Opinion

REDD: a reckoning of environment and development implications

Jaboury Ghazoul[1], Rhett A. Butler[2], Javier Mateo-Vega[3] and Lian Pin Koh[1]

[1] Institute of Terrestrial Ecosystems, ETH Zürich, CHN G 73.1 Universitätstrasse 16, 8092 Zürich, Switzerland
[2] Mongabay.com, P.O. Box 0291, Menlo Park, CA 94026, USA
[3] Environmental Leadership & Training Initiative of the Yale School of Forestry & Environmental Studies, 195 Prospect Street, New Haven, CT 06511, USA; and the Smithsonian Tropical Research Institute, Apartado 0843-03092, Balboa, Ancón, Panama

Reducing Emissions from Deforestation (REDD) aims to curb carbon emissions from deforestation by financially compensating forest owners. However, compensation based on the opportunity costs of REDD might underestimate true costs by failing to account for downstream economic values of current land uses, including employment and wealth generated by processing and service industries. A comprehensive analysis of REDD impacts should also include sociopolitical impacts. REDD might exclude people from forest land, causing demographic shifts, and the declining tax revenues from commodity production and associated industries might be a disincentive to government investment in forested regions to the detriment of forest communities and regional development. We argue for the need to recognize and appropriately compensate the full range of economic, social and political net costs of REDD.

Reducing Emissions from Deforestation and Degradation (REDD)

Tropical deforestation and forest degradation represent the second largest source of global greenhouse gas emissions, accounting for 12–20% of anthropogenic carbon emissions [1,2]. Reducing Emissions from Deforestation and forest Degradation (REDD) is a mechanism that aims to reduce carbon emissions from deforestation by providing financial incentives to conserve rather than exploit forests [3,4]. Reducing emissions by avoiding deforestation was excluded from the Kyoto Protocol owing to both political and technical obstacles [5,6], but the concept of a REDD mechanism was promoted at the Conference of the Parties (COP) of the UN Framework Convention on Climate Change (UNFCCC) in Montreal in 2005 by the Coalition for Rainforest Nations. The proposal was that developed nations compensate developing countries for lost income opportunities associated with reducing deforestation rates relative to a historical baseline. The carbon credits thus generated from emissions savings in developing nations could be purchased and used by developed nations to meet their emissions reduction targets. REDD was a key agenda item discussed during the December 2009 COP meeting in Copenhagen. The resulting 'Copenhagen Accord', signed by the United States, China, India, Brazil and South Africa, recognized natural forest protection (and specifically REDD+ which additionally recognizes reforestation and sustainable management of forests) as key to reducing global carbon emissions (http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf). The accord did not, however, specify binding emission reduction targets, and details

Glossary

Biodiversity banking and offsets: a financial scheme designed to compensate forest owners with biodiversity credits for maintaining forests and biodiversity on their lands; these credits can be sold to developers to offset the impacts of biodiversity on lands elsewhere as a result of development.
Carbon capture and storage: a technology-based means of reducing fossil fuel carbon emissions by sequestering carbon dioxide from point sources (e.g. power plants) and storing it to prevent its release into the atmosphere.
Coalition for Rainforest Nations: an international consortium of developing nations established to foster collaboration both among themselves and with developed nations to reconcile forest stewardship with economic development.
Google Earth: a freely accessible, virtual geographic information program that maps the Earth by superimposition of satellite images obtained from various sources.
Kyoto Protocol: a protocol of the United Nations Framework Convention on Climate Change (UNFCCC), aimed at mitigating dangerous climate change.
Leakage: the displacement of deforestation or forest degradation from protected sites to other locations such that the net benefit of protection is reduced.
Life cycle assessment: a comprehensive evaluation of the full range of environmental and social impacts of a given product or service throughout its life cycle including raw material production, manufacture, distribution, use and disposal, and all intervening transportation steps.
Market chain analysis: an analytical framework that seeks to obtain a comprehensive accounting of actors, activities, costs and benefits associated with the flow of a particular product and associated services from producers through to targeted consumers.
Opportunity cost: relating to a specific course of action: the potential benefit that would have been gained by taking an alternative and foregone action.
Payment for Environmental Services (PES): a transaction in which a service provider is (financially) rewarded for maintaining service provision.
Permanence: the degree to which confidence can be attributed to a REDD or other emissions reduction programme such that carbon is indeed stored and not subsequently released through forest clearance or degradation.
REDD: Reducing Emissions from Deforestation and forest Degradation: one form of payment for environmental service where carbon storage value of forests threatened by degradation or clearance is financially recognized through payments to forest owners (usually, but not exclusively, nation states) to conserve the forest.
REDD+: a REDD scheme that explicitly recognizes conservation, sustainable management of forests and enhancement of forest carbon stocks through restoration activities.
REDD refugees: forest users dislocated from their lands owing to the curbing of financially unrewarding activities, including small-scale agriculture and fuelwood harvesting, under a REDD scheme.
Remote sensing: the acquisition of information, such as an image, of an object or locality using aircraft, spacecraft or satellite technology.
Watershed management: the development and implementation of plans to sustain and enhance ecosystem functions, including water supply, quality and drainage, within a watershed boundary.

Corresponding author: Ghazoul, J. (jaboury.ghazoul@env.ethz.ch)

0169-5347/$ – see front matter © 2010 Elsevier Ltd. All rights reserved. doi:10.1016/j.tree.2010.03.005 Trends in Ecology and Evolution 25 (2010) 396–402

Box 1. Key challenges facing REDD implementation

REDD challenge	Description	Key reference
Ethical dilemma	REDD allows rich nations or corporations to 'absolve their sins' of carbon emissions through carbon offsetting with REDD credits. Some opponents of REDD argue that this would create disincentives for genuine efforts to reduce emissions or develop cleaner technologies.	[21]
Additionality	A key criterion for valuing carbon stocks for a REDD project is 'additionality' – the net emissions savings calculated using a baseline deforestation and carbon emission rates. Establishing the baseline deforestation rate is technically challenging. It might also be prone to political meddling that can inadvertently lead to environmentally damaging land-use policies [33] . Furthermore, the criterion of additionality may also castigate countries that have maintained their forests prior to the establishment of baseline dates. Not only have they paid the opportunity cost of not using their lands, but they may have fewer opportunities to access REDD payments.	[3,6]
System leakages	The avoidance of deforestation in one area can displace it to another area. Such 'leakages' can be difficult to quantify. Unless there is coordination among REDD and other conservation strategies, forest clearing and degradation activities can still occur in areas not under REDD protection.	[6,7]
Permanence	It may be difficult to ensure the permanence of carbon storage after the REDD project period has ended or even within the project period. Forests and carbon stocks could be lost or degraded through human activities and also from natural events such as drought causing tree die-offs, or natural fires burning huge tracts of forests.	[3,6]
National sovereignty and native land rights	Participation in REDD schemes imposes long-term constraints on land use that can be construed as an infringement of a nation's sovereign right to manage the land according to its needs. To allay fears of compromising future development options and national sovereignty, some have suggested a carbon rental option as a temporary measure, whereby developed nations rent carbon credits from developing countries. Similarly, there is concern about the future rights of indigenous communities to access or use resources from forests protected under REDD, for traditional subsistence needs or other livelihood purposes, although the latest draft text of REDD offers better prospects in protecting the rights of indigenous peoples.	[6,12]
Equity	REDD rhetoric emphasizes the equitable distribution of REDD benefits, with particular recognition of the needs of the rural poor, yet arrangements and mechanisms remain unclear. Notions of equity within REDD policy proposals are often inconsistent. Prevailing ideas focus on market-based benefit distribution, which is less likely to serve the interests of poor and indigenous peoples.	[14]
Crashing carbon market	Finally, there are concerns by some environmental groups that allowing large volumes of REDD credits to be traded in the compliance market would drive carbon prices down and crash the market.	[41]

on implementation and governance of a REDD mechanism remain scant.

These details need thought, not least because a REDD mechanism would bind protagonists to long-term decisions which might have economic and social implications extending far beyond the areas and people directly concerned. REDD faces several technical, social, economic, ethical and governance challenges (Box 1). Some technical challenges are already well recognized and are being negotiated and resolved. Leakage, for example, is the displacement of environmentally destructive activities to other locations such that the net benefit in emissions reductions is lower than planned under REDD [7]. Current estimates of leakage in forest carbon projects range from 10% to over 90% [8]. National-level carbon and forest accounting, as advanced by the Copenhagen Accord, would effectively neutralize the net effects of leakage within national boundaries, but cannot account for cross-border leakage [6]. The accurate quantification of carbon stocks retained in forests and the carbon dioxide emissions avoided through REDD designation, is another technical challenge, albeit one that is likely to be resolved given rapid advances in remote sensing systems [9].

Social, economic and political challenges are more difficult to define or conceptualize. For example, it is not obvious that projected REDD values are economically competitive when compared to alternative agricultural land uses [10,11]. There is a need to fully recognize and compensate foregone livelihood opportunities of forest-based communities in REDD-affected areas [12], but in addition, forest-degrading activities support the livelihoods of many other people who might be far removed from the forest. Thus, opportunity costs of REDD are based on the financial returns of exploitative land uses [10,11,13], but the wider economic benefits these land uses accrue through the support of processing, marketing and service industries are usually not considered. Indeed, while Coalition of Rainforest Nations documents repeatedly refer to 'equitable distribution' of benefits from REDD, there is little description of how they will actually be distributed and to whom [14]. We emphasize here that the wider social and economic benefits and beneficiaries of the land uses that REDD seeks to replace need to be recognized and addressed in the course of negotiating and implementing REDD, to ensure the long-term viability of the mechanism and hence permanence of the forest stock.

Before continuing, we must emphasize that we support REDD as a mechanism that could both mitigate greenhouse gas emissions and conserve forests, and we are keen to see an effective REDD mechanism adopted widely for the benefit of the climate and biodiversity. However, we plead for more realism about the knock-on effects that might result and the potential inequitable distribution of costs and benefits. We hope to raise awareness about these effects and in so doing strengthen the REDD mechanism and its implementation. We recognize that many benefits might be secured by forest protection through

REDD, including not only carbon sequestration and storage, but also conservation of biodiversity [6], provision of a range of ecosystem services, and 'pro-poor' development [15]. However, we believe several costs associated with REDD have not yet been adequately recognized or addressed. We discuss these costs in this article in the hope that this will stimulate work towards the development of a truly effective and widely acceptable REDD mechanism.

A comprehensive trade-off analysis

We argue that alongside the negotiation and implementation of REDD, a comprehensive analysis of its implications and consequences is needed to show land owners and decision makers where, to what degree and in what context REDD could be appropriately adopted. This needs to go beyond the analysis of financial compensation for forfeiture of conventional land use activities to incorporate indirect and less tangible costs and benefits associated with REDD and REDD+. We conjecture that the success of these schemes will depend on their ability to achieve appropriate compensation that encompasses the full range of economic, social and political implications of avoiding deforestation. These must be realistically and transparently assessed lest REDD mechanisms are rendered theoretically attractive but practically unrealistic. Such effort towards the development of a comprehensive trade-off analysis will require the collaborative participation of ecologists, economists, and social and political scientists, and is likely to unfold over several years following the early implementation of REDD programmes.

Indirect economic costs

A variety of indirect economic, social and political impacts potentially exist (Table 1). Obvious examples include the loss of employment and revenue generation from raw material processing and other value-adding downstream industries (Figure 1). A downscaling of these industries could in turn limit the growth of a service industry, the consequences of which could further constrain opportunities for regional economic growth. It would also reduce tax revenues. In consequence, governments may be less inclined to invest in such regions, particularly if REDD requires long-term contractual agreements that tie land to forest cover. Reduced investment might be manifested as poor infrastructure and telecommunications, limited mobility and market access, lower quality public services such as education and health, less reliable energy and water provision, and reduced access to credit. Such chronic underdevelopment would impact on populations at local and regional scales. There are some signs that these issues are beginning to be recognized. The Coalition for Rainforest Nations is advocating that REDD funds be allocated to development outside the forest sector, and one of these

Table 1. Examples of indirect and less tangible economic and political-social implications of REDD implementation compared to a business-as-usual option of commodity production

Type of cost/benefit	REDD	Commodity production
Economic	Stable income, guaranteed payments	Risk-associated variable income streams
	Less adaptable to supply and demand (carbon market fluctuation and emergence of new technologies that render REDD obsolete)	Adaptable to supply and demand
	Limited opportunities for downstream industries, although new opportunities created (e.g. ecotourism)	Many opportunities for downstream processing and service industries
	Limited potential for job creation	Modest to large potential for job creation
	Restricts development and infrastructure	Development and infrastructure investments enhanced
	Subject to inflation	Less sensitive to inflation
	Limited potential for growth of service industry	Large potential for service industry growth
	Limited potential for economic growth	Economic growth promoted
	Little potential to respond to technical innovations	Possibility to benefit from technological innovations in commodity production
Economic/ Political-Social	Ecosystem services options retained	Ecosystem services options lost
	Risk of ecosystem disservices (e.g. human–wildlife conflicts)	Low risk of ecosystem disservices on account of little remaining natural habitats
	Reduced tax income	Tax income continues to grow with development
	Risk of government investments being diverted elsewhere	Attracts government investment through economic development
	Dependent on external financing	Less dependent on external funding sources
	Constrains future livelihood options	Does not limit future livelihood options
Political and Social	Encourages migration to cities	Encourages rural population (and economic) stability
	Restricts urban-to-rural migration	Facilitates rural migration, alleviates population and land pressures in densely populated areas
	Dissociates agricultural societies from land	Maintains agricultural societies' connection to land
	Retains forest peoples' cultural values	Exposes forest peoples to alternative cultural values
	Tenure/ownership processes clarified (unclear implications)	Tenure/ownership processes maintained
	'Colonialist' concerns regarding restricted development pathways	Allows integration in the global market economy (accelerates development)
	Political–economic ties altered (unclear implications)	Political connections based on trade are retained and strengthened
	Transboundary issues related to deforestation are alleviated	Transboundary conflicts remain

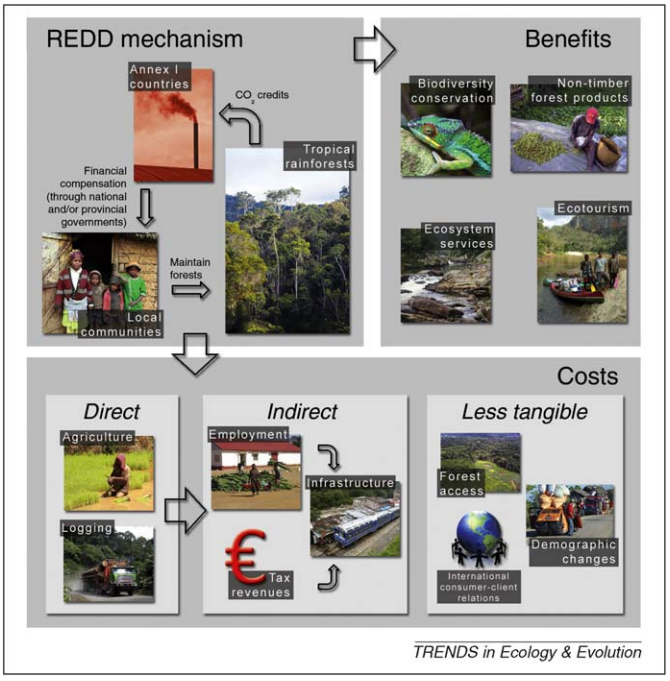

Figure 1. The REDD mechanism, its benefits and its direct and wider costs. REDD is a mechanism by which the costs of avoiding deforestation in developing countries are compensated by developed countries. REDD has the potential to provide benefits in addition to reducing greenhouse gas emissions. These include biodiversity conservation, provision of ecosystem services, and creation of new livelihood opportunities (see text for more examples and details). The costs of REDD are usually understood to be the direct opportunity costs of alternative foregone land uses, particularly logging and agriculture. Yet these activities support downstream industries which provide employment opportunities and generate tax revenues. Together, these provide incentives for rural development. In addition REDD might have less tangible costs at local, regional and international scales (see text for more details).

nations, Guyana, specifically calls for REDD investments in private sector entrepreneurship, electricity, roads, health and education [16].

Some of the indirect opportunity costs associated with REDD are illustrated by the forestry sector in Indonesia, which claims that in a single province (Riau), the paper and pulp industry alone generated over US$5 billion in 2006 [17]. Although this figure is debatable, it does provide some indication of the relative value of the forestry industry when compared to estimated figures for REDD income for the whole of Indonesia (US$3.8–15 billion per year depending on assumptions and biases). Furthermore, the forestry sector in Indonesia employs around 350 000 people directly and about 3.1 million people in broader forestry-related businesses [18]. Another example is the Malaysian oil palm industry, which contributes about 5-6% of Malaysian GDP and provides direct employment for 570 000 workers, with a further 830 000 workers employed in downstream activities. It generates foreign exchange earnings amounting to around US$10.1 billion annually, which provides revenue for national development. These funds contribute to the improved provision of piped water, electricity, communications, roads, schools and healthcare through land schemes coordinated by the Federal Land Development Authority (Malaysian Palm Oil Council: http://www.mpoc.org.my/pubs_view.aspx?id=cd34de06-b843-48ca-90e3-b873fb812499).

Potential employment opportunities generated by REDD have not been well quantified, but we expect them to be far fewer. The governments of Indonesia and Malaysia explicitly recognize that forestry and palm oil play a major role in regional development benefiting both district governments and local communities. For the successful implementation of REDD there therefore needs to be an acknowledgement and adequate compensation for loss of both direct and indirect contributions made by the forestry and other sectors to local and national economies.

For some commodities such as timber, quantifying indirect costs might be comparatively simple along the entire value chain. For other products, including oil palm, the calculations would be simple at the first steps of the value chain (e.g. crude palm oil production) but would become increasingly complex as the range of products and value addition opportunities multiply higher up the chain (e.g. through biofuel refining). One approach to address this could be to use market chain analysis to identify the activities and financial benefits derived by the range of actors involved in product development. Typically, this might include the producers of raw materials, as well as the processors, distributors, marketers, retailers and consumers. This could be coupled with life-cycle assessment which might help to identify the wider employment opportunities generated by industries that deal with environmental or other impacts associated with production, processing, distribution, marketing and disposal of products.

Less tangible costs

Looking beyond the purely economic implications of REDD, it will also be necessary to consider less tangible but equally important political and socioeconomic issues relating to national and local development. These include the potential social disruption of communities such as that caused by shifting cultivators who depend on forest clearing activities, and the dissociation of agricultural societies from the land. Committing land to REDD may constrain the future livelihood options of local communities, as is arguably the case with protected area systems [19]. For example, technological innovations that drive substantial improvements in commodity production could dramatically increase future opportunity costs of REDD. From a social perspective, forest-user communities with unclear land tenure might be denied access to the lands they manage and depend on, leading to 'REDD refugees' [20,21]. Providing alternative employment opportunities, even if these were available, might incur social costs for people forced to adjust to new livelihood cultures, as well as costs associated with acquiring the new knowledge and skills needed to successfully engage in such new employment opportunities.

Dissociating people from land and preventing their access to forest has other implications for the rural poor. Land conversion and improvement, whether legal or otherwise, is one of the few methods by which they can secure land titles. This is important since land ownership does not just facilitate production; it also represents security against inflation and an opportunity for speculation. In some cases, implementation of REDD might displace long-standing traditional management systems including some types of shifting cultivation (Figure 1).

At national scales, large-scale adoption of REDD may lead to demographic changes. Governments have often actively encouraged settlement of remote frontier areas to secure political control of peripheral regions, alleviate population pressures elsewhere, and expand economic development. It is well known that such rural development projects then drive further immigration into the area [22]. For example, it has been estimated that new agricultural opportunities in rural central Pará, Brazil in the late 1990s drew up to 100 families per week to the area [23]. In the event that adopting REDD reduces the development potential of the peripheral rural economies, the converse trend of migration from rural to urban centres might increase. This could raise political as well as social concerns and further undermine government priorities for investment in depopulated rural areas. Simultaneously, schemes that seek to alleviate population pressures by providing land to citizens from heavily populated regions might be undermined by virtue of underdeveloped infrastructure and lack of economic opportunities in REDD-affected regions.

At the international scale, REDD could restrict development support to areas in need, raising concerns of neocolonialism. Brazil's long standing opposition to internationally-led conservation in the Amazon stems in large part from real or imagined concerns over sovereignty [24] with respect to the use and development of its land and resources. By contrast, commodity production is largely free of international non-market constraints to national and local development. REDD is also unlikely to be adaptable to changes in supply and demand for carbon credits internationally, or sufficiently flexible to deal with unexpected economic inflation nationally. Land owners engaged in commodity production, on the other hand, can respond quickly to changing price signals, and are less susceptible to inflation because investment decisions can be made on shorter time scales. In the worst scenario, carbon market collapse might result from the emergence of new technologies such as Carbon Capture and Storage [25] which could render REDD obsolete.

In cases where there are strong political connections based on trade, a REDD mechanism that limits the supply of key commodities could alter conventional political ties. This has unclear implications. For example, strategic aid investments from consumer to producer countries are often built upon the exploitation of resources such as timber, as has been the case in Japan's historical relationship with Indonesia and the Philippines [26]. Indeed, a central priority of Japan's investment credits to foreign governments has been to secure 'the development and import into Japan of natural resources' [27]. The widespread implementation of REDD would change consumer–client relationships, including political and business ties that shape political and economic interactions between countries. Adoption of REDD may be constrained by these less tangible international relations.

New opportunities afforded by REDD

These costs, both tangible and less tangible, need to be balanced by new opportunities and benefits that a forest protected by REDD might provide. REDD potentially provides the advantage of guaranteed and stable income, subject to the details of the agreement, while an alternative income based on commodity production is subject to fluctuations driven by risk-taking and price variability. Needless to say, an entrepreneurial approach to commodity production may substantially reward risk-taking, an option not available under REDD agreements.

REDD+, which additionally allows for reforestation and sustainable forest management activities, is increasingly seen as the way forward in recognition of the importance of forestry for the economies and development strategies of tropical forest communities and nations [15]. Sustainable forest management would restrict the expansion of agricultural commodity production and processing, but maintain the wood production industry and secure its long term future. A REDD+ program might also generate benefits derived from sustainable forest use, including non-timber product commercialization and ecotourism, both of which have associated service industries. Income may be further enhanced by payment for environmental service (PES) schemes, whereby landowners receive payments conditional on their provision of desired environmental services to beneficiaries, often by maintaining natural forest cover. Although the capacity of these livelihood systems to support local communities and national economies remains debatable [28], promoting them alongside and in the context of REDD+ might be sufficient to secure viable rural livelihoods and retain forest peoples' cultural values [29].

Related to this issue is the importance of tenure processes. As has already been recognized, implementing REDD potentially clarifies land ownership as a necessary condition [30], although this might be at the detriment of wider forest-users who have been managing the land but do not legally own it [21]. On the other hand, under a business-as-usual commodity production approach, tenure ownership is likely to remain idiosyncratic.

Increased exposure to and incidence of mosquito-borne diseases, which incur social and economic costs to people and nations, have been frequently linked to deforestation [31–33]. REDD might therefore alleviate disease burdens to which people are currently subjected, with social, economic and human welfare benefits. Comparative assessments of disease incidence, in the context of REDD versus deforestation scenarios, need to consider not only exposure but also vulnerability to disease. This is affected by wealth and income, and infrastructure and physical capital, as well as basic components of health such as adequate nutrition, and access to safe water and clean air [34]. REDD might enhance some but not all of these components.

At the very largest scale, REDD has the potential to limit regional and cross-border costs and conflicts associated with deforestation. Amongst other things, such conflicts can influence watershed management and large-scale forest burning. Watershed management affects erosion and river sedimentation. This in turn, impacts on infrastructure and resources such as dams fisheries, as well as influencing valuable ecosystems including coral reefs and mangroves. REDD might also help reduce conflicts associated with atmospheric pollution resulting from forest burning. For example, annual burning of Indonesian forest has economic, health and transportation impacts. During the

1997–1998 El Niño-Southern Oscillation event this amounted to several billions of dollars and strained relationships with neighbouring countries [35]. By limiting the extent of future forest fires, REDD could minimize associated transboundary conflicts.

The need for a comprehensive trade-off model

If REDD is to be socially and politically acceptable there needs to be a comprehensive trade-off analysis incorporating an assessment of the less tangible costs and benefits. Although complex, such a comprehensive analysis is likely to provide welcome guidance for politicians reflecting on the issues identified during negotiation and implementation of REDD. From a social and conservation perspective, the benefits of a comprehensive trade-off analysis are myriad. It would allow researchers to integrate typically undervalued services, including sustainable harvesting of forest products, ecotourism and watershed protection, into a spatial economic model. This could be used to better inform policymakers and the public on various land-use allocation options. A comprehensive analysis could also promote equitable compensation for those affected by REDD. It is quite possible that once all economic, political, social and ecological factors have been carefully considered, the costs of forest protection through REDD might be far higher than initially thought.

On the other hand, by fully integrating biodiversity data into the costs and benefits of land-use decisions [13,36], the analysis could facilitate the development of new PES-related products such as biodiversity banking and offsets schemes [37]. This could also identify scenarios whereby activities that enhance biodiversity, such as reforestation using a wide variety of native species, might financially outperform other forms of land use on degraded lands. Where natural habitat conversion is likely to be more profitable than REDD, the analysis could serve as an early warning of potential deforestation sites for environmental organizations and government agencies (i.e. deforestation 'red-flags'), where pre-emptive conservation efforts might be focused (e.g. declaration of a protected area).

The development of the model would provide unprecedented opportunities for collaboration across multiple research disciplines (including economics, agronomy, ecology and remote sensing) and between institutions working on conservation and development issues (including universities, nongovernmental organizations, government agencies and the private sector). Once established, such an overarching framework could guide research and disseminate data and research outputs in a manner that is applicable to a real-world problem.

Finally, by publishing the model in an open-access, multi-lingual and user-friendly format such as an application in Google Earth , these benefits could reach millions of users worldwide, particularly those whose decisions and actions determine the fate of tropical forests. An open-access format would also allow continuous updating with new information, variables and computation scripts from end-users and experts, thereby improving the model's scale, scope and resolution. In this way, the utility of the analysis would not depend on its completeness; it can be useful as it improves incrementally.

Conclusions

A successful implementation of REDD must recognize and overcome both direct and indirect costs of forest conservation. There are many incentives for forest conversion that range in scale from those influencing household decisions to those that shape international client–consumer relationships among companies and countries. If REDD is to be implemented for as long as land-based carbon mitigation strategies are needed (i.e. several decades), it will be necessary to make a complete reckoning of its implications, in recognition of all incentives for forest conversion. By 2050, global population is expected to have increased by around a third, potentially driving the conversion of one billion hectares of natural habitat in developing countries to cropland and pasture [38]. It is therefore imperative that an evaluation of the full range of the economic, societal and political costs of REDD is undertaken. Of course, a comprehensive trade-off model is not in itself a panacea for halting tropical deforestation. Nevertheless, to the extent that environmentally damaging land-use decisions are the result of inadequate information, or even disinformation [39,40], the model would help to inform and guide land-use decisions, and so mitigate deforestation in the tropics. Is REDD a credible component of a feasible solution? We would like to think so, but we will not know for sure until we have tackled the complex issues affecting society's response to the full implications of REDD.

Acknowledgements

We thank C.J.P. Colfer and P. Levang for helpful discussions. We also thank William F. Laurance and two anonymous reviewers for their comments. L.P.K. is supported by an ETH Fellowship and the Swiss National Science Foundation.

References

1 Sala, O.E. *et al.* (2000) Global biodiversity scenarios for the year 2100. *Science* 287, 1770–1774
2 Houghton, R.A. (2008) *Carbon Flux to the Atmosphere from Land-use Changes: 1850–2005*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy.
3 Ebeling, J. and Yasué, M. (2008) Generating carbon finance through avoided deforestation and its potential to create climatic, conservation and human development benefits. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 363, 1917–1924
4 Miles, L. and Kapos, V. (2008) Reducing greenhouse gas emissions from deforestation and forest degradation: global land-use implications. *Science* 320, 1454–1455
5 Kanninen, M. *et al.* (2007) *Do Trees Grow on Money: the Implications of Deforestation Research for Policies to Promote REDD*, Center for International Forestry Research (CIFOR)
6 Laurance, W.F. (2007) A new initiative to use carbon trading for tropical forest conservation. *Biotropica* 39, 20–24
7 Murray, B.C. (2008) *Leakage from an Avoided Deforestation Compensation Policy: Concepts, Empirical Evidence, and Corrective Policy Options*, Nicholas Institute for Environmental Policy Solutions, Duke University
8 Kindermann, G. *et al.* (2008) Global cost estimates of reducing carbon emissions through avoided deforestation. *Proc. Natl. Acad. Sci. U. S. A.* 105, 10302–10307
9 Achard, F. *et al.* (2007) Pan-tropical monitoring of deforestation. *Environ. Res. Lett.* 2, 045022 DOI: 10.1088/1748-9326/2/4/045022
10 Butler, R.A. *et al.* (2009) REDD in the red: palm oil could undermine carbon payment schemes. *Conserv. Lett.* 2, 67–73
11 Strassburg, B. *et al.* (2009) Reducing emissions from deforestation-The "combined incentives" mechanism and empirical simulations. *Global Environ. Change* 19, 265–278

12 Dooley, K. *et al.* (2008) *Cutting Corners: World Bank's Forest and Carbon Fund Falls Forests and Peoples*, Forests and the European Union Resource Network (FERN) and Forest Peoples Programme
13 Venter, O. *et al.* (2009) Carbon payments as a safeguard for threatened tropical mammals. *Conserv. Lett.* 2, 123–129
14 Okereke, C. and Dooley, K. (2010) Principles of justice in proposals and policy approaches to avoided deforestation: towards a post-Kyoto climate agreement. *Global Environ. Change.* 20, 82–95
15 Campbell, B.M. (2009) Beyond Copenhagen: REDD+, agriculture, adaptation strategies and poverty. *Global Environ. Change* 19, 397–399
16 Republic of Guyana (2009) *Transforming Guyana's Economy while Combating Climate Change*. Office of Climate Change, Office of the President.
17 World Growth (2009) *Forestry and the Poor*, World Growth
18 Karyaatmadja, B. *et al.* (2006) *Indonesia's Forestry Long Term Development Plan 2006–2025*, The Ministry of Forestry of Indonesia
19 Kaimowitz, D. and Sheil, D. (2007) Conserving what and for whom? Why conservation should help meet basic human needs in the tropics. *Biotropica* 39, 567–574
20 Dowie, M. (2009) *Conservation Refugees*, Massachusetts Institute of Technology Press
21 FoE (2008) *REDD Myths: a Critical Review of Proposed Mechanisms to Reduce Emissions from Deforestation and Degradation in Developing Countries*, Friends of the Earth (FoE) International Secretariat
22 Fearnside, P.M. (2008) The roles and movements of actors in the deforestation of Brazilian Amazonia. *Ecol. Soc.* 13, 23 (www.ecologyandsociety.org/vol13/iss1/art23/)
23 Fearnside, P.M. (2001) Land-tenure issues as factors in environmental destruction in Brazilian Amazonia: the case of southern Pará. *World Dev.* 29, 1361–1372
24 Fearnside, P.M. (2003) Conservation policy in Brazilian Amazonia: understanding the dilemmas. *World Dev.* 31, 757–779
25 Azar, C. *et al.* (2006) Carbon Capture and Storage from fossil fuels and biomass-costs and potential role in stabilizing the atmosphere. *Clim. Change* 74, 47–79
26 Dauvergne, P. (1997) *Shadows in the Forest*, Massachusetts Institute of Technology Press
27 EXIM (1994) *Guide to the Export-Import Bank of Japan*, EXIM Bank of Japan
28 Wunder, S. (2001) Poverty alleviation and tropical forests-what scope for synergies? *World Dev.* 29, 1817–1833
29 Brosius, J.P. (1997) Prior transcripts, divergent paths: resistance and acquiescence to logging in Sarawak, East Malaysia. *Comp. Stud. Soc. Hist.* 39, 468–510
30 Cotula, L. and Mayers, J. (2008) *Tenure in REDD: Start-point or Afterthought?* International Institute for Environment and Development (IIED)
31 Taylor, D. (1997) Seeing the forests for more than the trees. *Environ. Health Perspect.* 105, 1186–1191
32 Singer, B. and De Castro, M.C. (2006) The enhancement and suppression of malaria in the Amazon. *Am. J. Trop. Med. Hyg.* 74, 1–2
33 Yasuoka, J. and Levins, R. (2007) Impact of deforestation and agricultural development on anopheline ecology and malaria epidemiology. *Am. J. Trop. Med. Hyg.* 76, 450–460
34 Myers, S.S. and Patz, J.A. (2009) Emerging threats to human health from global environmental change. *Annu. Rev. Env. Resour.* 34, 223–252
35 Lohman, D.J. *et al.* (2007) The burning issue. *Science* 316, 376
36 Grainger, A. *et al.* (2009) Biodiversity and REDD at Copenhagen. *Curr. Biol.* 19, R974–R976 DOI: 10.1016/j.cub.2009.10.001
37 Bekessy, S.A. and Wintle, B.A. (2008) Using carbon investment to grow the biodiversity bank. *Conserv. Biol.* 22, 510–513
38 Tilman, D. *et al.* (2001) Forecasting agriculturally driven global environmental change. *Science* 292, 281–284
39 Koh, L.P. *et al.* (2010) Wash and spin cycle threats to tropical biodiversity. *Biotropica* 42, 67–71
40 Koh, L.P. and Wilcove, D.S. (2009) Oil palm: disinformation enables deforestation. *Trends Ecol. Evol.* 24, 67–68
41 Livengood, E. and Dixon, A. (2009) *REDD and the Effort to Limit Global Warming to 2°C: Implications for including REDD Credits in the International Carbon Market*, Greenpeace International