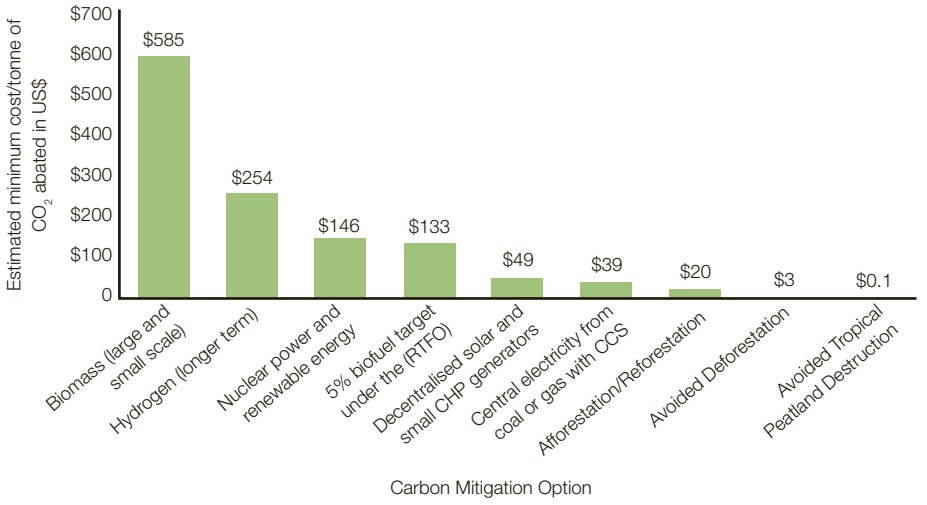
Yet current government policy places no value on protecting our forests and peatlands. The protection of these habitats is not included in the European Union's Emissions Trading Scheme (EU ETS) and is seriously neglected by the UN Kyoto Protocol. For example, only one forestry project has been approved by the Kyoto Protocol's Clean Development Mechanism (CDM).

In order to promote forest and peatland protection and policies such as afforestation and habitat restoration, the following policies should be introduced.

Policies the UK can introduce immediately:

1. *Abandon biofuel targets and subsidies.* Biofuel targets are responsible for the creation of price mechanisms that encourage biofuel crops to replace natural forests. This has led to an increase in both food prices and deforestation. This misjudged policy should be suspended until second-generation biofuels are tested and shown to provide net emission reductions without directly or indirectly causing deforestation. In the UK the 5% biofuel target under the Renewable Transport Fuel Obligation (RTFO) at £0.20 per litre will cost the

Figure 1: Cost comparison of carbon mitigation options[1]



Carbon Mitigation Option	Estimated minimum cost per tonne of CO_2 abated in US$	Estimated maximum cost per tonne of CO_2 abated in US$
Biomass (large and small scale)	$585	$644
Hydrogen (longer term)	$254	N/A
Nuclear power and renewable energy	$146	N/A
5% biofuel target under the Renewable Transport Fuel Obligation (RTFO)	$133	$292
Decentralised generation from solar and small CHP generators	$49	N/A
Central electricity from coal or gas with CCS	$39	$59
Afforestation/Reforestation	$20	$100
Avoided Deforestation	$3	$30
Avoided Tropical Peatland Destruction	$0.1	$4

Treasury £550 million annually in foregone revenue. The RTFO saves 2.6-3.0 $MtCO_2$/year, equivalent to only a tenth of the emissions of one UK power station and at a cost of £68-150 per tonne of CO_2.[2] A similar investment in preventing deforestation and peatland destruction could result in avoided emissions of 40-200 $MtCO_2$/year or a 50 times greater amount of avoided emissions. In 2005 alone, this would have offset the equivalent of up to 37% of all UK CO_2 emissions.

1 IPCC, 2007; Angus, F. et al, *Reducing Emissions from Peatland Deforestation and Degradation: Carbon Emission and Opportunity Costs, International Symposium and Workshop on Peatland Carbon-Climate – Human Interaction – Carbon pools, fire, mitigation, restoration, and wise use*, Yogyakarta, Indonesia, 27-31st August 2007; http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm; http://www.berr.gov.uk/files/file36782.pdf

2 http://www.opsi.gov.uk/si/si2007/em/uksiem_20073072_en.pdf

2. *Support immediate action to reduce peatland destruction in South-east Asia.*
   One of the lowest-hanging fruits of climate change mitigation are Indonesia's peat swamp forests, which contain millions of tonnes of carbon per sq km and where vast amounts of GHGs are now being released by logging, drainage and fire. Measures focused on illegal logging and canal building, and on blocking canals before swamps dry out, are among the best possible investments that can be made in avoiding GHG emissions.

3. *Build capacity in developing countries to prepare for avoided deforestation.*
   Avoided deforestation (AD) will be held back if developing countries do not have the capacity to support and monitor forest conservation. Government can contribute by helping developing countries to establish this capacity through financial support and technology, knowledge and experience transfer.

4. *Provide financial support to kick-start pilot avoided deforestation projects.*
   Large-scale pilot projects are urgently needed to inform policy development. The reduced deforestation that results would be profoundly beneficial and cost-effective. Government can help by contributing to the World Bank's Forest Carbon Partnership Facility, and by funding exemplary avoided deforestation projects such as the US$160 million Australian fund for reducing deforestation in South-east Asia.

Policies the UK can promote at European and international levels:

5. *Introduce forest carbon credits to give a realistic price for ecosystem services.*
   Current market failures mean that forest and peatland carbon services are undervalued relative to other uses. This can be corrected through a forest carbon market that recognises existing afforestation/reforestation credits, including those in developing countries and also avoided deforestation credits when they come on-line. The post-Kyoto climate policy and EU ETS should be developed/amended accordingly.

6. *Encourage immediate action to slow deforestation before 2012.*
   Every day of inaction results in further deforestation and the emission of GHGs with little benefit to the global economy and significant damage to the climate. Governments can help by developing clear long-term policies to encourage private sector-investment in avoided deforestation. Providing certainty that avoided deforestation credits will be recognized in future climate change mitigation policy will encourage the development of a pre-2012 market in Reduced Emissions from Deforestation and Degradation (REDD) credits.

7. *Recognise avoided deforestation in future international climate mitigation.*
   Avoided deforestation contributes 50-70% of the total forestry mitigation potential. However, it is excluded from the Kyoto Protocol and the EU ETS. Many challenges must be overcome before avoided deforestation can be integrated into future international climate change mitigation policy. Immediate targets are the 15th Conference of Parties meeting in Copenhagen in 2009, where substantial progress must be made if avoided deforestation is to commence in 2012 in time for a successor to Kyoto.

8. *Encourage development of the voluntary carbon/ecosystem services market.*
   The voluntary carbon market has huge potential and is already driving emission

reductions through forest restoration and avoided deforestation. Suitably encouraged and regulated it could help reduce deforestation immediately, years before avoided deforestation compliance mechanisms, such as an appropriately designed successor to Kyoto, are likely to be in place.

List of Terms

Anthropogenic – of human origin or caused by people.

Avoided deforestation (AD) – A loss of forest that is expected but does not occur, such as a loss that is less than that expected under 'business as usual' scenarios, and which could generate credits to reflect avoided carbon emissions.

Biomass - The amount of living material that exists in a particular area (usually expressed as kg per hectare or tonnes per sq km).

Biosphere – all parts of the Earth where life occurs, comprising the atmosphere, oceans, fresh waters, soils, and their underlying sediments and rock layers.

Carbon markets – A market that handles trade in carbon emission reduction credits and other carbon-related derivatives, thereby creating a price and ultimately an economic incentive for reducing carbon emissions.

Clean Development Mechanism (CDM) – An arrangement under the Kyoto Protocol that allows certain developed ('Annex I') countries to meet some of their emission reduction targets by investing in cheaper projects in developing countries as opposed to more expensive ones at home.

CO_2 equivalent (CO_2e) – a measure of the warming effect of mixtures of greenhouse gases, expressed as a standard concentration of CO_2. Thus in 1998 CO_2 concentration was 365 ppm of dry air, but the effects of methane, nitrous oxide and other GHGs in the air at that time were in warming terms equivalent to another 47 ppm of CO_2; the result is a CO_2e of 412 ppm. Throughout this report, 'CO_2' means 'CO_2e' unless otherwise stated.

CO_2 sink – An ecosystem or mechanism which, as it grows or operates, absorbs or 'sequesters' (i.e. isolates) CO_2 from the atmosphere.

CO_2 source – An ecosystem or mechanism which, as it decays or operates, releases CO_2 into the atmosphere.

CO_2 store – An ecosystem or artificial containment which holds carbon from previous growth or operation, but is now absorbing no new carbon. A store therefore has no direct effect on the atmosphere until it is destroyed or emptied. The destruction of ecosystems such as coral reefs, peatlands and primary forests that are CO2 stores now accounts for about a quarter of anthropogenic carbon emissions.

Ecosystem – All the organisms living in a place and time, all the relationships amongst them, all the physical features of light, heat, moisture, wind, waves and chemistry that affect them, and the history of the place as well.

Ecosystem services – All behaviours and functions of ecosystems that contribute to human well-being, including water catchment services (regular supplies of clean fresh water coupled with the prevention of droughts, flash-floods and landslides), coastal protection services (safe absorption of energy delivered by floods, waves and wind), and carbon storage (reduced GHG emissions).

European Union Emissions Trading Scheme (EU ETS) – A carbon market based on 'cap and trade', whereby binding emission targets are set by the EU and tradeable allowances to emit up to these targets are then offered to emitters (as gifts

or sold). Companies that pollute more can then buy surplus credits from those who pollute less, ensuring that overall emissions do not exceed the cap.

Forests, forest loss and forest planting – Forests are ecosystems dominated by trees. Deforestation means removing so many trees that the ecosystem becomes dominated by grasses or other low-stature vegetation, or bare ground. Afforestation means planting a forest in an area that was not previously forested. Reforestation means planting a forest in an area that has been deforested previously. Although nature can deforest (e.g. in volcanic eruptions), afforest (in areas that climate change has newly made hospitable to trees) and reforest (through colonisation and ecological succession), these terms usually refer to human actions.

Forest Carbon Partnership Facility – A proposed World Bank initiative to help developing countries reduce emissions from deforestation and [forest/land] degradation (REDD), with the two aims of building capacity for REDD, and testing performance-based incentive payments in some pilot countries, in order to prepare for a much larger system of incentives in the future.

Forest die-back – A process in which forests are gradually killed by parasites or drought.

Frontier Forests – About 40% of the world's forests that remain largely undisturbed and beyond the advancing 'frontier' of human exploitation and settlement.

Fungible – Mutually interchangeable, for example fungible REDD credits can be exchanged for other carbon credits, such as those achieved through the use of renewable energy.

Greenhouse effect – Warming of the Earth's surface by trapping solar radiation due to components of the atmosphere known as greenhouse gases (GHGs). Without this effect, the Earth would be a frozen and probably lifeless desert. The current biosphere is adapted to a greenhouse effect set by the composition of the atmosphere that has prevailed for millennia, but this is now changing due to anthropogenic emissions of additional GHGs, especially CO_2. The current CO_2 concentration is about 387 ppm (or 0.0387% of dry air), up from 315 ppm in 1960, and under 'business as usual' scenarios will reach around 700 ppm by 2100. This would result in an increase in the Earth's average surface temperature by several degrees more than would be needed to stimulate catastrophic change in all ecosystems. Policy efforts are focused on limiting the rise of CO_2 concentration to 450-550 ppm by 2050, and to stabilise or reduce it thereafter. This might avoid more than a 2°C rise, which will still have numerous adverse impacts.

Greenhouse Gas (GHG) – In the atmosphere, GHGs such as CO_2 trap sunlight as heat, thus contributing to the greenhouse effect which keeps the Earth's surface warmer than it would otherwise be. The six GHGs defined by the IPCC comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).

$GtCO_2$ – a thousand million tonnes of CO_2, also known as a billion tonnes or one gigatonne. Estimates put worldwide CO_2 emissions at 31.1 $GtCO_2$ by 2010.

IPCC – The Inter-governmental Panel on Climate Change was established in 1988 by the United Nations Environment Programme and the World Meteorological Organisation, to evaluate scientific evidence

and risks. It published its first assessment report in 1990, and a supplement in 1992 to inform the 'Rio Earth Summit'. As knowledge of climate change improved it produced further assessments in 1995, 2001, and 2007, all based on reviewing published scientific papers. The reports were prepared and reviewed by hundreds of professional scientists, and in the case of the 2007 report by nearly 4,000 of them. They have consistently firmed up our understanding of the processes involved in climate change, and reduced our uncertainty of the likely consequences.

Kyoto Protocol – A 1997 protocol of the UNFCCC, entering into force in 2005, by which parties agreed to engage in emissions monitoring, reduction and/or trading with an overall objective of reducing overall greenhouse gas inputs into the atmosphere, thus helping to prevent climate change. By the end of 2007, 175 countries had ratified the protocol. See also: UNFCCC.

$MtCO_2$ – a million tonnes of CO_2, also known as one megatonne.

Parts per million (ppm) – A measure of concentration often used for greenhouse gases in the atmosphere. One thousand parts per million is equivalent to 0.1% of dry air.

Peat and peatlands – Peat is a layer of dead vegetation that is only partly decayed because decomposition is slowed by waterlogging, lack of oxygen, high concentrations of tannins and/or by low temperatures. Thus, peat accumulates in swampy conditions beneath tropical forests, and at high altitudes and latitudes. Peaty soils are those that contain abundant peat as well as mineral components, such as sand and mud. Peatlands are all areas with pure peat or peaty soils, which amount to about 400 million hectares, most of which are in Canada (37%) and Russia (30%) although there are large areas of rainforest growing on deep peat swamps in the Amazon Basin, Sumatra, Borneo, New Guinea and elsewhere.

Plantation forests – Artificial forests usually planted for timber production, or as windbreaks or for water catchment purposes. These forests are often low-stature monocultures and function far less well than natural forests for biodiversity and ecosystem services including carbon storage.

Primary Forest – A forest stand that predates human interference or one that has undergone all known stages of ecological succession and is now mature and stable. Such a forest has as high a standing biomass as it ever will under the physical conditions where it grows (i.e. some mature forests are taller and/or denser and heavier than others), so it has stored a maximum amount of carbon and accretes very little or no new carbon each year, other than through reversible seasonal growth and leaf fall. Major expanses of primary forest occur in the sub-Arctic zones of Eurasia and North America, and across the moist equatorial tropics (principally the Amazon and Congo Basins and the Malay Archipelago), with lesser and/or more fragmented stands elsewhere.

Primary production – The amount of biomass that is formed from non-living matter and solar energy in a particular area during a specified time (expressed as kg per hectare per year).

REDD – Reduced Emissions from Deforestation and [forest/land] Degradation. A scheme to reward avoided deforestation proposed by the Coalition of Rainforest Nations and discussed at the climate change conference in Bali.

Secondary Forest – An area of forest which has re-grown after a major disturbance such as a fire or severe timber harvest. Due to their relative youth these store less carbon than primary forests but absorb more on a yearly basis. Most forests in the USA and Europe are secondary.

Silviculture – The applied science of controlling the establishment, growth, composition, health and quality of forests, usually with the aim of promoting the growth of harvestable timber.

UNFCCC – The United Nations Framework Convention on Climate Change, which came into effect in 1994, was one of three international conventions that were opened for signature at the 1992 'Rio Earth Summit'. The others were the Convention on Biological Diversity and the Convention to Combat Desertification, and involve matters strongly affected by climate change. The UNFCCC provides the legal basis for its Kyoto Protocol, which sets binding targets for industrialized countries and the European community for reducing GHG emissions.

1

Overview

Forests and peatlands play a critical role in maintaining the Earth's climate. Despite decades of conservation effort, these ecosystems continue to be destroyed - the tropics alone is losing an area almost half the size of the UK each year. These ecosystems weigh up to hundreds of thousands of tonnes per square kilometre even when dry, or up to millions in the case of deep peat deposits, and are largely composed of carbon-rich compounds such as lignin and cellulose. When these are burnt or decay, they release greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4).

> "Destruction of forests and peatlands account for about 20% of humanity's total GHG emissions; greater than the total released from every truck, car, train and aeroplane in the world"

Aside from their role in global climate change, forests and peatlands influence local and regional climates. Tropical moist forests are rainfall generators that recycle billions of tonnes of water into the atmosphere, whilst peatlands help to regulate drainage and absorb floods. Deforestation and peatland destruction can change rainfall patterns, resulting in droughts with serious economic and social consequences. Thus forests and peatlands contribute billions of dollars to the global economy via these and other ecosystem services. Such services are often taken for granted rather than being economically recognised, and forests and peatlands are cleared because their economic values are not recognised by those doing the clearing or those accountable to them. The trivial financial gains to be made by such uses contrast with the potential value of stored carbon that could be realised were there to be a way to generate income from this global service function. If carbon storage could be charged for at realistic prices, then forests and peatlands would become much more valuable alive than dead. Hence the central question in this report is how can forests and peatlands be priced effectively and through that and other policies, conserved.

Forests and peatlands as global carbon stores

Forests cover more than a quarter of the Earth's land surface or some 4 billion hectares[3], with each hectare containing 360-1450 tonnes of carbon dioxide equivalent[4] and therefore about 4,000 billion tonnes ($GtCO_2e$) in total. To put this in perspective, the average UK resident produces about 10 tCO_2e each year, so one hectare of forest stores the annual GHG emissions of up to 145 British people. Peatlands cover a tenth of the world's forest area but are much denser carbon stores and are estimated to contain a worldwide total of about 2,200 $GtCO_2e$. Between them, forests and peatlands contain twice or more of the CO_2 equivalent contained in the atmosphere[5], or more than 100 years' worth of human-caused GHG emissions.[6] As well as acting as carbon stores, forests also act as carbon sinks by absorbing carbon from the air as they grow. Each year, forests absorb

3 FAO, State of the World's Forests, Food and Agriculture Organisation of the United Nations, Rome, 2007.

4 Fearnside PM, Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation, Climate Change, 46: 115–145, 2000.

5 Prentice et al., Intergovernmental Panel on Climate Change (IPCC), Third Assessment Report, 2001.

6 With greenhouse gas emissions in 2004 of 49 $GtCO_2$ equivalent/year, IPCC, Fourth Assessment Report, 2007.

11 $GtCO_2e$ from the atmosphere, which is about 25% of total anthropogenic emissions.

Emissions from tropical deforestation and peatland destruction

Deforestation and peatland destruction release carbon into the atmosphere. Every year about 12 million hectares of tropical forests are logged, cleared or burnt.[7] In 1990-2005 deforestation reduced global forest cover by 3% and tropical forest cover by 8%[8], with about half of this occurring in Brazil and Indonesia. The IPCC's Fourth Assessment report calculated that tropical deforestation results in annual emissions of between 3.7 and 8.1 $GtCO_2e$[9], or 15-25% of total anthropogenic GHG emissions. This is greater than the emissions from the global transport sector and is similar to the amount emitted by the USA or China.

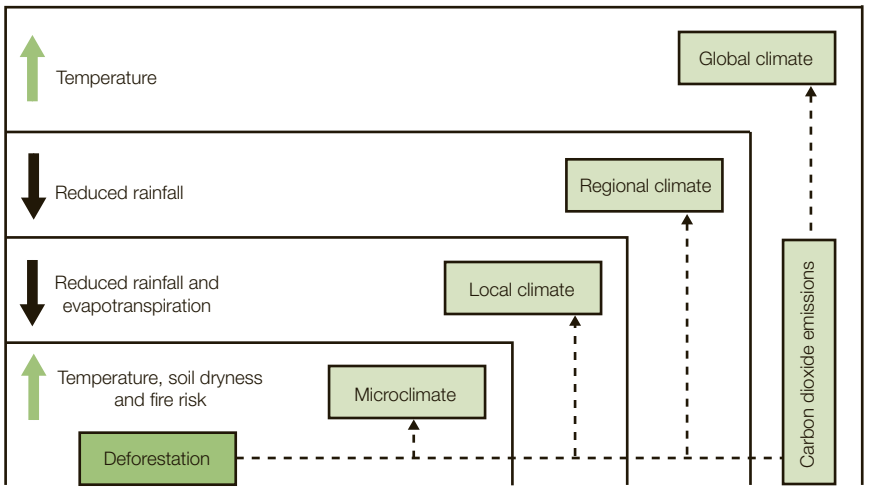
Peatlands are also being quickly destroyed, by melting and decay in circumpolar regions, and elsewhere by draining, land conversion, logging and fire. The high carbon density of tropical peatlands combined with its rapid depletion has helped Indonesia to become the world's third-largest GHG emitter, despite the country's relatively modest industrial activity. Drainage channels that cut through tropical peatlands to allow timber exploitation are often left open after use, causing the peat to 'bleed out' until it is completely dry, allowing it to decay or making it fire prone. This problem can be solved by blocking drainage channels so that the peat remains waterlogged, or (better) by preventing logging in the first place. Many peat swamps in Indonesia are being drained for oil palm plantations to meet food oil and biofuel demand.

> "The average UK resident produces about 10 tCO_2e each year, so one hectare of forest stores the annual GHG emissions of up to 145 British people"

The effect of deforestation on climate

The climate system is very sensitive to changes in land-use and the impacts of deforestation are complex and occur on local to global scales (Figure 2). Locally, tropical deforestation leads to increased temperatures and reduced humidity as more sunlight reaches the earth's surface[10],

Figure 2: Impacts of deforestation on climate at local and global scales.



7 FAO, *Global Forest Resources Assessment*, Food and Agriculture Organisation of the United Nations, Rome, 2005.

8 FAO, *State of the World's Forests*, Food and Agriculture Organisation of the United Nations, Rome, 2007.

9 IPCC, Fourth Assessment Report, 2007. The range of estimates is due to uncertainty in deforestation rates especially in some tropical regions and uncertainty in the amount of carbon stored per unit area of forest.

10 Didham RK. & Lawton JH, Edge structure determines the magnitude of changes in microclimate and vegetation structure in tropical forest fragments, *Biotropica*, 31: 17-30, 1999

while smoke from forests fires results in reduced rainfall downwind[11]. Deforestation can result in greatly reduced regional rainfall[12] due to decreased evapotranspiration.[13] Tropical deforestation can also modify global rainfall patterns through complex links in the climate system known as 'atmospheric teleconnections'. Thus, deforestation in the Amazon and central Africa results in reduced rainfall in the Midwestern USA and likewise, deforestation in South-east Asia results in reduced rainfall in China.[14]

Deforestation in the Amazon basin is estimated to reduce Amazon-wide rainfall by 10-25%[15] and could increase average Amazon-wide temperatures by up to 4ºC[16].

Deforestation is also predicted to cause similar reductions in regional rainfall in central Africa[17] and South-east Asia[18]. Thus large deforested areas can desiccate their surroundings and promote desertification. Of profound concern is that the Amazon may have an ecological 'tipping point', where so much forest is lost that reduced rainfall causes remaining forest to dry out and become vulnerable to fire and conversion to scrub and grassland. It is not yet known how much deforestation would need to occur before the tipping point is reached, but the mechanism has the potential to destroy the entire Amazon ecosystem. The resulting feedback system would involve a damaging spiral of deforestation reducing rainfall, causing forest dieback, increasing carbon emissions, amplifying climate change, and driving more forest dieback.[19] These complex ecosystem-climate feedbacks emphasize the importance of maintaining large areas of intact tropical forest.

Causes of tropical deforestation

The causes of tropical deforestation vary from region to region[20]. Subsistence farming is a major driver in Africa, parts of mainland South-east Asia and Central America, aggravated historically by weak institutions, poverty, disorder and in many places war. By contrast the main drivers in other parts of South-east Asia and much of South America are commercial agriculture and logging. Here, and more generally wherever powerful institutions drive change, it is the opportunity to capture supernormal profits from forest conversion that drive policies towards it, often aided by corruption and the official rejection of traditional land claims that might have preserved the forests[21]. Thus deforestation rates are influenced by policy, institutions, economics and technology, as well as by cultural and demographic factors. Infrastructure development is also important, as new roads open up formerly inaccessible forests and peatlands to agriculture and logging[22].

The national and international demand for commodities also drives a very large proportion of deforestation. The main areas are as follows:

- **Beef** – Cattle ranches cover 50 million hectares of the Amazon (more than twice the size of the UK) and accounted for 60% of deforestation in the 1970s and 1980s.[23]
- **Soya** – At least five million hectares of the Amazon are now farmed for soya.
- **Palm oil and rubber** – Plantations cover more than seven million hectares in South-east Asia and this is rapidly expanding.
- **Oil and minerals** – Exploration, mining, drilling, roads and pipelines all contribute strongly to the extension of infrastructure networks into forest areas.
- **Industrial logging** – Forest exports from the developing world are worth US$39 billion per year including US$10 billion annually in Southeast Asia[24], illegal logging results in a US$4 billion revenue loss in Indonesia.[25]

11 Rosenfeld D, TRMM Observed First Direct Evidence of Smoke from Forest Fires Inhibiting Rainfall *Geophysical Research Letters*, 26: 3105-3108, 1999.

12 Baidya Roy S & Avissar R, Scales of Response of the Convective Boundary Layer to Land-Surface Heterogeneity, *Geophysical Research Letters*, 27: 533-536, 2000

13 Bidin & Chappell, In: *Water: Forestry and Landuse Perspectives*, Abdul Rahim Nik (editor), UNESCO, 69-85, 2004.

14 Avissar R & Werth D, Global hydroclimatological teleconnections resulting from tropical deforestation. *Journal of Hydrometeorology,* 6(2): 134-145, 2005.

15 Moore N et al., Uncertainty and the changing hydroclimatology of the Amazon, *Geophysical Research Letters*, 34(14): L14707, 2007.

16 Sampaio G. et al., Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion, *Geophysical Research Letters*, 34, L17709, 2007.

17 Werth D & Avissar R, The local and global effects of African deforestation, *Geophysical Research Letters*, 32, L12704, 2005.

18 Werth D & Avissar R, The local and global effects of Southeast Asian deforestation, *Geophysical Research Letters*, 32, L20702, 2005

19 Da Silva RR et al., Regional impacts of future land-cover changes on the Amazon basin wet-season climate. *Journal of Climate*, 21(6): 1153-1170, 2008

20 Geist HJ & Lambin E, Proximate causes and underlying driving forces of tropical deforestation, *BioScience* 52 143–50, 2002.

21 Ross ML, *Timber Booms and Institutional Breakdowns in Southeast Asia*, Cambridge University Press, 2001.

22 Miles L, Caldecott J & Nellemann C, Challenges to great ape survival, in: *World Atlas of Great Apes and their Conservation* (Caldecott & Miles eds), California University Press, 2005.

23 Grainger A, *Controlling Tropical Deforestation*, Earthscan, London, 1993.

24 FAO, Global Forest Resources Assessment 2005: Progress towards sustainable forest management. FAO, Rome, 2005.

25 Phat NK et. al., Appropriate measures for conservation of terrestrial carbon stocks - Analysis of trends of forest management for S.E. Asia. *Forest Ecology and Management* 191, 283-299, 2004.

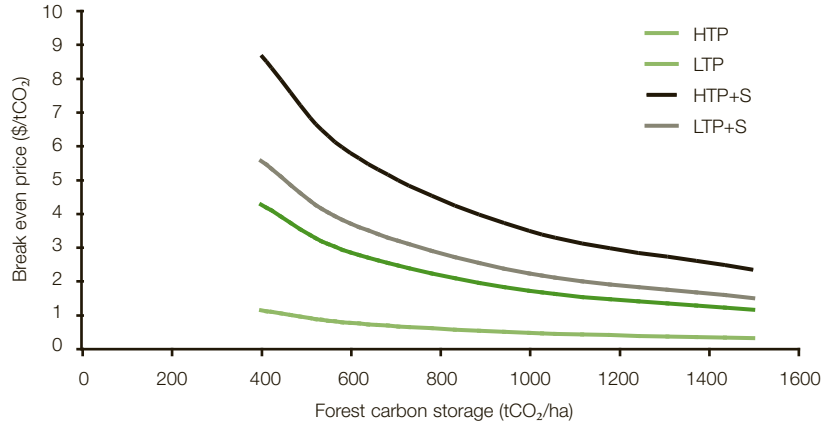
Quite simply, tropical forests are deforested and peatlands destroyed because this generates short-term financial rewards that can be captured by individuals and corporations, even though it makes no sense at an economic level. Leaving aside the majority of economically-important services including carbon storage, most tropical deforestation generates a return of less than US$5/tCO$_2$e, while in peatland returns of less than US$0.20/tCO$_2$e are common.[26] This is a serious market failure that reflects the difficulty of determining a price for untraded goods and services, especially in this case the ecosystem service known as carbon storage. Figure 3 shows the 'break-even price' – the price of carbon at which forest conservation becomes financially attractive compared to logging and agriculture. If the return from conservation can be increased above this level, then conserving peatlands and forests will become more attractive than destroying them.

All this might seem odd, when forests and peatlands provide ecosystem services that have an estimated global benefit of US$4.7 trillion annually.[27] However, many of these services are difficult to value and are often viewed as free benefits to global society (Box 1). With no market for these services, forests are undervalued and marginally profitable activities can result in their destruction.

> "Each year, forests absorb 11 GtCO$_2$e from the atmosphere, which is about 25% of total anthropogenic emissions"

Of all the ecosystem services, carbon storage is the most easy to quantify. Carbon markets could value a hectare of forest (containing 360-1450 tCO$_2$e) at US$500-3,500 (at US$5.5/tCO$_2$e) or US$2,500-20,000 (at US$27/tCO$_2$e). As shown in Figure 3, even carbon prices below US$10/tCO$_2$e would in many cases provide sufficient incentive to prevent deforestation. A funding mechanism for avoided deforestation could directly generate up to US$30 billion per year, comparable to revenues from industrial logging and additional to all the other benefits that intact forests and peatlands provide.

Figure 3: The carbon price at which forest conservation becomes financially attractive compared to logging (High Timber Price, HTP; Low Timber Price, LTP) and logging followed by soy-bean production (S) in the Amazon.[28]



26 Swallow BM et al., *Opportunities for Avoided Deforestation with Sustainable Benefits*. An Interim Report by the ASB Partnership for the Tropical Forest Margins. ASB Partnership for the Tropical Forest Margins, Nairobi, Kenya, 2007.

27 Costanza R et al., The Value of the World's Ecosystem Services and Natural Capital, *Nature*, 387, 253-260, 1997.

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