

Executive Summary:

The aim of the REDD-ALERT project was to make a contribution to the evaluation of mechanisms that translate international-level agreements into instruments that would help change the behaviour of the people at the 'coal-face' while minimising adverse repercussions on their livelihoods. The specific objectives of the project were to understand better the drivers of deforestation, to improve the methodology of estimating above-ground carbon stocks, obtain measurements of the carbon stock changes and GHG emissions associated with land use change in the tropics, analyse global level policies aimed at reducing deforestation and the implications for this at sub-national level, use modelling approaches to analyse impact of land use change on GHG emissions and the impact of policies and instruments on land manager decisions, and to develop tools that could be used by stakeholders. The project was focused on field sites in Indonesia, Vietnam, Cameroon and Peru that are used as part of the CGIAR ASB Benchmark Sites network.

Results showed that some developing tropical countries have recently been through a forest transition, thus shifting from declining to expanding forests at a national scale. However, in many of these (e.g. Vietnam), a significant part of the recent increase in national forest cover is associated with an increase in importation of food and timber products from abroad, representing leakage of carbon stocks across international borders. Avoiding deforestation and restoring forests will require a mixture of state-level command-and-control (regulatory) approaches, emerging market-based instruments (e.g. eco-certification of products, corporate environmental responsibility, stewardship agreements, and other demand-driven interventions), suasive options, and management measures. Most of the available policy instruments tend to focus on local and proximate drivers with very few instruments that address global underlying (e.g. world demand) and national underlying drivers (e.g. population growth, the perceived need for economic growth).

Significant progress was made in the quantification of carbon and GHG fluxes following land use change in the tropics, contributing to narrower confidence intervals on peat-based emissions and their reporting standards. Specifically, it was found that net CO₂ emissions and removals contributed more than 90% to the soil net balance of all GHGs across all land-use categories on peat soils, that the overall decrease in CH₄ emissions from conversion of peat swamp forests does not offset the simultaneous increase in soil CO₂ emissions due to accelerated peat decomposition, and that forest conversion to agriculture and agroforestry significantly and highly increased soil N₂O emissions. For mineral soils, it was found that there was a strong geographic bias in the published literature, with most studies being skewed toward regions with higher precipitation and allophanic clay mineralogy, while areas with low precipitation and high activity clays were clearly underrepresented. It was also found that measurement of soil carbon stocks down to one metre was sufficient to capture changes following land use change.

Policy analysis and modelling work showed the high degree of complexity at local levels and highlighted the need to take this heterogeneity into account - it is unlikely that there will be a 'one size fits all' approach to make REDD+ work. It is important to see REDD+ as part of larger systems which also include arable agriculture, grasslands, wetlands, and human

settlements, as these can often be a driver of deforestation (e.g. agriculture) or may represent leakage (alternative income opportunities). Dealing with any one land use component (such as forests) in isolation is likely to result in partial solutions at best as the Law of Unintended Consequences starts to operate.

There are indications that there is only a short and relatively small window of opportunity of making REDD+ work. These included the fact that forest-related emissions as a fraction of total global greenhouse gas emissions have been decreasing over time due to the increase in fossil fuel emissions, and that the cost efficiency of REDD+ may be much less than originally thought due to the need to factor in safeguard costs, transaction costs and monitoring costs.

Project Context and Objectives:

Context

Climate change is widely recognised as the most serious environmental threat facing our planet today. The Intergovernmental Panel on Climate Change (IPCC) published its Fourth Assessment Report (AR4) in 2007 which concluded that warming of the earth's climate is now indisputable, and that it is very likely that this is due to emissions of greenhouse gases (GHGs) from human activities, particularly from the last half of the 20th century onwards. Atmospheric concentrations of the GHGs, which include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), are higher than any time over the last 650,000 years.

We urgently need, therefore, to find ways of reducing our emissions of these gases. The Kyoto Protocol, agreed in 1997 at the third session of the Conference of Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC), and effective from February 16, 2005, obliged participating developed countries (Annex I countries) to collectively reduce their national GHG emissions by 5.2% below 1990 levels, averaged over the period 2008-2012. Developing countries (non-Annex I countries) do not have such obligations, but were able to participate in the Clean Development Mechanism (CDM), whereby Annex I countries were able to purchase credits for projects aimed at reducing GHG emissions in non-Annex I countries.

While fossil fuel use remains the dominant concern, conversion of forests into agricultural land is a major source of GHG emissions. Currently, a gross figure of 13 million ha of forests are lost annually (FAO, 2006), with net losses, allowing for afforestation and reforestation, at about 7.3 million ha y⁻¹ (Nabuurs et al., 2007). Degradation, defined as decrease of density or increase of disturbance in forest classes, affected tropical regions at a rate of 2.4 million ha y⁻¹ in the 1990s. Recent estimates are that deforestation released 3.0 Gt CO₂ y⁻¹ (range: 2.1-4.5 Gt CO₂ y⁻¹) into the atmosphere over the period 2000-2005 (Harris et al., 2012), both through the burning of the forest biomass, and from the oxidation of carbon stored in the soil under the trees during cultivation and in peatlands under drainage. Other GHGs, such as CH₄ and N₂O may also be emitted during slash-and-burn and subsequent land use. This represents an estimated 7 to 14% of total global anthropogenic CO₂ emissions over the time period analysed (Harris et al., 2012). Brazil and Indonesia are the countries with the highest net deforestation rates, losing 3.3 and 0.7 Mha of forest annually (Hansen et al., 2010), and as such, total per capita CO₂ emissions in Indonesia, for example, may be 30% above the average for Europe, despite a much lower energy use.

It was decided at the 7th COP in Marrakech in 2001 that CDM mechanisms of the Kyoto Protocol be largely restricted to the energy and industrial sectors. However, surrounded by many safeguards, afforestation and reforestation activities became eligible as Afforestation/Reforestation Clean Development Mechanisms (A/R CDM), although they have found little application as yet. Emission reduction by avoided deforestation was excluded because institutions were not ready to deal with the 'additionality' (what would have occurred without intervention), 'leakage' (emission reductions in one location causing emission increases in another) and 'permanence' issues at either local or national scale. Apart from ambiguities in the definition of a forest (which also affect the A/R CDM rules),

there are difficulties in accurate monitoring of the carbon stocks actually preserved. Part of forest conversion is due to planned development, part is linked to climatic extreme events, and part is beyond control of national governments. The costs of both applying and verifying rules more complex than those for A/R CDM rules, were expected to be too high, while there was uncertainty on the opportunity cost of clearing forests for land uses with higher economic returns.

However, there was a growing recognition that the contribution to global emissions from deforestation should not be neglected, particularly with the realisation that 'solutions' for Annex I countries, such as increased use of biofuels, had led to perverse incentives that were likely to have increased deforestation rates and global GHG emissions rather than reduced them. Stern (2007) concluded that reducing deforestation was a highly cost-effective way to reduce emissions relatively quickly, as well as providing co-benefits in terms of soils, water, climate protection, protection of biodiversity and livelihoods, rights of local communities, and sustainable forest management. Indeed, one study had suggested that with appropriate carbon pricing, emissions from deforestation could be stopped by 2020 (Rokityanskiy et al., 2007). Stern recommended that, with help from the international community, policies on deforestation should be shaped and led by the nations where the forests stand, and that compensation from the international community should be provided to take account of the opportunity costs of alternative uses of the land, the costs of administering and enforcing protection, and managing the transition.

At the 9th UNFCCC Conference of the Parties (COP-9), Santilli et al. (2005) presented a proposal for Compensated Reductions addressing some of these issues, in which non-Annex 1 countries such as Brazil or Indonesia could voluntarily choose to reduce their national emissions from deforestation. A certain annual rate of deforestation based on a historical period would be permitted and used as a baseline, but reductions in deforestation rate below this rate would then gain carbon credits at the end of a commitment period which could be sold on international carbon trading markets or to other governments, thus earning income for the country. As this was to be at the national level, it would help to address the issues of national leakage, as displacement of emissions to elsewhere in the country would still be accounted for in national inventories, although this would not be the case for international leakage (Mollicone et al., 2007). At a workshop in Bogor, Indonesia, in 2005, Schlamadinger et al. (2005) assessed the Santilli et al. (2005) proposal in more detail, and proposed improvements to some of the shortcomings that they perceived. These included the possible need for upfront financing to establish avoided deforestation schemes (with appropriate safeguards built in to ensure that emission reductions were actually delivered), the appropriate setting of baselines, and ways in which revenues generated from avoided deforestation could be actually used to address the drivers of deforestation at the local level (i.e. to the landowners who would have to change their behaviour). Revenues from avoided deforestation would have to be set against other income possibilities for the land. Possible mechanisms mentioned included a carbon tax if landowners wished to deforest for other land uses, payments to the landowners not to deforest, or investments in improving neighbouring agricultural productivity so that deforestation was not required.

While these proposals marked significant progress in the thinking, there were still many issues to resolve. These included how appropriate baseline deforestation rates were determined, how differences from these baselines would be measured, and how the uncertainties in these differences would be quantified. The sensitivity of these uncertainties of subsequent credits generated (particularly in relation to degradation as opposed to deforestation), and the implications of this for carbon markets and efficiency of emissions reduction, needed to be examined. Techniques for monitoring the change in national and regional carbon stocks caused by deforestation and degradation needed to be improved. Mixed land-use mosaics presented a specific challenge in this regard. Concerns were also expressed regarding potential loss of national or provincial sovereignty over natural resources, and that avoided deforestation schemes could create so many carbon credits that they would flood global carbon markets and trigger a price collapse that would undermine the market incentives for reducing emissions in other sectors (e.g. energy).

The Kyoto Protocol expires in 2012, and it was intended that a successor agreement should be finalized at the 15th COP in Copenhagen (2009). At the 11th COP in 2005, it was agreed that there should be a two-year period of discussion about Reduced Emissions from Deforestation and Forest Degradation (REDD), focusing on 'relevant scientific, technical and methodological issues, and the exchange of relevant information and experiences, including policy approaches and positive incentives'. At the COP-13 meeting in Bali in December 2007, REDD was a key agenda item, and it was decided that all countries should work towards improving data collection, estimation of emissions from deforestation and degradation, monitoring and reporting, and addressing institutional needs of developing countries. The drivers of deforestation should also be addressed, with a view to reducing emissions from this source through a range of policy approaches and positive incentives. Under the auspices of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), countries were invited to submit their views by 21 March 2008 on outstanding methodological issues such as assessment of forest cover and the associated carbon stocks and GHG emissions, how these are affected by sustainable forest management (SFM), and how reductions in emissions from deforestation and degradation below reference baselines (without displacement) could be demonstrated (see Herold & Johns, 2007). The coming two years would thus shape the post-2012 regime and the rules by which common but differentiated responsibility and accountability for climate change would be linked to global commitments to support development (Millennium Development Goals).

However, what had been largely missing from the debate at that stage, which Schlamadinger et al. (2005) touched upon but did not go into detail, was how emission reduction targets agreed at the national scale would be translated into changes of behaviour relating to land use at the local scale, while not affecting the rights of minority and vulnerable social groups, or the provision of ecosystem services in general. New ways to link the technical and institutional advances on REDD to local stakeholders were needed so that the various scenarios considered reflect local ambitions and response options. Social justice questions such as who will be the winners and losers (particularly in relation to common land), and how to avoid rewarding the 'bad guys' while forest dwellers are evicted from their homes or forced to abandon their agricultural activities, would all need to be addressed. Active 'negotiation support' was needed to achieve the 'free and prior informed consent' status

that is seen as a moral imperative to agreements that potentially affect livelihoods of people outside of the centres of political power. Moreover, a landscape perspective was required due to the spatial interdependencies of forest, agriculture and other land uses leading to deforestation and degradation at the forest margins - it is not a 'forest problem' alone. Solutions are likely to be quite context-specific and to vary from one country to the next, but without these crucial links between global and local, the climate policy discussions ran the risk of divorcing themselves from reality. The aim of the REDD-ALERT project, therefore, was to make a contribution to the evaluation of mechanisms that translate international-level agreements into instruments that would help change the behaviour of the people at the 'coal-face' while minimising adverse repercussions on their livelihoods.

Project objectives

The proposal addressed Topic ENV.2008.1.1.5.1 'Addressing deforestation in tropical areas: greenhouse gas emissions, socio-economic drivers and impacts, and policy options for emissions reduction'. The overall goal of the project was to contribute to the development and evaluation of market and non-market mechanisms and the institutions needed at multiple levels for changing stakeholder behaviour to slow deforestation rates of tropical landscapes and hence reduce GHG emissions. This was to have been achieved through the specific objectives of:

- a) Documenting the diversity in social, cultural, economic and ecological drivers of forest transition and conservation, and the consequences, in the contexts of selected case study areas in Indonesia, Vietnam, Cameroon, and Peru as representative of different stages of forest transition in Southeast Asia, Africa and South America.
- b) Quantifying rates of forest conversion and change in forest carbon stocks using improved methods.
- c) Improving accounting (methods, default values) of the consequences of land use change for GHG emissions in tropical forest margins including peatlands.
- d) Identifying and assessing viable policy options addressing the drivers of deforestation and their consistency with policy approaches on avoided deforestation currently being discussed in UNFCCC and other relevant international processes.
- e) Analysing scenarios in selected case study areas of the local impacts of potential international climate change policies on GHG emission reductions, land use and livelihoods.
- f) Developing new negotiation support tools and using these with stakeholders at international, national and local scales to explore a basket of options for incorporating REDD into post-2012 climate agreements.

REDD-ALERT would build on the ongoing work of the Alternatives to Slash and Burn (ASB) Partnership for the Tropical Forest Margins, which has been focusing since 1994 on the local and global causes and consequences of deforestation by small-scale farmers, but would also bring in partners with experience in international climate policy analysis, deforestation drivers, GHG flux measurement, and coupled human-environment modelling. REDD-ALERT would seek to understand what influences value systems and attitudes to deforestation, how these attitudes influence and determine individual and societal behaviour in deforestation, and finally, how this behaviour influences GHG emissions. These findings would be interpreted in respect to current and future UNFCCC policy on deforestation and GHG emissions, and also in the broader global context of the sustainable use of tropical forests.

Project Results:

Objective 1: Documenting the socio-economic drivers of deforestation and degradation

This section presents the main science / technology results from work carried out under WP1, by discussing

- (i) the current state of global land use and expected trends over the period 2000-2030,
- (ii) the knowledge on causes and impacts of past and ongoing forest transitions, and
- (iii) prospects and policy options for a global forest transition, and (iv) results from the study sites.

Current state and future trends of global land use

We summarized various low and high estimates of global land use for the year 2000 and the period 2000-2010 (Table 1). The least known figure is the area of potential available cropland (PAC). Based on a spatially-explicit approach within a limited number of regional or country case studies, we estimated that, once social, institutional, economic and physical constraints are taken into account, there is less PAC than is generally assumed (see World Bank, 2010), and that the social and ecological costs of converting that remaining land would be significant (Lambin et al., in preparation). Globally, the additional land demand for all agricultural, tree plantation, urban and nature conservation uses was estimated to range from 303 to 845 Mha by 2030 compared to the 2000 baseline, depending on various socioeconomic and policy factors (Table 1). Based on these global trends, which already includes significant land productivity increases, productive land could become a scarce resource in most developing countries by 2030.

Forest transitions

Our work showed that a handful of developing, tropical countries have recently been through a forest transition, thus shifting from shrinking to expanding forests at a national scale (Meyfroidt & Lambin, 2011). Different views exist on dening secondary forests and on whether reforestation should include some or all forms of tree plantations, or only naturally regenerating forests, which adds to the technical difficulties in measuring and characterizing reforestation. A few generic processes of forest transition were identified, as well as the broad geographical patterns of reforestation (Rudel et al., 2005; Lambin & Meyfroidt, 2010; Meyfroidt & Lambin, 2011). Countries do not necessarily follow a regular pattern of forest cover changes, and the causes and outcomes of forest transitions vary, so that forest transition is to be seen as a contingent process. Under certain conditions, environmental degradation can be perceived by land managers and, through such social-ecological feedback, can in turn become a driver of subsequent land use changes and of forest transition (Meyfroidt et al., in preparation). Restoring forests in one country is generally associated with a significant outsourcing of forest exploitation to neighbouring countries via increased imports of wood and sometimes agricultural products (Meyfroidt & Lambin, 2010). In Vietnam, the combination of policies restricting forest exploitation, rapid

development of the wood processing industry and of exports of wood products, led to an increase in legal and illegal imports of timber and a displacement of forest extraction to neighbouring countries, such as Laos and Cambodia, equivalent to 39% of the regrowth in Vietnam's forests from 1987 to 2006 (Meyfroidt & Lambin, 2010). Policies to protect forests and promote reforestation therefore need to control this displacement of land use and channel it toward areas where the impacts are minimal (or beneficial). The ecological effects of reforestation are highly dependent on the residual deforestation of old-growth forests, the proportions of natural regeneration of forests and tree plantations, and the location and spatial patterns of the different types of forests (Meyfroidt & Lambin, 2011). Furthermore, net reforestation can conceal a continuing degradation or clearance of partly irreplaceable old-growth natural forests (Echeverria et al., 2006; Meyfroidt & Lambin, 2008). Policies supporting afforestation and reforestation should not assume that it will lead indiscriminately to environmental gains.

Prospects and policies for sustainable forest transitions

Although in theory the trade-offs between conserving forests and feeding the world's population could be minimized (Angelsen, 2010), a decrease in the availability of productive land and competition with other land uses will make a global forest transition difficult to achieve over the coming decades (see Table 1). Policies to achieve a forest transition include approaches to improve the supply of land-demanding products, and to control the demand for them (Meyfroidt & Lambin, 2011). The following factors hold the potential to significantly affect the supply of and demand for wood and agricultural products, and therefore contribute to control deforestation by addressing its drivers: (i) technological innovations and more efficient land-use practices to intensify agricultural and forestry production and reduce its environmental impacts; (ii) sound land management policies to control for rebound-effects; and (iii) changes in consumption patterns especially reduction of wastes and decreasing demand of the most land-demanding products – e.g. meat. The combination of, first, promoting nature-friendly farming in areas with biophysical and social conditions unsuitable for large-scale intensive farming; and second, sparing land for forests through agricultural intensification in high-potential agricultural areas might control the expansion of competing agricultural land uses (Fischer et al., 2008; Lindenmayer & Cunningham, 2012). Increasing off-farm economy, especially in the most marginal rural areas, can contribute to reducing the dependency on local natural resources. For commodities with high elasticity such as biofuels, meat, and luxury goods like coffee or exotic timber, agricultural intensification and out-migration are unlikely to reduce the overall demand for agricultural land unless combined with policies to control rebound effects, e.g., by land-use zoning and demand-side interventions. Addressing final consumption and future global demand for wood and agricultural products is a critical aspect for any potential global forest transition (Meyfroidt et al., 2010; Lambin & Meyfroidt, 2011; Meyfroidt & Lambin, 2011). Across all these approaches, for the poorest fraction of humanity, the issues of equity, and access and sharing of food and land resources are crucial to ensure food security (Godfray et al., 2010). These approaches may rely on various tools, including state-level command-and-control, regulatory tools; rural and agricultural development policies; and emerging market-based instruments. REDD+ could support most

of these strategies, and thus should not be considered only as a program of Payments for Environmental Services for agents of deforestation and forest degradation.

Country studies

The country case studies highlight the high contextual variability in causes of deforestation and land use changes. This calls for tailoring the above-described general policy approaches and tools to specific contexts, rather than applying 'one-size-fits-all' approaches.

In Vietnam, we used remote sensing to analyze land use and cover changes and deforestation trajectories in the coffee-growing area in Dak Lak and Dak Nong provinces over 2000-2010 (Meyfroidt et al. in preparation). Land use changes and their links with deforestation and socioeconomic dynamics were analyzed with secondary statistics and spatial modelling. Gross and net deforestation rates reached respectively -0.50 %/y and -0.33 %/y of the total area between 2005 and 2010, including humid forests only. Deforestation was mainly directly caused by shifting cultivation for annual crops, but this was partly driven indirectly by expansion of coffee and other perennial crops over agricultural lands. Displacement of shifting cultivation into the forest margins, pushed by market crops expansion, was the spatial manifestation of the marginalization of local ethnic minorities and poor migrants, pushed by capital-endowed Kinh and other migrants. Colonization and agricultural expansion in the Central Highlands likely facilitated the reforestation elsewhere in Vietnam. But over the late 2000s, this rapid deforestation was strongly reducing the benefits of forest recovery, and might shift the country back to net losses of natural forest. Policies that may have an impact on deforestation are those that would promote inclusion of the ethnic minorities into the socio-economic, political and agricultural markets spheres, intensify staple crops, strengthen and clarify land use zoning to preserve the remaining forests of value and identify forested land with the lowest tradeoffs between environmental services and agricultural potential. In another study, in four villages in the Northern mountains of Vietnam, we analysed feedbacks from local environmental degradation on land uses of land managers, the conditions under which such feedbacks occur, and their possible roles in the forest transition (Meyfroidt, in preparation). These case studies showed how, under certain conditions, dramatic events or progressively increasing scarcity modified the perception, interpretation and evaluation of changes in forests, and this in turn affected land use practices. Transitions in forest area, density and turnarounds in the satisfaction and livelihoods of local actors are linked, but these three dimensions can evolve in different directions.

In Cameroon, results of remote sensing data analyses in our study area of 1.8 Mha (excluding clouds) showed that, in 2007, forest covered the 83.7% of the surveyed area, for a total of 1.57 M ha. Forest were mostly dense high stands (64.7%) whereas degraded forest covering overall 19% of the surveyed land was found in areas close to settlements and transport axes (see Meyfroidt et al., 2012 (in preparation) for more details on that study area). Deforestation reached gross and net rates of respectively -0.85 %/y and -0.24 %/y of the total area over the period 2001-2007. This deforestation was almost entirely concentrated in the non-permanent forest estate (NPFE), with deforestation hotspots close to roads and some towns, and reflected mostly the conversion of forest into fine grained

shifting cultivation land use mosaics. Gross rates of degradation of high dense forest stands reached 1.48%/y of the total area, due most probably to logging and forest thinning for forest-farms preparation. Based on these remote sensing data, and several villages and households surveys, further investigations are in progress to describe the landscape pattern of shifting cultivation, and the relations between agricultural intensification and deforestation. A second study assesses the effectiveness of the forest and land zoning policy by determining forest cover changes between 2002 and 2010 in a study area located in the Eastern region, which contains most of the types of units defined by the land zoning plan (Bruggeman et al. in preparation). Results show that deforestation rates in most units of the permanent forest estate (PFE) are low, a net reforestation is even observed for the entire estate. Yet, significant disparities exist between land zoning units, as deficiencies in the forest legislation and lack of enforcement by the State make the effectiveness of the land use zoning highly dependent on the willingness and capacity of logging companies and local authorities to prohibit agriculture practices. A third study showed that, without intervention and if present intensification trends continue, the potential of fallow vegetation to contribute to biodiversity conservation declines because of a reduced capacity, (1) to recover forest vegetation with anything like its original species composition, (2) to connect less disturbed forest patches for forest dependent organisms (Robiglio & Sinclair, 2011). Strategies to combat biodiversity loss, including promotion of agroforestry practices and the increase of old secondary forest cover, will need not only to operate at a landscape scale but also to be spatially explicit, reflecting the spatial pattern of species reservoirs and dispersal strategies and human usage across landscapes. Finally, a last study, based on data about volumes marketed in urban centres, harvesting operations and on-farm timber management, showed that, with current agricultural expansion and intensification trends associated with small-scale logging, timber resources on rural land are at risk of depletion with direct consequences for domestic timber supply and the thousands of livelihoods it sustains (Robiglio et al., 2012). Various marketing and regulatory changes to encourage the integration of timber production in agricultural management systems are discussed.

In Peru, we analysed livelihood strategies and environmental outcomes in the Ucayali region (Porro et al., 2012). Based on household surveys data, this study provides evidence that land use intensification is not associated with land sparing. Furthermore, the study shows that despite the relevance of forest products, mestizo and indigenous livelihoods heavily depend on agriculture, and highlight the need for conservation policies to strengthen the integration between agriculture and forest use.

Objective 2: Quantifying rates of forest conversion and change in forest carbon stocks using improved methods

The objectives of this work-package were to 1) quantify current land use change and deforestation, and 2) improve monitoring tools. Data collection in the context of national greenhouse gas inventories following IPCC guidelines has to balance the errors (uncertainty) involved in 1) the use of the classification system (both at the 'ground truth' and 'remote sensed image' level), 2) the uncertainty in the properties (C stock per unit area) of each class and 3) the eligibility of different land cover types with respect to the scope of the policy.

Deforestation rates depend on forest definition

While the legends we use for land cover classification include a range of systems with various quality and quantity of tree cover, the concept of 'deforestation' splits it into a 'forest' and 'non-forest' part. However, different stakeholders have different operational forest concepts - ranging from the interest in untouched old-growth forest of strict conservation agents, to the very 'weak' forest concept that was agreed as part of the Afforestation/Reforestation Clean Development Mechanism (A/R-CDM), referring to the FAO definition of minimum size, potential to reach a minimum tree cover and clarification what is meant by tree. Across such range of definitions we found the deforestation rate for Indonesia as a whole to be 3-5%/year without clear upward or downward trend within the 1990-2010 time frame, or shifting from +0.5%/year to -0.5%/year in the same time period (Figure 2). As the international negotiation arenas have not been able to clarify the forest concept that is to be used in REDD, there is far too much scope for picking the operational definition that matches the point one wants to make. Deforestation as such cannot be used to predict 'emissions from deforestation', and the second D of REDD is essential to quantify emissions; the results of net emissions are much less sensitive to forest definition - as earlier shown for Vietnam where an increase in net forest area was found to coincide with a continued loss of forest carbon stock, as densely stocked forest continued to be lost and the forest gained had much lower carbon stocks.

Reformulating allometric equations may help judge need for tree-specific equations

Part of the uncertainty in carbon stock data for land use systems is the use of 'generic' allometric equations that relate tree biomass to stem diameter, while details of tree architecture differ between trees. A common form of such equation is $\text{Biomass} = a(\text{Diameter})^b$. Empirical data sets suggest that both the a and b parameter differ considerably between tree species, and that thus tree-specific equations are needed. We noticed, however, that the a and b parameters of fitted equations are strongly linked, and that for a tree of 20-30 cm diameter the variation in predicted biomass is small. Reformulating the allometric equation to $\text{Biomass} = a_2(\text{Diameter}/\text{DiamStandard})^{b_2}$, with a standard tree diameter (DiamStandard) of about 20 cm leads to much lower variation in a and b , but a variation in a and b that is independent of each other (so it becomes a clean two parameter equation). At stand level, where there typically is a range of tree diameters, the choice of equation matters much less than the tree level differences suggest, as there is strong compensation. These results will help to improve C accounting methods, and justify the use of generic allometric models as default.

Simplifying from IPCC 5-pool data for carbon stocks

The IPCC prescribes that five pools of terrestrial carbon need to be assessed: trees, understory vegetation, roots of all plants, litter plus necromass, and soil organic carbon. Based on over 700 sample points we found that the data collection can be replaced by the use of defaults, as variation between land use types in soil carbon (in top 30 cm of the profile) plus litter layer plus necromass plus understorey vegetation represents only 6% of variation in tree biomass, while the belowground root biomass is estimated to be 25% (with little opportunity to verify this estimate). Under specific conditions of recent forest damage, however, the necromass pool can be more than 50% of the total carbon stock, and cannot be ignored in data collection.

Error propagation in C stock estimates

Errors in land use classification (with typically 85% accuracy at pixel level for a 25-point legend) combine with uncertainty around the typical C stock data used. We analysed how the combined errors relate to scale. Typically, aggregation across pixels reduces the random element in the error, while not reducing any bias that may be there. For REDD applications we found that aggregating up to a 1 km² scale reduces uncertainty in C stock change to below 5%, while estimates for smaller pixel sizes may have a higher chance of containing error. The acceptable error level for a government-based incentive system on performance in C stock change is not empirically known, so our 5% threshold may have to be revised in future.

Opportunity costs curves

The monitoring of land use change needs to relate the economic benefits that (local) actors derive, to the global consequences for emissions. Initial estimates by the ASB consortium in 2007 in Indonesia, Cameroon and Peru suggested that 85% of emissions yielded net economic benefits of less than 4/t CO₂ at current prices. Further analysis of the spatial determinants of such abatement costs focused on soil type (peat versus mineral soils), accessibility (rivers versus roads), actor (large scale operations versus smallholders) and policy domain (existing land use restrictions and forest protection rules). We refined the calculation procedure in the ABACUS tool, which was endorsed by the World Bank in training at national level, and was refined based on user feedback.

Recommendations on the design of national monitoring systems

Reflecting on the cost of data collection, the marginal reduction in net uncertainty of estimates of terrestrial carbon stock change, we recommend a national monitoring system that pays specific attention to the low frequency of high-diameter trees that contain a disproportionally high part of total carbon stocks, while simplifying data collection on pools that were found not to vary much. Soil sampling for typical land use types in a national accounting system may be worthwhile, but for smaller accounting areas the costs of data collection probably exceed any benefits that might be derived through carbon markets.

Objective 3: Improving GHG accounting methods and default values of land use change in tropical forests

The overarching objectives of this multi-partner work-package were twofold: (1) to quantify the magnitude of GHG emissions and changes in belowground soil carbon stocks resulting from the land-use change at tropical forest margins, and (2) to identify the controlling mechanisms underlying the GHG emissions in both deeply weathered mineral soils and peat soils. To address these objectives, the project used a comprehensive approach consisting of literature reviews, field experiments, regional sampling campaigns, and modelling.

Literature reviews

Four literature reviews using a meta-analysis statistical approach were conducted. The first one on the changes in soil CH₄ fluxes from the conversion of tropical peat swamp forests (Hergoualc'h & Verchot, 2012) demonstrated that CH₄ fluxes displayed an exponential response to water table depth changes across land-uses ranging from dry-drained to wet-undrained situations. There was a significant overall effect of size of land-use change on CH₄ emissions which indicated a small decrease of CH₄ emissions with peat swamp forest conversion to another land-use, including rice cultivation. The study indicated that the overall decrease in CH₄ emission from conversion of peat swamp forests would not offset the simultaneous increase in soil CO₂ emissions due to accelerated peat decomposition.

The second review on rationalising peat GHG emissions from land-use and land-use change in Southeast Asia provided emission factors of peat emissions/removals of CO₂, CH₄ and N₂O (Hergoualc'h & Verchot, 2013). The study demonstrated that across all land-use categories on peat soils, net CO₂ emissions and removals contributed more than 90% to the soil net balance of all GHGs (expressed as CO₂-equivalents). Acacia plantations, croplands, shrublands, and oil palm plantations were the land-uses displaying the largest emissions. The paper will be submitted to the REDD-ALERT Special Issue for the journal Mitigation and Adaptation Strategies for Global Change.

The third review on land-use change effects on soil emissions of NO and N₂O in the tropics and subtropics showed that forest conversion to agriculture and agroforestry significantly and highly increased soil N₂O emissions. A meta-regression produced evidence of relationships between the changes in N₂O and NO as affected by land-use change and that in soil water-filled pore space, soil nitrogen availability, soil temperature and N fertilization rate. The research will be submitted for publication in 2013 in the journal Global Change Biology.

The fourth literature review was a meta-analysis on existing studies that evaluated the impact of land-use change on soil organic carbon (SOC) stocks in the tropics. Our literature search yielded 837 observations reported in 80 different studies. For three land-use transitions with sufficient observations, both the direction and magnitude of changes in the soil C pool was shown to be a function of mean annual precipitation and the dominant soil mineralogy. Additionally, the analysis also highlighted a strong geographic bias in the literature published, where the distribution of field observations is skewed toward regions with higher precipitation and allophanic clay mineralogy, while areas with low precipitation

and high activity clays were clearly underrepresented. These results were published in the Proceedings of the National Academy of Sciences in 2011 (Powers et al., 2011).

Field measurements on mineral soils

We investigated the impact land-use change has on SOC stocks in deeply weathered mineral soils of three REDD-ALERT study regions: (a) Jambi province, Sumatra, Indonesia, (b) southern Cameroon and (c) Ucayali province, Peru. Using a space-for-time substitution sampling approach, we quantified SOC stocks in the top 3 m of soil and compared converted land-uses with adjacent reference forest plots. In each country, we investigated the most predominant land-use trajectories relevant for the respective region. These included conversions from forest to cash-crop tree plantations (rubber, oil palm and cacao), conversions from forest to cattle pastures, and the conversion from forest to shifting cultivation systems (a rotation of crop-fallow-crop). In total, 157 plots were established where soil samples were taken to a depth of 3 m from a central soil pit and from the topsoil from 12 pooled composite samples. All soil samples were analyzed in the laboratory at the University of Goettingen for C, N, pH and effective cation exchange capacity (ECEC).

This study found that the conversion of forests to intensively managed land-uses such as oil palm plantations, cacao plantations, rubber plantations and cattle pastures caused significant SOC stock losses in the topsoil (Table 2). In contrast, the less intensively managed shifting cultivation land-use exhibited minimal change in SOC stocks in the soil profile.

Despite the fact that most of the SOC from the 3 m profile is found below 1 m depth (50-60% of total SOC stock), this subsoil C stock remained relatively unchanged by the land-use conversion. The only exception was in cacao plantations where decreases in SOC stock were measured down to 3 m. These plantations were generally much older and it is speculated they had the time to reach a steady state condition throughout the soil profile. The results on the magnitude of SOC losses in the soil profile and the constraints regulating C concentrations and changes therein is expected to be published in early to mid 2013.

Measurements of GHG emissions from mineral soils took place in the province of Jambi, Sumatra, Indonesia. Along a gradient of forest disturbance including rubber and oil palm plantations on mineral soils, measurements of C stocks and soil trace gas emissions were conducted during the period July 2010-August 2011. Soil N₂O emissions were slightly reduced after forest degradation and conversion to rubber plantations but increased after conversion to oil palm plantation due to nitrogen fertilizer application. Soil CH₄ fluxes changed from sink to source with forest degradation and conversion to oil palm plantation because of increased termite nests presence in these land-uses. An analysis on how termite species differently influence soil fluxes of CH₄ is being conducted. Fluxes of N₂O were significantly correlated with CH₄ fluxes; mineralisation and nitrification potentials of the soil mineral N content and with the soil water-filled pore space during wet months. Soil respiration was not significantly affected by land-use change. The results on soil and vegetation C stocks are still being processed, and several publications are expected from the research.

Field measurements on peat soils

Field research in Jambi was also implemented in peatlands. Carbon stocks in living and dead vegetation, above- and below-ground, were measured in a primary peat swamp forest, a logged and drained peat forest, and a seven-year old oil palm plantation on peat. Total biomass C stocks decreased from 220 - 7 Mg ha⁻¹ in the primary forest to 100 ± 2 Mg ha⁻¹ in the logged drained forest, and 32 - 4 Mg ha⁻¹ in the oil palm plantation. Woody debris contributed 7% to total C stock in the primary forest, and as much as 43% and 31% in the logged drained forest and the oil palm plantation, respectively. Coarse root biomass represented 14%, 10% and 21% of total C stock in the primary forest, logged drained forest, and oil palm plantation, respectively. In the same land-use treatments, the root:shoot ratios of trees/palms were 0.19 - 0.01, 0.21 - 0.04 and 0.60 - 0.42. The research will be submitted to the journal Forest Ecology and Management in 2013. Soil respiration was also measured in these systems. Preliminary results of measurements conducted between January and September 2012 indicate emission rates of 16 - 1.2, 18.5 0.7 and 28.4 1.2 Mg CO₂-C ha⁻¹ yr⁻¹ in the primary forest, logged drained forest, and oil palm plantation, respectively.

A further five sets of field experiments to measure GHG emissions were conducted in five land-use types located in Jambi and Riau, Sumatra Island. The first study aimed to evaluate total soil respiration as a function of distance from oil palm trees in relation to root distribution. The study was conducted on peatland under 6 and 15 year old oil palm plantations in Jambi Province, Indonesia from June 2011 to April 2012 and from January to April 2012, respectively. CO₂ emissions were measured using an infrared gas analyser (IRGA), Li-COR 820. Total respiration was two to three times higher at points 1 m compared to that at points 3 m and linearly decreased with distances from the trees. At distances of 3.0-4.5 m from the trees the emission no longer increased with distance, indicating negligible influence of root-related respiration. The emission values at this distance for the 6 and 15 year old oil palm plantations were 38 and 34 Mg CO₂ ha⁻¹ yr⁻¹ respectively. CO₂ flux measurements in oil palm plantations would adequately represent the heterotrophic respiration if made at a distance of 3 m or more from the tree centre.

The second study was focused on the variation of CO₂ emissions at five land-use types including oil palm, acacia forest, rubber, secondary forest and bareland in Riau, Jambi and Aceh, Indonesia. We conducted a detailed study of CO₂ emissions using an infrared gas analyzer (IRGA LI-COR 820 model). CO₂ emissions (Mg ha⁻¹ yr⁻¹) under oil palm plantations in Riau, Jambi and Aceh ranged from 18 -13 to 66 - 24 Mg ha⁻¹ yr⁻¹, with the average of about 39 -19 Mg ha⁻¹ yr⁻¹. For adjacent plots with maximum distance between plots of 3.2 km, in Kampar Peninsula, Riau, CO₂ emissions from secondary forest, acacia forest, bareland, rubber and oil palm plantation were 60 25, 60 19, 56 26, 52 17, 66 24 Mg ha⁻¹ yr⁻¹, respectively. Our results showed that CO₂ emissions increased with the increase of water table depth. Our finding is comparable with other CO₂ flux measurement and can contribute to reducing uncertainty of peat CO₂ emission estimates.

In the third study, we examined effects of various levels of water contents and laterite application on microbial (heterotrophic) respiration of peat soil. Bulk samples of surface (0-20 cm depth) and subsurface (30-50 cm depth) layers were collected from an oil palm plantation in Riau Province, Indonesia. Peat water contents were adjusted at 20, 40, 60, 80, and 100% water-filled pore space (WFPS). Laterite soil (clay containing high Al and Fe oxides)

was applied at 3, 6 and 12 mg g⁻¹ dry weight (1.2, 2.4 and 4.8 Mg ha⁻¹) for peat samples at 60% and 100% WFPS. Peat respiration differed between the soil layers, and was distinctly affected by water content, but less affected by laterite application. Peat respiration increased sharply from wet (80% WFPS) to moist soil (60 to 40% WFPS) and decreased when the soil became dry (40% WFPS). Maximum peat respiration for surface and sub-surface layers occurred around 50% and 30% WFPS, respectively. Laterite as a peat ameliorant accelerates rather than reduces peat respiration and thus it cannot be used for CO₂ emission reduction.

The fourth study related to the spatial variation of CO₂ flux with water table depth, soil moisture, and temperature under oil palm plantation in Jambi Province, Sumatera, Indonesia. A total of 480 CO₂ flux measurements were made using an infrared gas analyzer (IRGA) every three months, at six different time intervals in a day. The results showed that the average CO₂ flux was 46 ±30 t CO₂ ha⁻¹ yr⁻¹ (n=480). Within the one year study, the average CO₂ flux did not show a clear relationship with instantaneous water table depth, soil moisture, and temperature. A positive correlation between these variables and the CO₂ flux only occurred in October 2010, coinciding with the beginning of the wet season. The distance measurement points from the edge of the canal showed a positive correlation between CO₂ flux (R²=0.6), water table depth (R²=0.6), and soil moisture (R²=0.5). The factors driving the CO₂ flux at the study site was very complex, each affecting each other and working simultaneously.

In the fifth study, CO₂ flux measurements were made in intact forest, logged forest, and oil palm plantation sites using four methods - sampling at specified distances from palms, ¹³C isotope analysis, random collar total efflux sampling, and simulation modelling. Results indicated interference in the ¹³C results - likely from methane oxidation, which has never been considered in this method before. Average total CO₂ emissions from sites were 29 t CO₂ ha⁻¹ yr⁻¹ in the wet season in the intact forest and 71 t CO₂ ha⁻¹ yr⁻¹ in the dry season. Logged forest emissions were double in the deeper peat sites (109 t CO₂ ha⁻¹ yr⁻¹) than the shallow peat sites (57 t CO₂ ha⁻¹ yr⁻¹). Across the different oil palm sites total emissions ranged between 33-98 t CO₂ ha⁻¹ yr⁻¹ on the deep and shallow peats. Heterotrophic emissions (excluding rhizosphere respiration) in the oil palm sites averaged 15-38 t CO₂ ha⁻¹ yr⁻¹. Modelled heterotrophic emissions were higher at 37-55 t CO₂ ha⁻¹ yr⁻¹ (higher due to the inclusion of rhizosphere respiration), and modelled net emissions at 44-60 t CO₂ ha⁻¹ yr⁻¹. Soil C sampling established peat depths and C stocks of all sites - peat depths varied between 3-7 m across all sites. Final analysis on the intact sites peat stocks is still ongoing, but in the oil palm sites total C stocks ranged between 171-199 t C ha⁻¹ m⁻¹ depth.

Effects of fire on the organic matter composition of tropical peat

This part of the work was based on investigation of how fire modifies peat organic matter chemistry with particular regard to shifts in carbon pools. The project was conducted in the tropical peatlands of Kalimantan, Indonesia. The research began with initially assessing the organic matter composition of recently burnt peat using a variety of methods including Pyrolysis-GC/MS (Py-GC/MS). This qualitative method provides a chemical fingerprint of the organic matter composition.

The first section of work assessed the short term effects of fire by assessing organic matter composition one month post-fire. Structural differences between burnt and unburned (inundated and drained) peat samples suggest that a combination of both fire and drainage causes alteration of the OM composition that is evident shortly after fire. The main observations are summarised as follows:

- (i) Unburned, inundated peat pyrolysates contain contributions from all compound classes. Lignin products such as guaiacol, methyl guaiacol and ethyl guaiacol are dominant for unburned samples.
- (ii) Long term drainage conditions induce oxic conditions in the upper peat layers causing a reduction in OM diversity particularly below 30 cm from the surface. Drained peat pyrolysates are dominated by aliphatic components.
- (iii) Surface, recently burnt and drained sample pyrolysates are, however, composed predominantly of aromatic and aliphatic compounds and are significantly reduced or depleted in all other compound classes, including lignin and polysaccharide derived compounds. A high aromatic and aliphatic content, including a large contribution from n-alkene/alkane doublets, suggests that the burnt peat is highly refractory and that much of the labile component has been lost or converted to other C forms.
- (iv) Subsurface burnt and drained sample pyrolysates are associated with aliphatic moieties with considerable variance from surface samples. Differences in surface vs. subsurface burnt and drained samples are attributed to differences in the impact of fire and decomposition.
- (v) Although fires in tropical peatlands are often considered to be smouldering, thereby penetrating the peat substrate, data in this analysis suggest that effects on the OM were predominately experienced in the surface peat layer (0-5 cm). Any differences between intact inundated peat and subsurface peat in burnt drained sites are likely to be caused by decomposition processes.

The work proceeded to investigate the impacts of different fire regimes on the peat organic matter including the longer term effects of fire on organic matter chemistry. Data suggests that there are significant differences in organic matter composition between recently burnt peat and peat collected approximately 1.5 years post-fire; however, these differences were only significant between surface samples. Below 5 cm organic matter composition does not significantly vary. Shortly after fire (November 2009), sample pyrolysates of the upper 5 cm of peat are significantly different from those collected approximately 1.5 years later (April 2011). PCA analysis differentiates between recently burnt peat and peat which had not been burnt for several years. Initially burning had transformed the peat OM composition so that it became highly aliphatic with considerable contributions from aromatic compounds as well as pyrolysis products thought to indicate the presence of charcoal e.g. naphthalene. 1.5 years later sample pyrolysates remain highly aliphatic, with considerable contributions from alkenes and alkanes. Dimethylnaphthalene and trimethylnaphthalene (biomarkers of charred material) both plot in similar factor space when assessing variance using PCA, the presence of such compounds 1.5 years after fire suggests charred organic matter is still present but less dominant than in those samples analysed shortly after the fire was extinguished. However the overall OM diversity (i.e. number of pyrolysis products identified,

(111 Vs 72-75) has increased and there is evidence for some labile components such as cellulose (as indicated by levoglucosan) and furans which were depleted immediately after the fire. The proportion of oxygen in surface sample pyrolysates increases during the 1.5 year recovery period (3.9 % Vs 0.75 - 0.35%) which is due to the increased abundance of oxygen containing functional groups in polysaccharide and lignin derived compounds. In summary, peat fires cause considerable alteration to peat organic matter however these predominately impact the upper 5 cm of peat - with less significant change at depth. The peat organic matter composition becomes more diverse 1.5 years after fire but even 14.5 years post-fire the organic matter does not recover back to its natural undisturbed state. Therefore it is suggested that fire has long term effects on peat organic matter however much of this change, albeit on a shorter temporal scale, mirrors compositional changes caused by long term peat drainage.

Understanding how tropical peatland fires modify peat OM composition can contribute to an improved knowledge of post-fire carbon cycling and nutrient cycling. Thermally induced alteration of peat OM may be inhibiting ecosystem recovery, ultimately influencing the global carbon balance. The results of this work also demonstrates that fire has caused the most labile OM components to be removed from the upper peat layer as well as the neoformation of aromatic structures, thus increasing the recalcitrance of the peat substrate. Changes in such carbon pools are likely linked to peat soil respiration rates as a recalcitrant peat effects by fire is more resistant to microbial decomposition than a labile peat- not affected by fire. Alteration of the OM composition may also have implications for physical properties on peat soil, for example enhanced water repellence, which would impact upon surface runoff and solute transport.

Objective 4: Identifying and assessing viable policy options addressing the drivers of deforestation

Drivers

The research in WP4 has shown that most instruments in the forest sector deal only with proximate drivers, and often in an inequitable manner. Very few deal with underlying drivers, and to the extent that they do so their effect is limited (e.g. debt for nature swaps, certification). However, the very nature of the underlying drivers (e.g. demographic, economic, technological, political or cultural trends) is that they are often slow processes operating at national or global levels resulting from the aggregated behaviour of many regional, national, subnational and individual entities (in some cases), referred to in the Panarchy literature as slow variables. Effecting change in these slow variables is either difficult due to their inertia, or unpredictable due to chance interactions with faster changing lower scale variables, and may therefore be beyond the power of any one of these entities to address. Collective action at the global level is clearly required, but there are often conflicting national interests (usually economic) that weaken the international resolve to find solutions to global environmental problems.

One way, however, to address underlying drivers of deforestation at the national level may be to mainstream forest protection into development paths. Forest policy needs to be integrated into sustainable development. This may not be easy in early stages of development or in early stages of the forest transition curve - as the motivation to develop often comes at the cost of resource extractions from forests and forest land. The implication of this is that without substantial financial and institutional support from external actors, mainstreaming forests into forest governance in countries where a large percentage of land is under forests is unlikely.

Systems approaches

Regardless of the degree of deforestation present in a country, for lasting solutions to be developed, it is essential to see forests as components of larger systems of land use, which also include arable agriculture, grasslands, wetlands, and human settlements. Deforestation is only one of several major problems that humans need to grapple with in the next century - together with concomitant increases in demand for food, water and energy against a backdrop of climate change, urbanisation, and limited land resources, this has been referred to as the 'perfect storm'. Dealing with any one land use component (such as forests) in isolation is likely to result in partial solutions at best as the Law of Unintended Consequences starts to operate. Providing alternative employment opportunities to reduce dependence of people on forests for their livelihoods, for example, may result in increased GHG emissions from the industrial sector.

Although REDD began as an initiative to reduce deforestation, it is becoming apparent that if the global community is serious about reducing net GHG emissions, a systems approach is needed. This systems approach should take into considerations the many and complex interactions between forestry, agriculture and urban sectors, so as to optimise the fluxes of carbon and other nutrients, as well as social and economic flows, between different parts of

the landscape. In this context, some even ask whether REDD funding might be effectively used for funding agricultural research to increase production on existing agricultural land, reduce losses in the food chain, and return nutrients from urban to rural areas, thereby reducing the need to clear further forests. Investing in agricultural research is a mitigation strategy in its own right - it has been estimated that the avoided emissions through agricultural intensification since the 1960s have only cost around 4/tCO₂e saved, cheaper than many other abatement measures.

Using the politics of scale approach, we have argued that countries have reasons to scale up or scale down forest governance issues. The potential promise of REDD helped to generate global consensus on the need to deal with forests at a global level. However, if the resources are not forthcoming, this may lead countries to revert to their original position of seeing forests primarily as a subject of national sovereignty and a source of income. We, however, makes the case for 'glocal' forest governance - a process by which local through to global issues, trends, drivers and instruments are given due attention and an iterative multi-level governance framework is developed for sustainable long-term policy that goes beyond REDD. A general principle in designing such a governance system should be in devolving decision-making down to the lowest relevant level for the issue being addressed, and developing conflict resolution mechanisms for when these decision-making processes don't align.

Expert opinion

We investigated experts' opinions about climate change mitigation forestry-based programmes/projects in the tropics, first of all under REDD+. Both qualitative and quantitative social science research tools, including Q-method, SWOT analysis, MCA and others, were elaborated further (Nijnik et al., 2011) and applied. The results provide some useful insights into REDD/REDD+ scope, financing, policy measures and instruments of tackling deforestation, institutions and governance, costs and benefits, major risks anticipated, etc.

Our findings show the diversity of experts' views on REDD+. Three out of four attitudinal groups identified and explained (named, accordingly, as Pragmatists, Conventionalists and Optimists) express their overall support to REDD+. They seem to be recognising the necessity of REDD+ and the importance of its main objectives (with the exception of monitoring and several others), yet expressing different levels of belief in REDD+ effectiveness and acceptability. Findings indicate a consensus on the necessity of (i) tackling climate change through forestry in the tropics; (ii) increasing the value of standing forests (including its biodiversity); and promoting sustainable forest management. Experts, however, have certain doubts about the inclusion of REDD+ into international carbon markets; concerning financial efficiency of REDD+; coping with leakages (Dyer & M, 2013); and involving community forests into REDD+ schemes (Nijnik et al., 2013).

Numerous challenges identified through attitudinal analysis relate to land eligibility, tenure rights, transaction and opportunity costs, shortage of local experts, etc. However, overall, there is evidence to suggest that tackling climate change through combating of deforestation and promoting sustainable forestry in the tropics could positively shape

climate mitigation policy (Nijnik, 2010), and, if successful, could provide additional economic, social and environmental opportunities (e.g. of biodiversity conservation, and/or poverty alleviation) in the host countries (Nijnik & Halder, 2013).

An important finding from this research is also that not all experts appeared to be supportive to REDD/REDD+. There is a category of people (named as Sceptics) who reject the majority of objectives and issues related to it, showing their general disbelief in REDD programmes (Nijnik et al., 2013). Thus, awareness raising and capacity building remain crucial for success (Nijnik et al., 2011).

The results also indicate that the potential of REDD/REDD+ is shaped not only by international climate change intervention policy, but to a large extent by national and regional policies and various cultural values that affect the ability to develop forest-based activities on the level of indigenous communities, businesses and on the acceptability of these projects by local people (Nijnik et al., 2011). There is a complex interplay of the proximate and underlying causes of deforestation. Its drivers operate at different scales and are not easy to handle. It has been the case that land use decisions are shaped less by market signals and more by the distortions generated by arrangements on the national, regional and local levels of governance.

To conclude, findings from this research could be of help to decision-makers in preventing and/or resolving the conflicts (e.g. between stakeholder interests), and in designing climate policy measures, as well as in better targeting of REDD type projects, for them to also provide co-benefits to end-users more effectively, both at a local level and internationally.

Measures to ensure REDD+ success

To the extent that REDD can provide temporary relief to the climate change problem, we have proposed twelve generic measures that can help to embed REDD within the domestic forest institutions and have shown how these generic measures have contextual implications in Vietnam, Indonesia, Cameroon and Peru.

First, REDD is only likely to work if there are enabling conditions in a country. This is partly the purpose of REDD Readiness activities. Second, REDD needs to be integrated into or linked to existing relatively successful domestic institutions, rather than distract resources and manpower away from other goals. In Vietnam, this would imply linking to the institutions of Programme 661 and the national Protected Areas; for Indonesia to existing concepts of community forests, ecosystem restoration, the moratorium and peat land policy, in addition to the existing zoning of conservation, production and protection forests; for Cameroon, the Council Forests, and the existing tax distribution opportunities to build upon for REDD payments; in Peru, the community forests, concession system, the Protected Areas, and ecosystem restoration. Third, REDD should build upon other international policies and programmes and not replace them. This implies it could build upon international certification standards through mutual learning. It could try and link the MRV to the existing FLEGT programmes. Lessons learnt from the implementation of CDM projects may be helpful. Fourth, there has been much discussion about the need to ensure co-benefits and local safeguards at the international level. The case studies reemphasized the need to

ensure that access to food and water by local and indigenous communities in the forest zones is not compromised. Some instruments tend to marginalize or even criminalize the existing customary rights of local communities and force them to 'encroach' on peripheral lands and buffer zones, or to move to marginal lands where they may have to engage in slash-and-burn activities which represent a form of leakage. If people lose their access to customary rights, their survival may be affected unless alternative incomes and resources are made available to these people. Fifth, reference levels need to balance the goal of reducing and eventually eliminating tropical deforestation with countries' needs for development. Sixth, if REDD aims at financing those who protect the carbon content of forests, it is important to identify what the possible categories of beneficiaries are and who in specific is eligible to be a beneficiary. Seventh, the beneficiaries need to understand what they are being compensated for. The Vietnam case study shows that local A/R-CDM participants did not quite understand the CDM and this affected their ability to effectively participate. Eighth, the benefit sharing system including payment levels need to be clear. It is highly likely that if these payment levels for protecting forests are lower than the opportunity costs of using the land for other purposes, they will not be effective. At the same time, if differentiated payments are made, this may ironically provide more resources to those who are already relatively resource-rich and wish to exploit the land for commercial purposes, and less to those who are poorer and have subsistence needs - thereby exacerbating local inequities. International NGOs suggest a Fair and Efficient REDD Value Chain Allocation to ensure equity in the process of benefit sharing. Ninth, it is important that how the payments are made and benefit sharing with the local people is clarified. This needs to be undertaken carefully to avoid elite capture, a key challenge in all four countries. Experiences in individual countries, for example, the payments to household groups in Vietnam, could be built upon. Tenth, the issue of free, prior and informed consent of local communities and individual groups is critical. Eleventh, the design of the instrument should combine a market approach with regulatory approaches in order to work in the context of these countries. Indigenous people's groups have argued that they wish to bypass the nation states to access REDD resources directly. However, without the enabling conditions that a national system would potentially provide, efficiency, effectiveness and equity might not be achieved. Twelfth, it may be necessary to think in terms of regional approaches to avoid regional leakage.

Future challenges

Countries are gradually investing in becoming ready for REDD projects in the hope that it will develop into a win-win situation. However, there are indications that if REDD is poorly designed and/ or implemented, it may turn into a lose-lose situation. But knowledge is power, and awareness of the risks may help countries and social actors mobilize themselves to prevent such risks. Furthermore, there is a possibility that the awareness of the actual costs of implementing forest conservation equitably may lead many to see this as less than cost-effective, and thus reduce the incentive to invest in. REDD faces considerable challenges; if these challenges are not rapidly addressed, REDD may disappear from the global agenda in its current form as suggested by the issue attention cycle.

Its enduring legacy, however, will be that it has mobilized global attention and social actors on the need to understand forests and human-forest interactions. There is far greater understanding of the drivers of deforestation in different countries and the limits of instruments in dealing with these forests. There is a realization that there is need to take a systemic view and see if mainstreaming forests in national development, agricultural, energy and mining policy leads to understanding how best to deal with forests. The next step thus is to understand how to mainstream forests and see if countries can reconcile their need and right to develop with the need to protect forests not just for themselves, but for the myriad local ecosystem services that they provide as well as for the global ecosystem services that they provide. This knowledge and the mobilization of a large number of actors may be in itself critical for creating a more comprehensive, equitable, legitimate, effective, efficient and enduring system for dealing with forests. As in the myth of Sisyphus, it will remain an uphill struggle.

Objective 5: Analysing policy scenarios on GHG emission reductions, land use and livelihoods

Assessing agent-based models

Agent-based simulation modelling has recently been arousing interest, due to its ability to model individual decision-making entities and their interactions, to incorporate social processes and non-monetary influences on decision-making, to conceptually reproduce non-linearities ('tipping points') often observed in space-time processes of innovation and change, and to dynamically link social and environmental processes.

As a starting point, Matthews & Dyer (2011) discussed whether traditional neo-classical economics models were adequate to analyse all policy instruments that might be deployed in a REDD+ context. It is now recognised that decision-making is influenced by many other factors beyond those considered by traditional economics (Geist & Lambin, 2002). Akerlof & Schiller (2009), for example, list a number of 'animal spirits' that include confidence, fairness, corruption, pride, shame, neighbour influence, and social pressure, that are also influential, all of which will be relevant to a household's willingness to engage with REDD schemes. For example, even if it is economically rational, people might be reluctant to participate if their previous experience with local government has given them little confidence in whether they will actually receive compensation for not deforesting, despite alluring promises from officials. To account for these non-economic factors, van Vugt (2009) has proposed a 4Is framework of Incentives, Information, Identity, and Institutions, that influence people's decisions. Incentives in this framework include any incentives that enhance a household's assets.

Gathering data on these decision-influencing factors, however, is a significant challenge, particularly in developing countries. However, Matthews & Dyer suggested that each aspect in itself needs to be explored in depth to provide greater insight into decision-making processes and their implications than we have at present. At some time in the future it might be necessary to combine the important factors, particularly if interactions between them are being explored. A first step would be to include these factors into the models that

we have already, and use sensitivity analysis to determine the likely influence they have on the overall dynamics of the system and the conclusions reached. Efforts could then be focused on obtaining information only for those factors that produce qualitatively different conclusions from traditional approaches.

Villamor et al. (2011) then reviewed different agent-based modelling approaches and the extent to which they consider the diversity factors inherent to landscape mosaics. Diversity challenges start from the representation of agents (i.e., aggregate or individual, and types), the agent decision making rule (i.e., social to less social factors approach), the agents' interaction medium (i.e., agent-to-agent, and/or agent with environment), and the integration of biophysical processes. They then discussed the challenges in integrating the non-economic motivations discussed above into the decision making of human agents, concluding that no comprehensive methodology is currently available for modelling of this type, and suggest that objective and interdisciplinary criteria should be used when scoping and constructing a model, and that the model should be based on the ultimate purpose of the outputs for planners or local people.

Modelling ecosystem carbon stocks

Most of the literature review and meta-analysis in WP3 (Powers et al., 2011) related to carbon stock changes associated with land-use changes in the tropical forest margins were partial with the analysis of either only NPP productivity or aboveground biomass or soil changes. To understand the effect of land-use change on the overall carbon stock changes, we need a whole system approach in which carbon in soils, roots, detritus, and other aboveground components are estimated following the pattern of land-use change. No review studies to our knowledge have been done to establish such relationships between the ecosystem carbon (sum of all organically derived carbon in various pools: both aboveground and belowground including soil) and various climatic or soil factors. We decided, therefore to extend this to also include above-ground carbon pools, using both a review of the literature and models for simulating the forest transition, to derive simple relationships between environmental variables such as temperature, water and soil variables such as clay and SOC content with the ecosystem carbon stock under a land-use or land-use change following deforestation in tropical forest regions.

The results of the study show only limited studies or data are still available that can estimate the carbon pools at an ecosystem level and we need more field studies to fill the gap. A simple regression model was derived using a small set of parameters, and was found to be useful to estimate the C stock changes associated with the land-use changes in the tropical forest margins. The results of the regression analysis showed that mean annual temperature is the most important single variable which explains much of the variability in carbon pools and pool changes under various landuse and landuse changes. However, there is a need to validate the model with a wider range of environmental and soil conditions before they can be used with confidence. Above- and below-ground measurements of carbon stocks were subsequently made (within WP2 and WP3) in three of the study sites - Peru, Cameroon and Indonesia - and at the time of writing are still being analysed. A draft paper is in preparation and is expected to be completed early in 2013.

Modelling carbon and GHG dynamics in tropical peatlands

This part of the work was closely linked with the field work on the peatlands in Jambi in Indonesia which has been described above. As a starting point, a review of peatland models was made to assess their suitability for simulating tropical peatland processes (Farmer et al., 2011). Modelling efforts to date have been restricted by the lack of available data for parameterisation, input and validation of simulation models, due to the complex and often inaccessible nature of tropical peatland ecosystems. There have been very limited experimental or modelling studies to predict GHG fluxes from tropical peatlands. A model for tropical peatlands would need to include descriptions of hydrological dynamics, temperature, litter quality, microbial community structure, redox potential, disturbance impacts, ebullition, plant mediated transport, and dissolved organic carbon. It was concluded that there is currently no single model suitable for application to tropical peatlands, but there are a range of models which have been used in temperate zones that could be adapted. Although all models reviewed used a C pool approach, they do not yet include enough detail of the specific characteristics of these systems, including the nature of the C inputs and details of the relevant microbial processes. One of the most physically obvious differences between temperate and tropical peatlands is the 'lumpiness' and resulting heterogeneity of the C inputs in the woody litter from the tropical forests in comparison to the more readily decomposed input in temperate and boreal peats. The differences in net primary productivity, litter inputs and rooting structures all present challenges in adapting temperate peat models for use in tropical peatlands.

Following this review, work started on the ECOSSE (Estimating Carbon in Organic Soils - Sequestration and Emissions, Smith et al., 2010) model to adapt it to tropical conditions. ECOSSE is a model that simulates carbon and nitrogen dynamics in mineral and organic soils, and the emissions of CO₂, CH₄ and N₂O. At the same time, a simpler spreadsheet model, the Tropical Peatland Plantation-Carbon Assessment Tool (TROPP-CAT) was developed to provide policy makers, plantation managers and researchers in Indonesia and internationally with a user friendly tool to evaluate and predict soil carbon losses and carbon dioxide emissions from tropical peat soils. The tool requires twelve simple input values to determine the rate of subsidence, of which the oxidising proportion results in CO₂ emissions. TROPP-CAT has been applied for both site specific and national level simulations, on existing oil palm and acacia plantations, as well as on peat swamp forest sites to predict likely emissions from future land use change. Through an uncertainty and sensitivity analysis, literature reviews and comparison with other methods of estimating soil carbon losses, opportunities for future model development were identified, bridging between different approaches to predicting CO₂ emissions from tropical peatlands under land use change. A paper is in preparation on the development and application of the TROPP-CAT model, which will be submitted to the Special Issue of Mitigation and Adaptation Strategies for Global Change.

Modelling REDD+ scenarios

The work described here is concerned with developing agent-based models to investigate how local actors, such as subsistence households, firms, companies or local government institutions, may respond to various REDD+ policy instruments. Three such models were

developed to represent actual actors in each of the three study areas, Indonesia, Peru and Cameroon. An innovative aspect in the Indonesian model was to develop representations of institutions through which the main policy levers that are considered for REDD+ could be implemented at a local level. Decision-making rules for the agents in terms of land use choices were developed from the econometric data and stakeholder information collected in surveys. The rules used were used to understand the likely responses to various policy instruments, including taxes, incentives, regulations, provision of alternative employment, etc.

Indonesia

In Indonesia, the model goal was to understand the role of carbon credit price and collective action on REDD+ in a multi-stakeholder forested landscape (Purnomo et al., 2012). The model represented a general provincial landscape with a forest core, forest margin, and agricultural mosaic with various actors i.e. local government, service providers, buyers, designated national authority (DNA), national government, and international supervisory body. A conceptual map rather than a real map was used to enhance the usability of the model. Issues pursued were related to the effect of carbon prices, brokering, actors' altruism and institutional arrangements on the effectiveness, efficiency and equity of the reduction of carbon emissions. Taking into account actors' altruism at the landscape level in designing REDD+ implementation options is often overlooked in the current REDD+ modelling research and debates.

The model was used to evaluate the impact of REDD+ options on Effectiveness, Efficiency and Equity (3E+). Effectiveness refers to the magnitude of the emission reduction, Efficiency refers to the magnitude of the emission reduction in relation to the cost, while equity refers to fair distribution of benefits between and within countries and the effects of REDD+ activities on local communities. News on carbon trade from Carbon Buyer agents is disseminated among potential Credit Provider agents. Providers then ask the Facilitator agent to assess their patches on land rent, carbon stock, reference level, additionality and threat. The Facilitator agent then informs the patch owners/managers of the available carbon credit. The Facilitator agent also offers the carbon credit to Carbon Provider brokers that want to buy carbon credit. The negotiation occurs at this point. Meanwhile the potential Buyers will assess the degree of trust that the Providers hold. Negotiation between two kind of brokers (i.e. Buyer brokers and Provider brokers) will or will not produce an agreement on the carbon trade. The Facilitator is a local government, with help from central government, DNA and international supervisory bodies. The Verification Body agent works to verify the carbon emission potential from the patches facilitated by the Facilitator. The main actors are all economically rational, wanting to maximize their own interests and benefits. Their rationality determines the way they negotiate to reach an agreement. Only when they can all benefit can REDD+ work. There is no collective action based on the common goal and interest among actors. All are driven by self-interest and economic rationality to maximize their benefits from the resources they exploit and manage. Under these circumstances, results showed that if, and only if, the global price of carbon is more than \$25 tCO₂e⁻¹, then carbon stocks will be increased in the landscape.

We next explored the implication of including altruism into the model. If, for example, campaigns to make actors aware of global warming are intensified and they are willing to pay for reducing global warming, then it may be possible to reduce carbon emission even with a lower price through collective action. Each agent was given an altruism index (a) which was influenced by degree of communication (c), welfare (w), equity (e) and how they perceive threat from environmental damage (t). Results showed that an environmental awareness campaign on carbon may well work and help improve the effectiveness of REDD+. Starting from a carbon price of \$15 t⁻¹, effectiveness increased as the price increased, but more so if the campaign was carried out effectively.

Peru

For Peru, an agent-based model in a general equilibrium context was used to explore via four scenarios the implications of a simple PES program and three variations designed to address its shortcomings (Dyer et al., 2012). The model represents various agents interacting within the local economy of a farming community in a developing area. Every household in the sample -i.e. 49 households- is modelled as an independent decision maker that engages in various economic activities, including on-farm activities and wage labour. Although independent, each agent interacts with multiple other agents across the local economy. Among the defining characteristics is land ownership, which distinguishes landholders from the landless. According to survey data, 96% of households in the locality own arable land. The average land holding is only 0.4 hectares, but endowments vary widely (s.d. = 0.50). The skewed distribution reflects the fact that 2% of households own nearly one fifth of the land. The presence of a land-rental market is implied by the fact that farmers outnumber landowners. In fact, 37% of arable land is traded in this market, creating an alternative classification of agents: a household that rents land out constitutes a landlord, while those renting it in constitute his/her tenants. Two out of three landless households - i.e., 4% of the local households- are tenant farmers; but an additional 35% of landowners also rent land in to complement their own endowments. Almost 20% of rented land is supplied by local landlords; the rest is rented out by absentee landowners who own 30% of the land in the locality. The market thus entails the involvement of exogenous agents, i.e., individuals who do not live in the locality but own and rent land within its boundaries. Agents also interact through the exchange of labour and through trade in local maize markets. Labour exchanges identify agents as either employers (48% of households and absentee landowners) or employees/farm workers (48%). Similarly, participation in maize markets distinguishes subsistence farmers (94% of households) and non-farmers, all of whom buy maize, from the commercial (or surplus) producers who sell it. Commercial farmers nevertheless consume a variable share of their output on-farm; i.e., they sell only their surpluses. Finally, the program's implementation introduces an additional agent, namely a program administrator. Interaction with this agent, who is otherwise exogenous to the local economy, identifies agents as either a program participant or a non-participant.

Results showed the following points:

- There was a complex relationship between the 3Es (effectiveness, efficiency and equity) not evident in more aggregate analyses

- Landowners could benefit by enrolling local land into a REDD+ program, but local subsistence demands would raise their opportunity costs
- Rent and wage changes create net costs for most private stakeholders
- Increasing C prices reduces the program's efficiency without solving its inequities
- Expanding the program reduces inefficiencies but increases private costs with only minor improvements in equity
- A program that prevents job losses could be the best option, but its efficiency compared to direct compensation could depend on program scale
- REDD+ mechanisms should avoid general formulas by giving local authorities the necessary flexibility to address the trade-offs involved

Cameroon

An agent-based model was developed to study the impacts of agricultural intensification on the reduction in deforestation in a REDD policy context, using data from household surveys in Southern Cameroon. Simulations were run for a business as usual scenario, with results reproducing the current rate of deforestation in the area. Agricultural intensification was studied by introducing a fertiliser subsidy scenario for mixed food crops to estimate avoided deforestation as a function of the subsidy levels.

Simulations showed that a considerable decrease of deforestation rate can be achieved at less than 10% increase of productivity during the initial five years: deforestation rate goes from 1% in the BAU scenario to a negative rate of -0.4% (reforestation) when crop productivity is increased by 10%. Although an additional benefit of the scheme is the net increase in the number of households meeting their food demand when they have access to subsidised fertilizer, the efficiency of the scheme seems to be independent of the subsidy level. However, it is expected that the incorporation of transaction costs would make lower levels of subsidy less cost-effective.

Objective 6: Developing and using new negotiation support tools

The objective of this work-package was to seek the direct engagement of local, national and international stakeholders in the emerging mechanisms to reduce emissions from deforestation and degradation (REDD), by 1) synthesizing their perspectives, and 2) exploring with the stakeholders how the various REDD+ mechanisms (combining positive and negative incentives) could work out in practice. Role-play versions of process-based simulation models allowed for active engagement with 'agents of change' that provide incentives to increase or decrease emissions. In parallel, 3) agent-based modelling and simulations explored the efficiency/fairness trade-off in REDD+ incentives and sought to establish benefit-sharing solutions that are acceptable to all.

Emission reduction primarily requires a shift in development trajectory for tropical forest margins, dealing with multiple actors, multiple incentives and multiple knowledge types. Actual economic benefits derived from land use changes that cause emissions have been low for forest-to-pasture conversion in the Amazon and for most types of land use change on

peatlands in SE Asia. Even where such 'opportunity costs' (net economic benefits of land use change foregone) are below a feasible C price, actual shifts in development trajectory require incentives that work for all, are within acceptable concepts of fairness and efficiency for all who might otherwise sabotage the process.

Four approaches to opportunity cost estimates

We compared the methods for four approaches to opportunity cost curves and advised where in the process of negotiating actual contracts that include Free and Prior Informed Consent, information needs to shift from (I) retrospective costs of system level change, and (II) retrospective analysis at pixel level, to forward looking scenario comparisons at landscape (III) or agent (IV) level.

Multiple paradigms within Payments for Ecosystem Services (PES)

In a major review of the literature on PES we found that the paradigms of commoditisation, compensation and co-investment need to be disentangled. Much of the PES literature describes commoditisation ('carbon markets') as an ideal, but most of the practices that work have a strong co-investment character, where multiple currencies are at play (respect, recognition, rights as well as economic rewards), while risks as well as benefits are shared.

Paradigms across scale

Contrary to current perceptions of REDD+ where exchanges of money for emission reduction are to be expressed in the same units from international transactions to farm-level contracts, we found that there is considerable opportunity to combine commoditisation at national borders (performance based economic incentives, with an annual assessment linked to pay-or-no-pay), a compensation paradigm for allocations and performance between sectors and provinces, and a co-investment paradigm with a twenty-year perspective on tree-based land uses initiated at the farm level. Such a concept, however, is more likely to derive from a NAMA (Nationally Appropriate Mitigation Actions) perspective across sectors, than from a REDD+ one per se, where cross-sectoral leakage is hard to assess and evidence-based commoditisation will be hard.

The cross-scale exchanges in REDD+ application were found to involve an 'efficiency' (emission reduction versus economic incentives) as well as 'fairness' dimension (recognition and respect versus commitment). Most of the existing discourse underestimates the fairness and non-financial exchanges, while success likely depends on getting the paradigms and incentives right at all scales.

Role play game as prospective tool

We tested the combination of role-play games with household surveys and agent-based models as a way of developing forward looking scenarios of change, including new incentive mechanisms that are under discussion. The combination of methods was found to yield many insights, with evidence for group-based decision making that differs from household-based preferences. Follow-up studies add gender specificity to these results.

Further steps: fairness/efficiency prospects of knowing Shapley values?

With the 2012 Nobel Prize in Economics awarded to Shapley, the quantification he proposed of benefit distribution in multi-stakeholder situations caught attention. Derivation of benefit allocation ratios based on bargaining (and sabotage) power, require trusted agent-based models of the negotiation and implementation steps. Currently such models are not good enough yet to trust results, but a yardstick for fairness plus efficiency may be derived if better agent-based models can be developed. Currently stakeholder opinion on the 'fairness vs. efficiency' trade-off is the best we have; the FERVA method suggested reasonable agreements between stakeholders that investment in long term solutions and direct emission reduction should get equal attention, while transaction costs plus REDD rents should be contained to be less than 30% of the total.

Land use planning for high carbon stock landscapes

We combined the various perspectives in a redesigned participatory land use planning tool ('LUWES') that allows the exploration of scenarios for many emission reduction options in land use change. Initial user response has been promising, and the approach was adopted as the Indonesian national standard for use in the national emission reduction planning.

Potential Impact:

The work on drivers of deforestation has helped to improved our knowledge on the global status, trends and issues of global land use, including on the looming scarcity of and increasing global competition for productive land, and the availability of potential available cropland for future expansion, and the associated constraints and tradeoffs. These estimates have high policy significance, as assumptions about availability and types of land considered environmentally appropriate for cropland expansion contribute to the design of bioenergy policies. Agricultural production standards, such as the Roundtables for Responsible Soy and Sustainable Palm Oil, target non-forest lands to minimize environmental impacts from industry expansion. Indeed, most conservation policies consider that forests should be protected and often cite the abundance of previously cleared land, without considering tradeoffs or constraints. The debate over risks and benefits of large-scale land acquisitions and foreign investments in agriculture also rests on assumptions on the availability of land for agricultural expansion. Thus, many policies for controlling deforestation can be impacted by this research.

The work has also improved our knowledge on the various processes by which globalization and markets increasingly influence land use and deforestation. With globalization, markets and private decisions have an increasing influence on land use, opening opportunities for a number of emerging market-based instruments. The final consumers of agricultural and wood commodities, the corporations involved in their transformation and retailing, and civil society show a growing concern for sustainability. These actors are starting to express a preference for goods whose supply chain has been certified as meeting sustainability criteria. Simultaneously, large agri-business corporations increasingly adopt sustainability standards and apply these to their suppliers. Improved knowledge of these mechanisms and their potential influence on deforestation can thus significantly contribute to reduce deforestation and promote sustainable forest management.

It was also shown that a significant proportion of reforestation in a number of countries is resulting in leakage of the carbon saved abroad. In Vietnam, for example, forest cover has increased from 25% in 1992 to around 38% in 2005, but around half of this increase has been achieved at a cost of increases in food and timber imports, implying that this has been met by increased deforestation abroad. This is an important finding, as it highlights the need to take a systems approach to reducing emissions and increasing carbon sequestration by accounting for changes at least under all land uses (or AFOLU = Agriculture, Forestry and Other Land Uses) and not only forestry, and ultimately under all emission sectors and not only AFOLU. Dealing with any one land use component (such as forests) in isolation is likely to result in partial solutions at best as the Law of Unintended Consequences starts to operate. Providing alternative employment opportunities to reduce dependence of people on forests for their livelihoods, for example, may result in increased GHG emissions from the industrial sector. Related to this is the recognition that there is major competition between different land uses, particularly food and fuel production arising from an increasing global population and changes in dietary preferences. Use of REDD+ funds to fund agricultural research on sustainable intensification may be a cost-effective way of also reducing GHG emissions, for example.

The project has also contributed to a greater knowledge on the drivers of land use changes and deforestation in the four countries, and their relations with population dynamics, socio-economic development, agricultural systems and rural economies, market forces, and international, national and local policies. This knowledge can significantly contribute to improve local policies, as well as market-driven efforts, to control deforestation while simultaneously supporting local human development. In each country, cooperation among partners from international and local institutions will ensure that the results of the project are disseminated, and can be appropriated by local authorities and policy-makers.

Overall, the increase in knowledge of the drivers of deforestation can strongly contribute to improving the design and implementation of multiple policies from the EU, including those affecting trade such as FLEGT and VPA, eco-labelling, biofuels policies, how to develop effective and contextualized REDD+ schemes, land acquisition and foreign investments in agriculture.

The research on the quantification of carbon sequestration and GHG emissions will contribute to the REDD-Readiness of non-Annex 1 countries by providing adequate methods and better quantification of the emission factors of land use change associated with deforestation. The literature reviews provide average soil NO, N₂O emissions and peat net fluxes of CO₂, CH₄ and N₂O in the most common land-use categories in the tropics.

The outputs of the field measurements provide valuable information relevant for country level quantification of GHG emissions and changes in belowground C stocks. In Indonesia, CIFOR placed a strong emphasis on the forest conversion to oil palm plantations on both mineral and peat soils for which emission factors are critically required. The pan-tropic SOC field study focussed on the land-use transitions relevant to each study region. The quantification of SOC stocks and the changes caused by land-use conversion are extremely important for C accounting at regional and national scales.

The experiences and insights gained from literature reviews and fieldwork also generated various concrete recommendations for future field-based studies. The review article on land-use change and soil carbon identified a serious geographic bias in the extrapolation of soil C stocks since current field observations fail to correspond to the distribution of biophysical conditions in the tropics. The direct implication is that with the current state of knowledge it is not possible to extrapolate to continental or global scales, and further studies are required to establish a more spatially representative depiction of soil C changes following land-use conversion. Meanwhile, the pan-tropic SOC study found that: (a) it was not necessary to sample deeper than 1 m to adequately describe belowground carbon changes, (b) pooled composite soil samples are superior to a single sample from a soil pit, and (c) for root biomass determination the root washing method is superior to hand picking.

Until recently, estimates of GHG emissions from peatland is much debated, due in part to different methodologies used, and in part to spatial variation of emission rates not covered by individual research units. Our multi-site research using direct CO₂ flux measurements will be important to provide better estimates of emissions from peat under different land-use systems and can contribute to the national and sub-national Tier 2 default values of peat emissions. The results of this study will also be used as the basis for sustainable peatland

management as well as emission reduction from peatland. This result will also be very important in the development of Locally Appropriate Mitigation Actions (LAMA) and National Appropriate Actions (NAMAS).

The results were widely disseminated targeting multiple audiences (policy-makers, scientific community, stakeholders and interest groups, and public) through participation in local, regional and international courses, meetings, workshops and conferences. The results on peatlands are making a significant contribution to the 2013 Wetlands Supplement Chapter to the 2006 IPCC Guidelines for national greenhouse gases inventories. Several scientific papers were published and some of them are still in the publication pipeline. Several young scientists (MSc and PhD students, post-docs) were enrolled in the project and received guidance of senior researchers. Partnership with key stakeholders such as conservation NGOs (e.g. The Zoological Society of London), governmental institutions (e.g. Indonesian national park authorities) and land-owners (small holders and private companies) were developed for research collaboration. Our research was also disseminated through interviews, blogs and video; the last ones being available on the CIFOR website.

The objective of the policy analysis work was to analyse the trade-offs between certain forestry related policies within the current climate regime and the larger goal of sustainable forestry. To a large extent, this analysis builds on stakeholder dialogue. The work has shown that countries have reasons to scale up or scale down forest governance issues. The potential promise of REDD helped to generate global consensus on the need to deal with forests at a global level, but if the resources are not forthcoming, this may lead countries to revert to their original position of seeing forests primarily as a subject of national sovereignty and a source of income. However, it may be that 'glocal' forest governance is the best approach - a process by which local through to global issues, trends, drivers and instruments are given due attention and an iterative multi-level governance framework is developed for sustainable long-term policy that goes beyond REDD. A general principle in designing such a governance system should be in devolving decision-making down to the lowest relevant level for the issue being addressed, and developing conflict resolution mechanisms for when these decision-making processes don't align. We identified generic measures that can help to embed REDD within domestic forest institutions and showed how these generic measures had contextual implications in the four study areas.

The potential impact of the research is to deepen the understanding and enhance the awareness of these stakeholders on the tradeoffs and interconnections between on the one hand REDD, and sustainable forestry on the other hand. The research has been used as an input into the MSc course 'Environment and Resource Management' at VU University, resulting in 12 MSc. theses on REDD. To ensure a wide dissemination and lasting impact of the results of the research of WP4, a book on Climate Change, Forests and REDD has been published by a commercial publishing company.

The modelling work highlighted that it is essential to see forests as components of larger economies and systems of land use, which also include arable agriculture, grasslands, wetlands, and human settlements (Matthews & De Pinto, 2012). Dealing with any one land use component (such as forests) in isolation is likely to result in partial solutions at best as

the Law of Unintended Consequences starts to operate. A systems approach is needed. This is a key point as much of the euphoria surrounding REDD when the project started focused only on forests, but it soon became clear that it was not a forest problem alone, that it was a landscape problem, particularly when agriculture is a major driver of deforestation. Considering only forests could potentially just move the deforestation problem somewhere else - people still have to make a livelihood, and if they are prevented from clearing land for their crops in one location, they may well just move somewhere else to do so. Even providing alternative (i.e. non-agricultural) employment opportunities may result in other enterprises emitting more GHGs cancelling out any benefits from reduced deforestation.

The modelling work also indicated that there is unlikely to be one local solution to reduce deforestation or to restore forests, and that it is essential to take the local contextual diversity into account. For example, disaggregated (household) analysis showed that there was a complex relationship between the 3Es (effectiveness, efficiency and equity) not evident in more aggregate analyses. Thus, it is likely that a mixture of state-level command-and-control, regulatory approaches, and emerging market-based instruments (e.g. eco-certification of products, corporate environmental responsibility, stewardship agreements, and other demand-driven interventions) will be necessary. Even so, there are likely to be winners and losers - land owners may benefit from increased rents, but the landless are likely to suffer from increased food prices and lower wages. Land tenure more important than financial incentives per se. Indeed, co-investment rather than payments for environmental benefits may be a better paradigm. Although carbon price was highly influential in increasing the carbon stocks of landscapes, it was also shown that increasing C prices can reduce a program's efficiency without solving its inequities. Similarly, expanding the program reduces inefficiencies but increases private costs with only minor improvements in equity. A program that prevents job losses could be the best option, but its efficiency compared to direct compensation could depend on program scale. The need to consider other factors besides pure economic analysis was also highlighted - some of the agent-based modelling work, for example, showed that actors with altruistic motives, such as could be generated through environmental awareness campaigns, could also make a significant contribution at lower cost. Thus, REDD+ mechanisms should avoid general formulas by giving local authorities the necessary flexibility to address the trade-offs involved, i.e. general policy approaches and tools need to be tailored to specific contexts rather than applying 'one-size-fits-all' approaches.

Progress was also made on modelling peatland dynamics of carbon and GHGs. Modelling efforts to date have been restricted by the lack of available data for parameterisation, input and validation of simulation models, due to the complex and often inaccessible nature of tropical peatland ecosystems. Consequently, it has not been easy to predict GHG fluxes from tropical peatlands. A simple spreadsheet model, the Tropical Peatland Plantation-Carbon Assessment Tool (TROPP-CAT) was developed to provide policy makers, plantation managers and researchers in Indonesia and internationally with a user friendly tool to evaluate and predict soil carbon losses and carbon dioxide emissions from tropical peat soils. Calculations provided by TROPP-CAT demonstrate the potential emissions reductions that could be achieved through changes to plantation management, even by as little as a 20 cm raising of the WT depth. Considering that WT is a key driver of subsidence and oxidative losses of soil

C, the outputs of this model highlight the validity in WT management. Enforcement of national regulations coupled with conservation legislation offers the best opportunity for emissions reductions on Indonesian peats. The calculator offers the opportunity for site specific, regional and even national simulations within Indonesia, and with caution can be applied to other countries in SE Asia. It has been shown to be a practical tool that can be used by a range of stakeholders to determine likely soil C losses and CO₂ emissions from areas converted from peat swamp forest to plantations.

Similarly, the redesigned participatory land use planning tool ('LUWES'), that allows the exploration of scenarios for many emission reduction options in land use change, was adopted as the Indonesian national standard for use in the national emission reduction planning.

Main dissemination activities and exploitation of results

The work carried out in the project is being disseminated through various peer-reviewed and other publications, as well as various activities, including broad audience publications, policy briefs, conferences and other presentations (see Tables A1 and A2). Here we present just some of the major activities which included presentation of project results at side events of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (CoP) meetings to which many negotiators attended and contributed to the discussions.

UNFCCC CoP-14, December 2008, Poznan, Poland: This was before the project commenced, but the following talks were given in anticipation of the project:

1. "Introducing new initiatives to support implementation of REDD". Talk by Robin Matthews at ASB/MLURI side event at UNFCCC CoP-14 Forest Day, Dec 6, 2008.
2. "REDD-ALERT: Investigating ways of linking global climate policies to local behaviour change in tropical rainforest countries". Invited talk at EU side-event "Climate change research and observations beyond Europe", Dec 10, 2008.

Copenhagen Climate Change conference Mar 10-12, 2009: 'REDD-ALERT: Evaluating global-level climate policy options and their local level implementation'. Poster presented by R B Matthews at Copenhagen Climate Change conference.

UNFCCC CoP-15, December 2009, Copenhagen, Denmark: A side-event was organised by the EC DG-RTD entitled 'Deforestation, Forest Conservation and the Climate Change Challenge' exploring the social, economic and environmental drivers of deforestation, their interdependence and consequences in South-East Asia, Africa and Latin America. Presentations included:

1. Welcome and introduction by Dr. A. Kentarchos (Climate Change and Environmental Risks Unit, DG-Research, European Commission)

2. 'Solving the climate challenge within the planetary boundaries' by Prof. J. Rockstrom (Director of Stockholm Resilience Centre at Stockholm University, Director of Stockholm Environment Institute)
3. 'From deforestation to reforestation: conditions for sustainable land use' by Prof. E. Lambin (Universite Catholique de Louvain, Belgium)
4. 'REDD-ALERT: linking global climate arrangements to local land-use behaviour' by Dr. R. B. Matthews (Macaulay Institute, Aberdeen, UK)
5. 'Opportunity costs of carbon emissions from land-use change: need to broaden scope of REDD' by Dr. M. van Noordwijk (ICRAF - regional coordinator for SE Asia)
6. Panel discussion & debate. Moderator: Dr. E. Lipiatou, (Head of Unit, Climate Change and Environmental Risks Unit, DG-Research, European Commission)

A video-clip of this side-event can be viewed at

<http://ec.europa.eu/avservices/video/player.cfm?sitelang=en&ref=66868>

UNFCCC CoP-18, December 2012: A side-event was organised by Dr Robin Matthews at the EU Pavilion at CoP-18 in Doha, Qatar on 29 November 2012 entitled 'Is the window of opportunity for REDD+ closing?'. Presentations included:

1. Welcome and introduction by Dr Luca Perez (Climate Change and Environmental Risks Unit, DG-Research, European Commission)
2. 'Linking global climate arrangements to local land-use behaviour' by Dr Robin Matthews (Theme Leader, James Hutton Institute, Aberdeen, UK)
3. 'Understanding, measuring and governing changes in forest carbon stocks in complex landscapes' by Dr Ole Mertz (I-REDD+ Coordinator, University of Copenhagen, Denmark)
4. 'Diversity of land use trajectories and implications for REDD+' by Dr Daniel Mäler (Senior Scientist, Humboldt Universität zu Berlin and IAMO)
5. 'Progress in determining reference emissions levels' by Dr Lou Verchot (Programme Director, CIFOR)
6. 'Nationally Appropriate Mitigation Actions for the forests and other land uses of Indonesia: complementarity of policy instruments, funding streams and motivation' by Dr Meine van Noordwijk (Chief Scientific Advisor, ICRAF)

An article was prepared and published in the December 2011 issue of the stakeholder magazine *International Innovation (Environment)*: Matthews, R.B., 2011. Evaluating local impacts from global GHG policies. In: *International Innovation (Environment: December 2011 issue)*, pp. 64-66.

CNN Television broadcast a brief documentary on REDD-ALERT project activities by the Centre for International Forestry Research (CIFOR) and the World Agroforestry Center

(ICRAF) in Indonesia. The programme was aired with the title 'Indonesia aims to halt deforestation' on 27 November 2010, which can be viewed using the following link:

<http://www.cnn.com/2010/WORLD/asiapcf/11/22/indonesia.halt.deforestation/index.html>

It is planned to publish a selection of papers from the REDD-ALERT project in a Special Issue of Mitigation and Adaptation Strategies for Global Change.

A full list of dissemination outputs is given in the Use and dissemination of foreground is given at Section A.

List of Websites:

Project website:

<http://www.redd-alert.eu/>

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