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Facilitating agroforestation of landscapes for sustainable benefits: Tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model

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Abstract

Although Indonesia has no shortage of land area that lost its forest cover before 1990 and has become the global leader in land-use based greenhouse gas emissions, the widespread expectation that the afforestation/reforestation approach to Clean Development Mechanisms (A/R CDM) could lead to sustainable development benefits has not so far materialized. The main challenges to implementation of the current A/R CDM mechanisms are in (1) the definition of forest and its institutional implications, (2) the projectization that is embedded in the definition of CDM, (3) non-linear baselines related to forest transitions that complicate attribution, (4) inherent lack of synergy with other development activities and (5) high transaction costs and temporary nature of credits. In possible new international regimes that aim to include all relevant changes in land-use based emissions, a more outcome-based programmatic approach may partially replace the project cycle assessments of CDM. However, there will still be a need to assess the combination of factors and policies that can be expected to enhance terrestrial carbon storage through voluntary land-use decisions, by a combination of reduced emissions and enhanced storage. Tradeoffs usually exist between local livelihoods and carbon storage, but assessment of the opportunity costs of C sequestration requires analysis at the landscape and community scale at scenario level, including local adjustment and optimization. We explored such scenarios for a number of cases in Indonesia that range from a forest margin to a degraded lands setting. FALLOW model applications were set up for 4 landscapes in Indonesia (15–98% forest cover, 1–55% grassland, 17–51 persons km^{-2}) to test the internal consistency of the hypothesis that farmer-led development of tree-based land-use systems in response to accessible markets, legal tenure arrangements, availability of reliable technical information and local investment can convert degraded forest lands at low public cost and form an attractive alternative to project-based interventions with detailed prescriptions and planning. The calculated (non-linear) baselines for carbon stocks varied from an average trend of -0.26 to $+0.23$ Mg C ha^{-1} $year^{-1}$ over a 25 year period of assessment, equivalent to a net sequestration of -0.95 to 0.84 t CO_2 ha^{-1} $year^{-1}$ The highest value for predicted additional carbon storage in the wider landscape did not coincide with the best results for local livelihoods, but in each of the case studies the results for a ‘programmatic’ removal of constraints to profitable smallholder tree-based production systems was more attractive than a ‘prescribed’ tree planting in designated project areas. These results support the design of international modalities for an outcome-based approach to enhancing carbon storage with local flexibility in implementation.

Keywords: Clean Development Mechanism; FALLOW model; Landscape carbon assessment; Scenario analysis; Tradeoffs analysis

1. Introduction

1.1. Expectations of A/R CDM

Indonesia has an estimated 48 M ha of land that had effectively lost its forest cover before 1990, is potentially

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eligible for A/R CDM under the Kyoto protocol and does not have high value agricultural use in the form of irrigated rice fields (Murdiyarso et al., 2006). Recent estimates suggest that Indonesia has become the global leader in land-use based greenhouse gas emissions (Murdiyarso and Adiningsih, 2007). Widespread expectations that the afforestation/reforestation approach to Clean Development (A/R CDM) could lead to sustainable benefits in Indonesia and available data on tradeoffs involved (Tomich et al., 2002) have not so far materialized as no projects have completed the approval process, despite considerable investment in efforts to develop pilot projects. Globally, the expectations are that forms of agroforestry can enhance both livelihoods and C storage in many parts of the world (Montagnini and Nair, 2004; Kandji et al., 2006; Lasco, 2002; Lipper and Cavatassi, 2004; Palm et al., 2005). The way increased carbon storage can lead to local benefits, however, is still under debate (Murdiyarso and Herawati, 2005; Murdiyarso and Skutsch, 2006; Van Noordwijk et al., 2005; Verchot et al., 2007a).

With the new wave of interest in dealing with climate change (IPCC, 2007; Sari et al., 2007), the necessity of ‘whole system’ accounting for net anthropogenic emissions of greenhouse gasses is gaining ground (Schimel et al., 2001; Cowie et al., 2007: ‘‘Ideally, the accounting approach should cover all significant biospheric sources and sinks, avoid biased or unbalanced accounting, avoid leakage and require no arbitrary adjustments to remedy unintended consequences’’). The current system of rules and its ‘path dependence’ (O’Riordan and Jordan, 1999), or stepwise evolution from precursors under the selection pressures of the day, is under scrutiny and a wider set of alternatives is needed (Benndorf et al., 2007). This is particularly so for the net emissions from land use and land cover change (globally about 25% of the anthropogenic emissions; Watson et al., 2000; Skutsch et al., 2007), where only a partial accounting has been achieved so far. In the Annex-I countries of the Kyoto protocol all emissions and terrestrial sinks are included (at national borders), but of the non-Annex-I countries only the very small area where the A/R-CDM rules apply (per May 1st 2007 only one fully approved project globally). Current concerns relate to the non-accounting for net emissions in Non-Annex-I countries due to production of biofuels that will be used by Annex-I countries to meet their emission reduction requirements (Cramer et al., 2007). As contribution to the debate on more efficient and effective modalities beyond the 2008–2012 first commitment period of the Kyoto protocol, we want to review some of the complexities of the current rules and explore how other mechanisms could more effectively contribute to net reduction of anthropogenic emissions from land use and land cover change. We will here review some of the challenges at conceptual as well as operational level and provide experience with a tool for analyzing both ‘project’ (space and time-bound interventions in incentives and rules) or ‘programmatic’ (generic changes in incentives and rules) approaches to enhance terrestrial carbon storage in profitable land-use options.

1.2. Issues in current AR-CDM rules

References to specific rules of the executive board (EB), Modalities and Procedures (CMP) and Project Design Document Guidelines (PDD GL) of the Clean Development Mechanism (CDM), in the following text are based on Mizuno (2007). Restriction of ‘clean development’ rules to the afforestation/reforestation domain rather than to ‘whole system’ accounting (IPCC, 2006) and accountability has led to a number of challenges on the interface of biophysical, socio-economic and political-governance processes:

(1) *The operational definition of ‘forest’* (on which the concept of re- or afforestation hinges) is a hybrid of criteria based on actual tree cover (Verchot et al., 2007b), and governance issues: forests include ‘‘areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest’’ (EB28 Rep, para 36; NB the circularity in use of the term forest within the definition of forest). In Indonesia 70% of the land was considered to be ‘forest’ on December 31st 1989 (the reference date for CDM) and all areas in that domain that did not have forest cover at that date were supposed to revert to forest according to the government. Only tree planting outside of the 70% is eligible if one interprets the definitions strictly. This leaves vast areas of ‘forest lands without trees’, that are in fact unlikely to revert to forest under current rules and conditions, out of the consideration of CDM. This includes at least 32 M ha or 16% (or 36 M ha and 18% if the ‘no data’ categories are proportionally allocated) of Indonesia’s land area (MOFR, 2003; Worldbank, 2007). In fact the current position of the Ministry of Forestry and the Designated National Authority (DNA) in Indonesia is that only projects outside of the ‘forest estate’ are eligible for A/R-CDM.

(2) *Projectization*: ‘‘A CDM-project activity is *additional* if GHG emissions are reduced below those that would have occurred in the absence of the registered CDM-project activity’’ [CMP/2005/8/Ad1, p. 16 para 43]. The reduction as such implies ‘environmental’ or ‘carbon stock’ additionality, the second part of the sentence implies ‘project additionality’ and the attribution what ‘would have’ occurred in the absence of a project. While carbon stock additionality, and its effect on net transfers to the atmosphere, is clearly relevant to the mitigation of climate change, the ‘projectization’ of CDM poses a number of challenges in the context of tropical land use. The ‘project’ focus that is inherent in the set-up (and definition) of CDM requires a sharp delineation of ‘project partners’, ‘project boundary’ and ‘leakage’. ‘‘The project boundary shall encompass all anthropogenic GHG emissions *by sources under the control of the project partners* that are significant and reasonably attributable to the CDM-project activity’’. [CMP/2005/

8/Ad1, p. 17], while ''Leakage is defined as the net change of GHG emissions which occurs *outside* the project boundary, and which is measurable and *attributable* to the CDM-project activity. [CMP/2005/8/Ad1, p. 17 para 51]''. The key distinction is thus one of 'control'. For anyone familiar with the realities in most developing countries, the concept of 'control' is complex, given the substantial 'implementation gaps' between policies and reality. Where government agencies or a local community would be involved as 'project partners', the 'project boundary' will have to coincide with administrative boundaries, that supposedly indicate shifts in the level of 'control'. Attribution to the CDM-project activity is limited to what is 'reasonable', but any shift in investment budgets of the local government may have to be included. Within the CDM framework, a program of activities can be registered as a single CDM-project activity provided that approved baseline and monitoring methodologies are used that, inter alia, define the appropriate boundary, avoid double counting and account for leakage, ensuring that the emission reductions are real, measurable and verifiable, and additional to any that would occur in the absence of the project activity [CMP/2005/8/Ad1, p. 97 para 20].

In the rural development arena the term 'project' has obtained a rather negative connotation of a time-bound lifting of the rules of economics with provision of incentives that will disappear and allow the system to revert to its normal trajectory, unless essential components are absorbed in a programmatic approach. In that sense sustainable Clean Development may not be optimally served by a project approach. The recent steps towards a more programmatic approach in CDM still essentially refer to a bundling of projects.

(3) *Non-linear baselines*.

Baselines are used to compare the actual emissions with conjecture on what would have been expected in the absence of interventions. In the simplest case, baselines are static. Small-scale reforestation CDM is allowed to assume a steady, zero baseline. Linear trends (either positive or negative) are often used, but in reality baselines probably are non-linear as standard and make transitions from a degradation into a rehabilitation phase in the absence of specific interventions. In the environmental literature the phenomenon is discussed by reference to the Kuznetz curve (Ranjan and Shortle, 2007), or 'forest transition' (Mather, 1992; Angelsen, 2007). A number of Asian countries already show an increase in forest area (but not necessarily in terrestrial carbon stocks) in their national statistics, based on plantation forestry (Mather, 2007). Rudel et al. (2005) suggested two possible pathways for advanced forest transition. One is the ''economic development route'', where the agricultural population declines as industrialization and urban migration proceed, and abandoned agricultural land is spontaneously reforested (this has happened in parts of Europe and N America). The other is the ''forest scarcity pathway'', where scarcity of forest products drives up price and stimulates tree planting. There are, however, considerable time lags in this response (Palo, 2004). Rudel et al. (2005) emphasized that overlaps can occur between these two types, but the implication is that different causes apply to the two pathways. Neither of them refers to specific interventions made in response to 'Clean Development' mechanisms, and both aspects will therefore have to be considered in discussions of additionality. Generosa (2007) found mixed results on forest transition patterns in 20 Asian countries, with some evidence for positive effects on forest plantations of export suggesting a key role of market incentives in channelling private and public investments in expanding forest plantations and forest carbon sinks. Related to the forest transition concepts is the distinction by Chomitz (2007) of 'core forests', 'forest margins' with rapid loss of forest cover and contests over land-use rights, and 'mosaic forests' in the (partial) recovery phase after land rights were established. A/R CDM will likely be part of such 'mosaic forests', but it may be hard to establish the specific requirement for additional interventions in this phase of land-use dynamics when an increase in tree cover meets local expectations of functionality. Much of Indonesia is still in the 'forest margins' stage in the sense that the contest over land-use rights has not been productively solved (Contreras-Hermosilla and Fay, 2005; Suyanto, 2007). In the formal government policies, however, the perception that it is 'core forest' is retained, against the evidence on the ground. To further complicate matters, available evidence suggests a gradual shift in the primary drivers of deforestation (Rudel, 2007) or in the 'agricultural transition' (Geist et al., 2006) that is the interlude in the forest transition. These forces and drivers will first have to be countered and stopped before reforestation can be expected to succeed. An empirical approach to 'non-linear baselines' by choosing 'control' areas outside the project intervention domain is based on an assumption of constancy of drivers and absence of leakage or influence that is hard to prove if areas are close together; if the control area is far away the similarity of conditions and drivers will be in doubt.

(4) *Inherent lack of 'synergy' with other development activities*, as synergies further complicate attribution and 'additionality'. ''If the starting date of the project activity is before the date of validation, provide evidence that the incentive from the CDM was seriously considered in the decision to proceed with the project activity. This evidence shall be based on (preferably official, legal and/or other corporate) documentation that was available at, or prior to, the start of the project activity. [PDD GL ver6.2, p. 11]''. This rule, for

example, excludes all government tree planting support in Indonesia in areas prioritized for the 'national reforestation and regreening' program (GERHAN or GNHRL), as this multiyear program was set up to recover forests for national and local benefits, without reference to CDM. National reforestation programs tend to focus on the provision and planting of Trees—not on removing other constraints to spontaneous (non-project based) tree planting. For CDM any credible removal of 'key constraints' is eligible as project design, and current focus on 'tree planting projects' may in fact be unnecessarily restrictive.

(5) *High transaction costs and temporary nature of credits*. Because the governance framework for CDM had to respond to many different concerns and interests, the resulting procedures involve many steps, concepts and language that is hard to understand for local stakeholders. Analysis of the experience so far in both the formal and voluntary forms of 'clean development' point to high transaction costs. Cacho et al. (2003) and Cacho (2006) calculated that at a (rather optimistic) CER (Carbon Emission Reduction Certificate) price of 20$/t CO_2 equivalent, and an average farm size of 2 ha, a minimum of 415 farms would have to be combined for a 'breakeven' point, at which the transaction cost would be 100% of the value. With a smaller number of farms there is a net cost; if one wants the transaction cost to be les than 50% (while in 'regular' development support an administrative overhead of more than 15% is usually frowned upon) one will need nearly twice the number of farms. These calculations are based on a number of assumptions and indicate a number of directions for improving the feasibility. Efficient ways for smallholders to get together and undertake joint action, with full support of local and higher level government, are definitely needed to make it work and 'pilots' can help reduce the costs of information for followers, but even the pilots with substantial external support are not moving as fast as expected. As A/R CDM is 'sink creation', while fossil fuel substitution or emission reduction activities are 'source reduction', direct comparison has been difficult on the basis of 'permanence' criteria. In the absence of national bottom-line accountability for terrestrial carbon stocks in interconnected commitment periods, the international rules created a 'temporary emission reduction credit' system, that is much less attractive on the carbon market than other credit types, and will fetch a lower price.

(6) *Other issues*. 'Lack of mitigation of climate change' (as the emission reduction achieved outside Annex-I countries is used to off-set continued emissions within Annex-I countries within the commitment cap), 'Loss of flexibility and sovereignty', and 'Lack of development dividend' are all mentioned in the current debate and reduce public support for the issue (Griffiths, 2007). These issues have all been considered in the design stage of CDM and various parts of the rules are intended to deal with them, contributing to the high transaction costs. The 'development' side of CDM has been left to the national authorities to judge—as international imposition of criteria and rules was considered to be inappropriate and ineffective. The first set of approved projects in the energy sector and in the reduction of fluorocarbon emissions (advanced relative to a baseline of compliance with the Montreal protocol; Schwank, 2004), however, has left many questions about how this national filter in the decision-making works. In the land use and land cover change domain, especially where rural poor are involved, the imposition of further restrictions on land use will have to meet the criteria of 'free and prior informed consent', if real development is to be achieved.

1.3. Achieving net reduction of emissions from land use and land cover change

The first five issues discussed are all specific to the application of 'flexible mechanisms' outside of the jurisdiction of the Annex-I countries that made binding commitments to reduce their net emissions. Within and between Annex-I countries questions of forest/non-forest (a much larger set of land cover classes is used, more linked to actual carbon stocks), additionality, baseline, leakage, synergy and transaction costs do not apply, because all accounting occurs at national boundaries and refers to 'outcomes' (changes in stock) rather than 'projections'. Within an Annex-I country, a wide array of mechanisms can and is used to provide effective incentives and rules to switch to an economy with lower net carbon emissions, but this is handled within national sovereignty. The simplest way to achieve a stronger net reduction of anthropogenic emissions from land use and land cover change may therefore be to emulate the regime of Annex-I countries where the net land-based emissions are concerned, by applying national scale outcome (net stock change) accounting (Cowie et al., 2007). At national boundaries, the 'leakage' issues disappear (or at least substantially change in character), while a pure 'outcome' based accounting over large areas reduces the need for the 'micro-management' that current project design implies. A national scale accountability will interact with the existing economy and multiscale decision making, without imposing a rigour of international standards on process, and 'locking in' of specified land areas from flexible decision making.

A change towards such an international regime is obviously constrained by the 'path dependence' of the international debate so far, and will have considerable 'vested interest' in the current administrative set-ups to deal with, but the rest of this article is based on the assumption that a review of the modalities beyond the first commitment period of Kyoto is needed and that substantial change is in the air, in the context of the debate on 'avoided deforestation' or 'reduced emissions from deforestation and degradation'. If national scale accountability emerges, governments will have full incentives to remove obstacles to remove current constraints to economically attractive use of trees in the landscape, in ways that are explicitly multifunctional and retain flexibility and responsiveness to market forces (Van Noordwijk et al., 2007b).

In the context of a project to support the development of the first set of A/R-CDM projects in Indonesia, we carried out an analysis of scenarios of land-use change for the pilot areas that had been selected on the basis of a broad stakeholder consultation process. Within the context of A/R-CDM our analysis was aimed at deriving dynamic baselines for a business-as-usual scenario, as well as an exploration of the changes in net carbon stocks that can be expected to occur outside of the area of project intervention. In current terminology, such changes have to be partitioned according to the degree of control of 'project partners': changes within their 'domain' are to be included in the 'project boundary' (which implies that both negative and positive changes are accounted), outside that domain they are handled as 'leakage' (but only if they involve a reduction in net carbon stocks; positives are considered to be 'public goods'). As in most agricultural landscapes there is a multitude of interactions between stakeholder decisions on the use of land, labour and capital, as well as the generation and use of know-how, and the expectations of benefit flows that stakeholders use for their decisions, any credible derivation of baselines and projected carbon stocks under 'intervention' scenarios, requires appraisal of the interactions.

The FALLOW model (Van Noordwijk, 2002) was designed to represent such interactions in a schematic form. It takes the concept of the tradeoff matrix of the ASB project (Tomich et al., 2005) into a dynamic decision process by multiple actors who respond to changes in accessibility of land and information as well as to price signals for agricultural inputs and marketable products. Simulations with the model with parameter settings that allow for human migration tend to even out pressures on resource use across the landscape, but can also represent the 'urban pull' version of the forest transition. Suyamto and Van Noordwijk (2005) and Suyamto et al. (2006a) developed a procedure to use the 1990–2005 period (or similar, depending on data availability) for model validation and extrapolate the model into the future for a baseline, as well as exploration of specified changes in the boundary conditions for local decision making. The model can then be used to explore two types of changes: a 'tree planting project' approach in which a specific part of the landscape is used for scheduled tree planting (interacting with the rest of the landscape through availability of land and labour), and a 'generic changes in policy' approach where rules that apply across the landscape are modified. Whereas it is not impossible to use the second approach as basis for CDM-project design, all current discussion (at least in Indonesia) is focused on the first approach.

Using the FALLOW model, Suyamto et al. (2006b) explored the hypothesis that ''Farmer-led development of tree-based land-use systems in response to accessible markets, legal tenure arrangements, availability of reliable technical information and local investment can convert degraded forest lands at low public cost and form an attractive alternative to project-based interventions with detailed prescriptions and planning''. The authors established consistency of the hypothesis with available data for two sites designated for CDM in Indonesia: Sidenreng in South Sulawesi and Way Tenong in Lampung. These two sites were selected from a much larger number of potential sites on the basis of institutional readiness, compliance with formal Kyoto Protocol criteria and interest of local stakeholders to enhance the tree biomass in their landscape (Murdiyarso et al., 2006).

Here we will combine the data for Sidenreng and Way Tenong with two further sites in Indonesia: Muara Sungkai as a typical land rehabilitation area in Lampung province, and Sebuku as an 'avoided deforestation' area in East Kalimantan (Table 1). We will focus on the expected differences between 'area-specific rigidly planned tree planting' and 'generic programmatic support' types of approach, in the context of these four benchmark areas.

2. Material and methods

2.1. Sites

The four case studies represent areas where recent carbon stock surveys have been made, as well as analysis of land-use change and opportunities to reduce the losses and/or stimulate increase. Details of the model set-up are listed in Table 2. Sebuku (Nunukan, E. Kalimantan) represents the case of an active forest margin where both legal and illegal logging provide local income while reducing carbon stocks and where 'avoiding deforestation' will have to provide

Table 1
Basic characteristics of the four case studies at the regency (Kabupaten) scale (Murdiyarso et al., 2006)

Regency and province	1990 forest cover, %	Fraction of Kyoto eligible lands, %	Area, km^2	Human population density, km^{-2}	Human Development Index
Nunukan, E. Kalimantan	98	1	15833	7	68
Sidenreng Rappang, S. Sulawesi	52	24	1932	127	66
Lampung Barat, Lampung	74	20	5170	72	63
Way Kanan, Lampung	18	75	4101	90	65

alternative local employment. An externally funded project has tried to reconcile enhancement of local livelihoods with reduced emissions of carbon, but did not have a quantitative baseline to compare their results with (Lusiana et al., 2005). Suyamto and Van Noordwijk (2005) parameterized the FALLOW model for this situation where forms of upland rice—fallow rotation provide for the staple food, and mixed agroforests for part of the income, but legal and illegal logging also provide major income sources, while off-farm jobs in the oil palm industry in neighbouring Malaysia are part of the array of options considered.

Sidenreng (Sidenreng Rappang, S. Sulawesi) is a district where irrigated rice fields provide for the staple food and income, while a commercial tree crop or agroforest sector has developed on the basis of cashew nut. The national CDM pilot project identified this as a priority candidate for testing the CDM procedures as there is an area of state-owned grasslands outside of the forestry domain that could qualify for afforestation. Suyamto et al. (2006b) provided details of the FALLOW model for this situation. The expected gain in carbon stocks for the CDM-project scenario selected by the local stakeholders was also quantified with the CO2FIX model (Masera et al., 2003).

Way Tenong (Lampung Barat, Lampung) was until recently part of the Sumberjaya district where a number of migration waves from the 1950s onwards lead to large-scale forest conversion to coffee gardens (Verbist et al., 2005) and conflicts with the forestry department. Van Noordwijk et al. (2002) provided measurements of carbon stocks at plot and landscape scale with coffee monoculture and forms of Multistrata coffee gardens as the main options that can provide for local livelihoods. Suyamto et al. (2003) described the first efforts to apply the FALLOW model to this landscape with Suyamto et al. (2006b) using the specific CDM design proposed for the area as basis for scenario calculations. Recent data on N_2O emissions for the area suggest that abundance of leguminous trees can increase nitrous oxide emissions (Verchot et al., 2006), but in the absence of data for other sites and systems these effects were not included in the model.

Muara Sungkai (Way Kanan, Lampung) is part of the Northern Lampung benchmark area of the Alternatives to Slash and Burn project characterized in the early nineties as an *Imperata cylindrica* grassland domain (Van Noordwijk et al., 1995), with only small remnants of forest left, low productivity of food crops (mostly cassava) and a government sugarcane plantation providing off-farm labour and in some of the years an outgrower scheme. Carbon stocks in homegardens in the area were characterized by Roshetko et al. (2002). In the last 10 years rubber and oil palm entered the area as tree crop options and experiments with smallholder timber showed the potential for farmer-led agroforestation. The area is a stepping stone in the human migration patterns between densely populated Java, the attractions of (illegal) opening of coffee gardens in the mountains of Sumatra and circular migration to urban jobs.

Table 2
Basic characteristics of the four case studies for application of the FALLOW model

Site	Initial forest cover[*], %, year of image	Initial grassland area, %	1990 population density, km^{-2} (assumed growth rate, $year^{-1}$)	Dominant forest use	(Potential) commercial plantation sector	Agroforestry options	CDM issues	CDM 'project' area (total area of simulated landscape), km^2	Programmatic elements considered
Sebuku, Nunukan	98, 1996	1	17 (0%)	Timber, NTFP extraction	Oil palm	*Jakaw* (upland rice/fallow), mixed fruit garden	Avoided deforestation	Not applicable (247)	AF system productivity, price of AF products, reducing timber market
Sidenreng, Sidenreng Rappang (Sidrap)	15, 1989	27	14 (2.3%)	Timber extraction	Cashew-	Cashew-based system, mixed systems, timber-based systems (*Gmelina* sp.)	Afforestation	11.5 (854)	Access to land (tenure security), knowledge on AF/tree management (extension)
Way Tenong, Lampung Barat	16, 1989	33	51 (2.3%)	Timber extraction	Coffee	Multistrata coffee	Reforestation	89.4 (306)	Access to land (tenure security), knowledge on AF/tree management (extension)
Muara Sungkai, Way Kanan	22, 1990	55	27 (0%)	Timber extraction	Cassava, sugarcane, oil palm rubber	Rubber-based systems, timber-based systems,	Reforestation	42.6 (548)	Fire control, knowledge on tree management (extension), access to timber market, access to financial capital (credit)

[*] The value here may differ to value in Table 1 due to differences in area size. Value in Table 1 refer to % to whole regency/Kabupaten while value here refer to site of simulation study.

Profitable land-use options here can therefore reduce pressures elsewhere in the landscape, but the concept of 'leakage' can be only assessed by considering as wide a range of livelihood options as the local farmers do. Suyamto et al. (2006a) provided details of the FALLOW model set-up for this site.

2.2. Model

The rural landscape of Southeast Asia has been developed from a basis of 'shifting cultivation' and fallow-crop rotations into a diverse mosaic of agroforestry systems, forest patches used for non-timber products as well as timber harvesting, permanent cropping systems and fire-climax *Imperata* grasslands. The primary agents of change are the farmers who make their strategic decisions on land-use patterns and tactical decisions on labour allocations, both likely to be based on the results they expect to obtain, and strongly conditioned by capital availability. In addition to the farmers, however, large-scale operators also modify land, typically within spatially explicit 'concessions'; these concessions interact with the local population via demand for labour and as alternative source of income. The expectations of the rural population gradually change on the basis of local experience, and are influenced by external information sources (knowledge diffusion from elsewhere and 'extension' or the priming of expectations for land-use practices that are not yet widespread). At the local community scale, specific restrictions on land-use options are set, and issues such as fire control are determined by the cohesiveness of the local community. Prices of the various commodities and their volatility are determined by the surrounding economy, as does the wage rate for off-farm and out-of-the-landscape labour opportunities. The overall outcome of the dynamic land-use mosaic determines the amount of biomass and carbon stocks of the landscape, the way incoming rainfall is processed and the opportunities for flora and fauna of pioneer-to-late-successional species groups to make a living along with the people in the landscape.

The FALLOW model was designed to provide a comprehensive description of the factors and interactions described above, to allow the testing of hypotheses about causal explanations (including the various direct and indirect feedbacks) and to evaluate 'scenarios' of 'baseline' and policy-change land-use evolution. (Van Noordwijk, 2002; http://www.worldagroforestry.org/sea/Products/AFModels/FALLOW/Fallow.htm). Given the complexities of interactions, the FALLOW model is intended as a 'prospecting' tool, to provide foresight of changes of drivers of landscape dynamics, reveal the implications of baseline trajectories based on currently understood causality, and illuminate options for future action. Detailed predictions are unlikely to be feasible for the open system that dynamic landscapes are, full of non-linearities and exogenous drivers of change.

The core dynamic modules of the FALLOW model were originally developed from a simple model that relates soil fertility dynamics of fallowed and cropped fields to crop productivity, proposed by Trenbath (1989). In its further development, explicit spatial representation of fields and explicit incorporation of farmers' decision making on land-use systems/off-farm jobs were included. The current version of the model is built using PCRaster, a shared spatio-temporal dynamic modelling tool developed by Utrecht University, the Netherlands (http://pcraster.geo.uu.nl/index.html). More detailed description of the conceptual framework of the model is provided elsewhere (Van Noordwijk, 2002; Suyamto et al., 2003; Suyamto and Van Noordwijk, 2005).

2.3. Model validation, baselines and scenarios

For all four sites we first attempted a 'validation' phase, by comparing the predictions over a 10–15 year time frame that are based on a generic set of properties of the various land-use systems (initialized on the basis of recent surveys) and the land cover maps as close as feasible to 1990, with the reality as observed in the 2000–2005 period (depending on image availability for the various sites). The discrepancies observed were analyzed for their likely cause, and a number of refinements in model structure or input data were made to reduce discrepancies (noted in the various basic site model descriptions), but no attempt was made to 'fit' the model to the results as such. The validation test may therefore be used as indication of the type of deviation that can be expected for the 'baseline' predictions. After this validation phase, model runs were made for 30 years with the recent land cover maps as input to establish a dynamic baseline, followed by simulations that represent the CDM-project design developed by local stakeholders, and a stepwise 'programmatic' approach based on changes in generic parameters (Table 3).

Any difference (either over time or due to different methods of assessment) in total carbon stocks of a landscape can be split into two terms (Van Noordwijk et al., 2000):

$$\begin{aligned}\mathrm{Cstock}_2 - \mathrm{Cstock}_1 &= A_2\sum_{i=1}^{n} a_{i,2}C_{i,2} - A_1\sum_{i=1}^{n} a_{i,1}C_{i,1}\\ &= A\left(\sum_{i=1}^{n}(a_{i,1}(C_{i,2}-C_{i,1}) + (a_{i,2}-a_{i,1})C_{i,2})\right) \qquad (1)\end{aligned}$$

where A is the total area (assumed to be constant with time) and a_i are the fractions under a range of land cover types and $C_{i,t}$ is the C stock per unit area under land use i at time (or method) t. The first term in the right hand side of the equation represents change (or uncertainty) in the average C stock per land-use class, rated at the initial area fraction, and the second term the change (or uncertainty) in area for each land cover class, rated at the final C stock density.As

Table 3
Steps in the modelling process of project and program scenarios relative to a dynamic baseline

	Validity test	Baseline	Additionality and leakage tests
Parametrization	Survey data (2005) + default parameters	Same	Specific modifications to simulate spatially explicit 'project' or generic 'program' designs
Initialization	Land cover in 1990 (Remote sensing)	Land cover in 2005 (Remote sensing)	Land cover in 2005 (remote sensing)
FALLOW predictions	Land cover in 2005	Land cover, C stock and income dynamics 2005–2035	Land cover, C stock and income dynamics 2005–2035
Interpretation	Model validity test based on C-stock, LU fractions and spatial pattern, compared to remote sensing data 2005	Dynamic baseline	Additionality of C stocks, net effects on non-food expenditure

part of the model validity tests we thus calculated:

Uncertainty in carbon density

$$= \sum_{1}^{n} \left((\mathrm{Csim}_i - \mathrm{Cref})_i \cdot \frac{\mathrm{Aref}_i}{\sum_1^n \mathrm{Aref}_i} \right), \tag{2}$$

where Csim_i is total simulated carbon stocks of land use type i, Cref_i is total reference carbon stocks of land use type i, and Aref_i is total reference area of land use type i, and

Uncertainty in land cover fraction

$$= \sum_{1}^{n} \left(\left(\frac{\mathrm{Asim}_i}{\sum_1^n \mathrm{Asim}_i} - \frac{\mathrm{Aref}_i}{\sum_1^n \mathrm{Aref}_i} \right) . \mathrm{Cref}_i \right), \tag{3}$$

where Asim_i is total simulated area of land use type i, Aref_i is total reference area of land use type i, and Cref_i is total reference carbon stocks of land use type i.

Spatial goodness of fit was calculated based on procedure proposed by Costanza (1989), at $k = 0.0075$. Spatial goodness of fit in Sebuku was done at overall landscape scale, while in Sidenreng and Way Tenong, it was done by land-use classes.

The 'project' activity at the three A/R CDM sites was simulated on the basis of tree plantation development with growth rates and labour requirements derived for *Acacia mangium.* Labour for the projects was obtained from the local population at the official minimum wage rate. Leakage was estimated using the following equation:

$$\frac{(\mathrm{Ap} - \mathrm{Al})}{\mathrm{Ap}} \times 100\%, \tag{4}$$

where Ap is carbon additionality (compared to baseline for the area) at project scale and Al is carbon additionality (compared to the appropriate baseline) at landscape scale.

The programmatic approach for the various sites (as indicated in the right hand column of Table 2) was based in Sebuku on improvement of productivity of agroforestry systems, better markets for agroforestry products and an effective reduction on timber prices through implementation of a (local) logging ban or similar landscape-wide rules. In Sidenreng and Way Tenong the program consisted of legal tenure (or at least use) rights creating unconstrained access to the grasslands. In Way Tenong the use rights were restricted to the use for multistrata coffee systems practices, while such systems were promoted through extension, subsidy of planting materials and market improvement. In Muara Sungkai the program consisted of a better local timber market, effective extension in timber-based systems management and better social control of fire.

3. Results

3.1. Validation test results

The Sebuku landscape operates at an average aboveground C stock density of 170 Mg ha^{-1} (based on assessment methods described in Hairiah et al. (2001), while the three others are on the 20–30 Mg ha^{-1} range (Table 4). Over the 10 year validation period the model prediction of land cover change, based on endogenous drivers of change in local land-use decisions, was −6 to +6 Mg C ha^{-1} range, with most of the uncertainty in the

Table 4
Comparison of FALLOW model predictions over a 10-year simulation period initiated with 1990 data with the actual land cover and C-stock estimates for 2000

Site	Type of model evaluation	Estimated time-averaged baseline aboveground C stocks for 30-year period, Mg ha^{-1}	Δ estimated landscape C-stocks, Mg ha^{-1}		Spatial goodness of fit: mean (standard deviation), %	Area difference: mean (standard deviation), %
			Due to uncertainty in carbon density	Due to uncertainty in the land cover fraction		
Sebuku	Validation test	178	−5	−1	70 (*)	+11 (11)
Sidenreng	Validation test	33	+4	+2	41 (12)	+10 (30)
Way Tenong	Validation test	28	+4	+1	54 (26)	+19 (59)
Muara Sungkai	Sensibility test[a]	37	*	*	*	*

[a] Sensibility test as defined by Huth and Holzworth (2005) as comparison with expert opinion.

mean C stock within a land-use class (which the model treats as an age-dependent dynamic property and the 'observed reality' treats as a mean of observations). Some compensation occurs between land cover classes that are over- or under-predicted when the comparison is made at the total C stock level. A pixel level goodness of fit test revealed 40–70% consistency, suggesting that the spatial patterns of land cover classes are far less predictable than their total amounts. Visual inspection of the maps suggested that the current setting of the model still leads to insufficiently spatially clustered land cover changes, and results in a pattern that is more fine-grained than the one observed.

3.2. Baselines of carbon stock development

Accepting the validation results for each of the site a set of simulations was made to derive dynamic baselines of aboveground C stock in the landscape under the standard parameter conditions, and without exogenous changes influencing the results (Fig. 1). For all 4 sites the baseline is non-linear.

The Sebuku baseline suggested a gradual increase in the rate of C stock loss (average -0.8 Mg C ha^{-1} year^{-1}), the Way Tenong a gradual further C stock loss (average trend -0.25 C ha^{-1} year^{-1}, the baseline for Sidenreng was approximately stable, while Muara Sungkai showed an upward trend (average trend 0.27 C ha^{-1} year^{-1}, but with a cycle with amplitude of about 10 Mg C ha^{-1} superimposed on it.

3.3. Tradeoffs between livelihoods and C gains

Table 5 summarizes results for the project scenario as well as the best among the various programmatic scenarios considered, with full details in the various site publications. The predicted gains in time-averaged C stock over the baseline scenarios were highest in Muara Sungkai, at about 60 Mg ha^{-1} for the 30 year time frame of evaluation and contains multiple harvest cycles and 25 Mg ha^{-1} for the 5 year value; the tree growth rate assumption for the fast growing timber plantation may, however, be an overestimate for the possibilities on this site. The local human welfare effect of such a project will, however, be small if the local population is only engaged as wage labourer. Given the low baseline human welfare indicator for this area, a substantial increase is feasible when constraints to tree-based systems are removed for this area in a programmatic approach. This can lead to a threefold increase in the additional carbon storage in the assessment area, along with a doubling of welfare.

For the Way Tenong and Sidenreng case the prospects of additional carbon storage and human welfare are much less, because there are profitable local agroforestry systems to compete with: coffee-based production in Way Tenong where the higher C stocks of multistrata systems are approximately neutral in income effect; the cashew-based agroforestry in Sidenreng also provides higher returns to labour than the timber plantations according to our survey data, while there is no excess labour in the area. Consequently, the project (which assumes that the labour requirements for the plantation are met before the other land-use activities get a chance, has negative effects on welfare. It initially has negative effects on C stocks as well in the specific simulations, because fire in the landscape is a major factor. In reality in a case like this outside labour might be brought to meet the labour demand for the plantations, but decreasing the interactions with local livelihoods.

In Sidenreng the 30 year project has a 200% leakage: the labour absorbed by tree planting reduces multistrata cashew elsewhere, and leads to a landscape level reduction in simulated carbon. All other 'leakage' calculations show negative results, suggesting that landscape scale C stocks increase surrounding the project, through positive effects on expected financial gains from planting trees as they see happen (or do as temporary labour) within the project domain. The programmatic

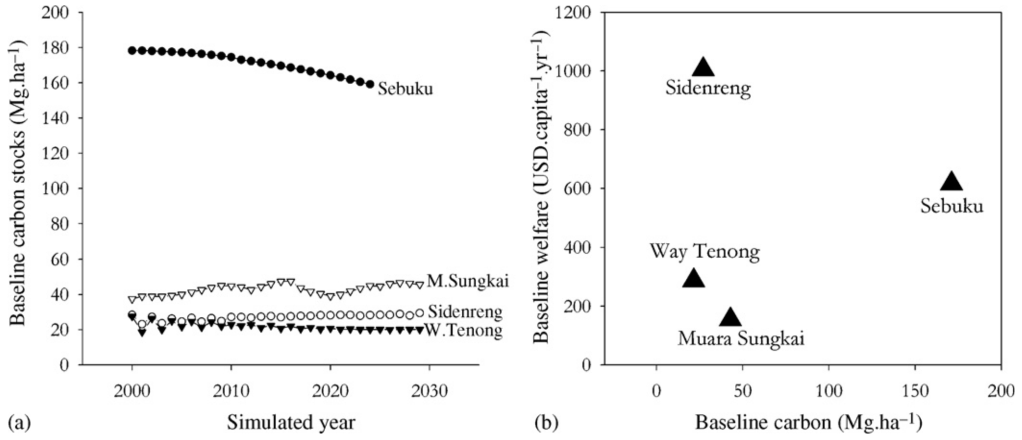

Fig. 1. (A) Predicted aboveground carbon stock for the simulated area for a baseline scenario and (B) relationship between baseline carbon stock and baseline human welfare indicator for the four test areas using the validated FALLOW model.

Table 5
Predicted changes in carbon stock and indicators of human welfare compared to the dynamic baseline for FALLOW model scenario results for the project approach of tree planting in a specified area and the best combination of program approaches that reduce constraints to profitable tree use on farm

Site	Scenario	Evalua-tion period (years)	Project scale time-averaged C stocks (baseline and additionality)			Landscape scale time-averaged C stocks (baseline and additionality)			Project leakage in %	Time-averaged welfare indicator[a]		
			Baseline, Mg ha^{-1}	Additionality		Baseline, Mg ha^{-1}	Additionality			Baseline, USD. capita^{-1} year^{-1}	Additionality, USD. capita^{-1} year^{-1}	Relative, %
				Mg ha^{-1}	Gg		Mg ha^{-1}	Gg				
Sebuku	Programmatic	25				171	6.8	168		616	−124	−32
		5				178	0.4	9		1216	−17	−1.6
Sidenreng	Project	30	28	5.9	6.8	27	−0.1	−6.6	197	1005	−361	−37
		5	27	−5.3	−6.1	26	−0.6	−51	−731	1338	−339	−25
	Programmatic	30	28	3.9	4.4	27	1.5	129		1005	566	96
		5	27	0.5	0.5	26	−0.6	−51		1338	−34	−2.4
Way Tenong	Project	30	21	3.6	32	22	1.8	56	−75	287	−28	−4.3
		5	23	0.7	5.8	24	0.1	2.2	62	399	−139	−35
	Programmatic	30	21	2.1	18.4	22	2.0	60		287	9.7	2.6
		5	23	−0.2	−2.0	24	−0.1	−3.0		399	13	3.1
Muara Sungkai	Project	30	9	64.8	276	43	5.9	322	−17	154	−21	−17
		5	8	26	112	39	2.4	130	−16	99	−16	−20
	Programmatic	30	9			43	17.2	941		154	244	204
		5	8			39	2.6	140		99	43	65

[a] Sebuku uses total income as welfare indicator, other sites non-food expenditure as measured.

scenario with full local labour employment gives best results in Muara Sungkai, where the wage rate feasible in cassava production in the baseline scenario is below the minimum wage rate used for the project scenario calculations.

The upper right corner of the tradeoff graph between gain in C stock and rural welfare, which would represent real win–win scenarios, is remarkably empty (Fig. 2). The predicted increases in aboveground C stock density over the landscape as whole were less than 10 Mg ha^{-1} for a 5 year evaluation period and generally less than 15 (with a maximum at 17) Mg ha^{-1} for a 30 year evaluation period, as most tree-based systems simulated have a rather short harvest cycle.

In the Sebuku landscape a clear tradeoff between C stock and income was evident, because forms of logging are profitable but reduce C stock and none of the alternatives in the model could off-set such benefits. A number of scenarios that lead to C stick increase reduce human welfare, by replacing more profitable land use of lower C stock density. In general the circular symbols of the projects were lower than their program counterparts, while being substantially lower in human welfare benefits.

4. Discussion

Before we can draw conclusions with respect to the agroforestation hypothesis, we need to reflect on the validity of the tool that we use. After initialization with the 1990 parameters the model approximates the situation in the 2000–2005 test period at landscape scale, but the agreement between predictions and reality obviously gets less with increasing spatial resolution. Certain aspects of the spatial pattern are not well captured, especially the clustering of actual land-use changes where the model predicts too fine a pattern. When expressed as landscape scale carbon stock, the discrepancies are −6 to +6 Mg C ha^{-1} or 4–25% of the baseline value. This error can be decomposed in an error in the land cover fractions and one in the average C stock for land cover category, and the data suggest that the uncertainty on C stock density *within* each land-use category is the major component of overall uncertainty. The larger the area involved, the more likely it is that such variation 'averages out' across the full range of ages and growth conditions involved.

Against this qualified level of 'validity' of the model scenario results, we can expect that qualitative patterns and trends will have some reality value, but that the specific

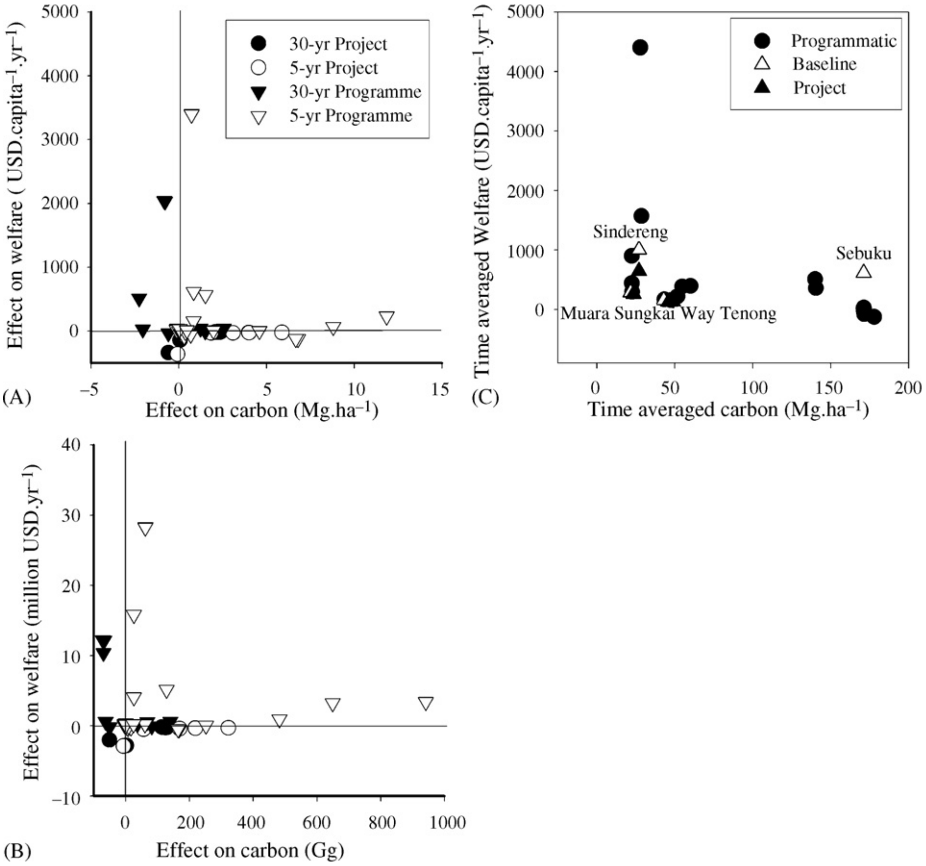

Fig. 2. Predicted tradeoff between change in aboveground C stock relative to the dynamic baseline and the net effect on income for the various project and programmatic scenarios; (A) with C stock expressed per ha and income per capita; (B) with both expressed as totals; (C) comparison of the carbon stock versus welfare tradeoff (compare Fig. 1B).

configurations predicted for each landscape only represent one of a rather broad range of plausible outcomes. For the purpose of the current comparisons and as 'prospective' tool the model may suffice, but for real C accounting measurements cannot yet be substituted.

For all 3 afforestation/reforestation sites the current model indicates that some of the solutions 'found' within the model by the simulated actors and their heuristic learning from experiences within the model, are superior to the 'CDM-project design' that was used as input. In that sense, the results support the *hypothesis* that ''farmer-led development of tree-based land-use systems in response to accessible markets, legal tenure arrangements, availability of reliable technical information and local investment can convert degraded forest lands at low public cost and form an attractive alternative to project-based interventions with detailed prescriptions and planning''. This support for the internal consistency of the hypothesis is only partial, however, as one could use the 'optimized' land cover trajectory that results from the model as predefined project, and achieve the same results. A broader discussion of the various interventions for supporting agroforestation is provided by Van Noordwijk et al. (2007b), in the context of current plans by the Government of Indonesia to develop long-term land-use contracts with local communities for converting 'non-forested forest lands' to productive tree plantations.

The approach proposed here is compatible with both the ''Net Accounting with Negotiated Baselines'' and the ''Average Carbon Stocks'' approach discussed by Cowie et al. (2007) as most promising options for a future 'all lands' accounting framework. Schlamadinger et al. (2007) discusses weaknesses of the current system of land use, land-use change and forestry accounting in the Kyoto Protocol's first commitment period, and proposes a mechanism that addresses the weaknesses but is based on the existing structure. Beyond 'deforestation' in a black-or-white binary classification, forest degradation also contributes to greenhouse gas emissions but it is more technically challenging to measure than deforestation. Data on carbon stocks per unit of land, which are needed to estimate emissions, cannot currently be observed directly over large areas with remote sensing, and considerable 'ground truthing' is still required to establish reliable carbon stock estimates (DeFries et al., 2007).

As part of the institutional arrangements and political discussions it is necessary to partition natural, indirect, and direct human-induced effects on terrestrial carbon (C) sources and sinks as part of debates on attribution, commitments and inter-country benefit transfers (Canadell et al., 2007). However, the human-induced changes will occur partially in 'adaptive response' mode to the ever changing opportunities of the environments and markets, that in themselves respond to natural events that reflect climate variability rather than change. A simple additive model will not adequately reflect these interactions.

Canadell et al. (2007) discussed five options for including various groups of influences including climate variability, CO_2 and N fertilization, and legacies from forest management. These are: (i) selecting longer accounting or measurement periods to reduce the effects of inter-annual variability; (ii) correction of national inventories for inter-annual variability; (iii) use of activity-based accounting and C response curves; (iv) use of baseline scenarios or benchmarks at the national level; (v) stratification of the landscape into units with distinct average C stocks. They concluded that more sophisticated modelling approaches will provide essential learning but are not yet ready for adoption in an inclusive international C accounting system. We concur with this conclusion in as far as the validity of the FALLOW model is concerned. These models can, however, be used as guide in the development of outcome-based incentive systems within the sovereign countries that seek efficient ways to meet international obligations and participate in an international market for consumable goods as well as environmental services. Such 'outcome-based' approaches can provide a 'selective landscape' (Beinhocker, 2007) for self-organizing local initiatives that may lead to a more inclusive search and adaptive response than ant a priori project design can generate.Sathaye and Andrasko (2007) discussed how Stratified Regional Baselines can explicitly acknowledge the heterogeneity of carbon density, land-use change, and other key baseline driver variables across a landscape and provide more objective, standardized and transparent methodologies than the project-specific experience to date.

Negative leakage was estimated to be negligible in Mexico's application of the Plan Vivo, according to De Jong et al. (2007). The Plan Vivo project is selling voluntary carbon credits to national and international institutions and uses the funds to provide financial incentives and technical assistance to farmers interested to participate in the project. It avoids many of the procedural steps of A/R CDM and yet applies rigid rules for baselines, accountability and leakage (De Jong et al., 2005). It has several characteristics in common with the scenarios explored here for Indonesian landscapes.

Brown et al. (2007) discussed baselines for avoided deforestation in the tropics because these are a critical part of establishing additionality. They compared three models, ranging from simple extrapolations of past trends in land use based on simple drivers such as population growth to more complex extrapolations of past trends using spatially explicit models of land-use change driven by biophysical and socio-economic factors. Across six regions the simplest model, applied at the national administrative-unit scale, projected the highest amount of forest loss (four out of six regions) and the intermediate complexity model the least amount of loss (four out of five regions). Readily observable physical and biological factors as well as distance to areas of past disturbance were each about twice as important as either sociological/demographic or economic/infrastructure factors (less observable) in explaining empirical land-use patterns. Baselines projected forward for more than 10 years are likely to be too rigid in their assumptions of all else being equal, and will no longer provide plausible outcomes.

The project mindset that underlies CDM is based on simple cause-and-effect paradigms that may work in an industrial setting, but that does not apply to the complex, adaptive, integrated socio-ecological systems that determine land-use change. Constanza et al. (2007) stated: ''Complex systems may exhibit multiple interactions between apparent drivers and responses where the direction s and strength of interactions are not necessarily explicable in terms of simple cause–effect relations''. A bottom-line accountability by the primary actors at an appropriate scale that ultimately accepts 'baselines' as negotiated outcomes of a discussion rather than based on objective science is needed. Once again, the Annex-I country regime for terrestrial carbon stocks is viable, but piece-meal approaches in developing countries under the current rules have not proved to be effective. A broader and more participatory approach to landscape scenarios (Evans et al., 2006) may have to provide the basis for such 'baseline commitments', which would allow stronger synergy with other environmental services as the primary motivator for clean development in the local context (Leimona et al., 2006; Van Noordwijk et al., 2006, 2007a).

In conclusion, our analysis suggests that the primary constraints to an increase in terrestrial carbon stocks vary substantially between the sites. In some cases profitable agroforestry systems operating at relatively low time-averaged carbon stock density are the preferred option from a local livelihood perspective. In such cases imposing tree planting may enhance C stock at the cost of local livelihoods, and will not happen if decisions are left to the farmers. In other cases, creating access to lands that currently have low C stock vegetation and low utility may be sufficient to achieve substantial carbon stock gains. The active search for better solutions of local actors under a 'programmatic' facilitation may be expected to give better results than 'project design', but calls for an outcome-based type of carbon benefit accounting with less requirements of 'additionality' and hence more opportunities for synergy. Such schemes should be based on actual C storage rather than on the current definition of forest, if environmental benefits are to be achieved.

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References

Angelsen, A., 2007. Forest cover change in space and time: combining the von Tünen and forest transition theories. World Bank Policy Research Working Paper, 4117.

Beinhocker, E.D., 2007. The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics. Random House Business Books, London, 526 pp.

Benndorf, R., Federici, S., Forner, C., Pena, N., Rametsteiner, E., Sanz, M.J., Somogyi, Z., 2007. Including land use, land-use change, and forestry in future climate change, agreements: thinking outside the box. Environm. Sci. Policy 10, 283–294.

Brown, S., Hall, M., Andrasko, K., Ruiz, F., Marzoli, W., Guerrero, G., Masera, O., Dushku, A., DeJong, B., Cornell, B., 2007. Baselines for land-use change in the tropics: application to avoided deforestation projects. Climate Change Adapt. 12, 1001–1026.

Cacho, O.J., 2006. Abatement and transaction costs of carbon-sink projects involving smallholders. In: Paper to Climate Change Mitigation Measures in the Agro-Forestry Sector and Biodiversity Futures, Trieste, Italy, 16–17 October 2006.

Cacho, O.J., Hean, R.L., Wise, R.M., 2003. Carbon-accounting methods and reforestation incentives. Aust. J. Agric. Resour. Econ. 47, 153–179.

Canadell, J.G., Kirschbaum, M.U.F., Kurz, W.A., Sanz, M.J., Schlamadinger, B., Yamagata, Y., 2007. Factoring out natural and indirect human effects on terrestrial carbon sources and sinks. Environ. Sci. Policy 10, 370–384.

Chomitz, K.M., 2007. At loggerheads? Agricultural Expansion, Poverty Reduction and Environment in the Tropical Forests. World Bank Policy Research Report. The Worldbank, Washington (DC), USA.

Contreras-Hermosilla, A., Fay, C., 2005. Strengthening Forest Management in Indonesia through Land Tenure Reform: Issues and Framework for Action. Indonesia Forest Trends and World Agroforestry Center, Washington, DC and Bogor.

Costanza, R., 1989. Model goodness of fit: a multiple resolution procedure. Ecol. Model. 47, 199–215.

Constanza, R., Graumlich, L.J., Steffen, W. (Eds.), 2007. Sustainability or collapse: an integrated history and future of people on earth. Report of the 96th Dahlem Workshop on Integrated History and future Of People on Earth (IHOPE). Massachusets Institute of Technology Press, Cambridge, MA, USA, p. 495.

Cowie, A.L., Kirschbaum, M.U.F., Ward, M., 2007. Options for including all lands in a future greenhouse gas accounting framework. Environ. Sci. Policy 10, 306–321.

Cramer, J., Wissema, E., de Bruijne, M., Lammers, E., Dijk, D., Jager, H., van Bennekom, S., Breunesse, E., Horster, R., van Leenders, C., Wonink, S., Wolters, W., Kip, H., Stam, H., Faaij, A., Kwant, K., 2007. Toetsingskader voor duurzame biomassa. Eindrapport van de projectgroep Duurzame Productie van Biomassa. , http://www.vrom.nl/docs/20070427-toetsingskader-duurzame-biomassa.pdf.

DeFries, R., Achard, F., Brown, S., Herold, M., Murdiyarso, D., Schlamadinger, B., 2007. Earth observations for estimating greenhouse gas emissions from deforestation in developing countries. Environ. Sci. Policy 10, 385–394.

De Jong, B.H.J., Hellier, A., Castillo-Santiago, M.A., Tipper, R., 2005. Application of the ''Climafor'' approach to estimate baseline carbon emissions of a forest conservation project in the Selva Laconda, Chiapas, Mexico. Mitig. Adapt. Strat. Glob. Change 10, 265–278.

De Jong, B.H.J., Esquivel Bazan, E., Quechulpa Montaivo, S., 2007. Application of the ''Climafor'' baseline to determine leakage: the case of Scolel Te. Mitig. Adapt. Strat. Glob. Change 12, 1153–1168.

Evans, K., Velarde, S.J., Prieto, R., Rao, S.N., Sertzen, S., Davila, K., Cronkleton, P., de Jong, W., 2006. Field Guide to the Future: Four Ways for Communities to Think Ahead. Center for International Forestry Research (CIFOR), ASB, World Agroforestry Center, Nairobi, Kenya, p. 87.

Geist, H., Lambin, E., Palm, C., Tomich, T.P., 2006. Agricultural transitions at dryland and tropical forest margins: actors, scales and trade-offs. In:

Brouwer, F., McCarl, B.A. (Eds.), Agriculture and Climate Beyond 2015. Springer, The Netherlands, pp. 53–73.

Generosa, A.D.C., 2007. Forest area dynamics in Asia. Asian J. Water Environ. Pollut. 4, 85–99.

Griffiths, T., 2007. Seeing ''RED''? ''Avoided deforestation'' and the rights of Indigenous Peoples and local communities. A Forest Peoples Programme Briefing Paper. , http://www.forestpeoples.org.

Hairiah, K., Sitompul, S.M., van Noordwijk M., Palm, C.A., 2001. Methods for sampling carbon stocks above and below ground. ASB Lecture Note 4B. Bogor, Indonesia. International Centre for Research in Agroforestry, SEA Regional Research Programme. pp. 23. http://www.worldagroforestry.org/sea/Publications/searchpub.asp?publishid=1003.

Huth, N., Holzworth, D., 2005. Common sense in model testing. In: Zerger, A., Argent, R.M. (Eds.), MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 170–176., In: http://www.mssanz.org.au/modsim05/papers/huth.pdf.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture. Forestry and Other Land Use, In: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm.

IPCC, 2007. Climate Change, Fourth Assessment Report. Cambridge University Press, London.

Kandji, S.T., Verchot, L.V., Mackensen, J., Boye, A., van Noordwijk, M., Tomich, T.P., Ong, C.K., Albrecht, A., Palm, C.A., 2006. Opportunities for linking climate change adaptation and mitigation through agroforestry systems. In: Garrity, D.P., Okono, A., Grayson, M., Parrott, S. (Eds.), World Agroforestry into the Future. World Agroforestry Centre, ICRAF, Nairobi, Kenya, pp. 113–121., In: http://www.worldagroforestry.org/sea/Publications/searchpub.asp?publishid=1481.

Lasco, R.D., 2002. Forest carbon budgets in Southeast Asia following harvesting and land cover change. Sci. China 45, 55–64.

Leimona, B., Boer, R., Arifin, B., Murdiyarso, D., van Noordwijk, M., 2006. Singkarak: combining environmental service markets for carbon and watershed functions? In: Murdiyarso, D., Skutsch, M. (Eds.), Community Forest Management as a Carbon Mitigation Option: Case studies. Center for International Forestry Research, Bogor, Indonesia. , In: http://www.worldagroforestry.org/sea/Publications/searchpub.asp?publishid=1507.

Lipper, L., Cavatassi, R., 2004. Land-use change, carbon sequestratio0n and poverty alleviation. Environ. Manage. 33, S374–S387.

Lusiana, B., van Noordwijk, M., Rahayu, S. (Eds.), 2005. Carbon stocks in Nunukan, East Kalimantan: a spatial monitoring and modelling approach. Report from the Carbon Monitoring Team of the Forest Resources Management for Carbon Sequestration (FORMACS) project. World Agroforestry Centre, ICRAF, SEA Regional Office, Bogor, Indonesia, p. 98.

Masera, O.R., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G.J., Pussinen, A., de Jong, B.H.J., Mohren, G.M.J., 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecol. Model. 164, 177–199.

Mather, A.S., 1992. The forest transition. Area 24, 367–379.

Mather, A.S., 2007. Recent Asian forest transitions in relation to forest transition theory. Int. Forest. Rev. 9, 491–502.

MOFR, 2003. Rekalkulasi Sumber Daya Hutan (Recalculation of Forest Resources). , In: http://www.dephut.go.id/INFORMASI/BUKU2/Rekalkulasi_03.htm.

Montagnini, F., Nair, P.K.R., 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforest. Syst. 61, 281–295.

Mizuno, Y. (Ed.), 2007. CDM in CHARTS, Version1. 0 (April 2007 Updated). IGES, Japan. , In: http://www.iges.or.jp/en/cdm/pdf/charts.pdf.

Murdiyarso, D., Adiningsih, E.S., 2007. Climate anomalies, Indonesian vegetation fires and terrestrial carbon emissions. Mitig. Adapt. Strat. Glob. Change 12, 101–112.

Murdiyarso, D., Herawati, H. (Eds.), 2005. Carbon forestry: who will benefit?.Proceedings of Workshop on Carbon Sequestration and Sustainable Livelihoods, Bogor, 16–17 February 2005. CIFOR, Bogor, Indonesia, p. 215.

Murdiyarso, D., Skutsch, M. (Eds.), 2006. Community Forest Management as a Carbon Mitigation Option: Case Studies. Center for International Forestry Research (CIFOR), Bogor, Indonesia, p. 125.

Murdiyarso, D., Puntodewo, A., Widayati, A., van Noordwijk, M., 2006. Determination of Eligible Lands for A/R CDM Project Activities and of Priority Districts for Project Development Support in Indonesia. CIFOR.

O'Riordan, T., Jordan, A., 1999. Institutions, climate change and cultural theory: towards a common analytical framework. Global Environ. Change 9, 81–93.

Palm, C.A., van Noordwijk, M., Woomer, P.L., Arevalo, L., Castilla, C., Cordeiro, D.G., Hairiah, K., Kotto-Same, J., Moukam, A., Parton, W.J., Riese, A., Rodrigues, V., Sitompul, S.M., 2005. Carbon losses and sequestration following land use change in the humid tropics. In: Palm, C., Vosti, S.A., Sanchez, P.A., Ericksen, P.J., Juo, A. (Eds.), Slash and Burn: The Search for Alternatives. Columbia University Press, NY, USA, pp. 41–63.

Palo, M., 2004. Poverty Reduction By Tropical Forests: Rhetoric Or A Viable Option? FAO, Bangkok.

Ranjan, R., Shortle, J., 2007. The environmental Kuznets curve when the environment exhibits hysteresis. Ecol. Econ. 64, 204–215.

Roshetko, J.M., Delaney, M., Hairiah, K., Purnomosidhi, P., 2002. Carbon stocks in Indonesian homegarden systems: can smallholder systems be targeted for increased carbon storage? Am. J. Altern. Agric. 17, 138–148.

Rudel, T.K., Coomes, O., Moran, E., Angelsen, A., Achard, F., Lambin, E., Xu, J., 2005. Forest transitions: towards an understanding of global land use change. Global Environ. Change 14, 23–31.

Rudel, T.K., 2007. Changing agents of deforestation: from state-initiated to enterprise driven processes, 1970–2000. Land Use Policy 24, 35–41.

Sari, A.P., Sari, R.E., Butarbutar, R.M., Mauliyadi, M., Rusmantoro, W., 2007. Indonesia and Climate Change: Current Status and Policies. Worldbank, Jakarta. , In: http://siteresources.worldbank.org/INTINDONESIA/Resources/Environment/ClimateChange_Full_EN.pdf.

Sathaye, J.A., Andrasko, K., 2007. Land use change and forestry climate project regional baselines: a review. Climate Change Adapt. 12, 971–1000, doi:10.1007/s11027-006-9061-6.

Schimel, D.S., House, J.I., Hibbard, K.A., Bousquet, P., Ciais, P., Peylin, P., Braswell, M., Apps, B.H.J., Baker, D., Bondeau, A., Canadell, J., Churkina, G., Cramer, W., Denning, A.S., Field, C.B., Friedlingstein, P., Goodale, C., Heimann, M., Houghton, R.A., Melillo, J.M., Moore, B., Murdiyarso, D., Noble, I., Pacala, S.W., Prentice, I.C., Raupach, M.R., Rayner, P.J., Scholes, R.J., Steffen, W.L., Wirth, C., 2001. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature 414, 169–172.

Schlamadinger, B., Johns, T., Ciccarese, L., Braun, M., Sato, A., Senyaz, A., Stephens, P., Takahashi, M., Zhang, X., 2007. Options for including land use in a climate agreement post-2012: improving the Kyoto Protocol approach. Environ. Sci. Policy 10, 295–305.

Schwank, O., 2004. Concerns About CDM Projects Based on Decomposition of HFC-23 Emissions from 22 HCFC Production Sites. , In: http://cdm.unfccc.int/public_inputs/inputam0001/Comment_AM0001_Schwank_081004.pdf.

Skutsch, M., Bird, N., Trines, E., Dutschke, M., Frumhoff, P., de Jong, B.H.J., van Laake, P., Masera, O., Murdiyarso, D., 2007. Clearing the way for reducing emissions from tropical deforestation. Environ. Sci. Policy 10, 322–334.

Suyamto, D.A., Van Noordwijk, M., 2005. Scenario studies of land use in Nunukan, East Kalimantan (Indonesia): drivers, local livelihoods and globally relevant carbon stocks. In: Lusiana, B., Van Noordwijk, M., Rahayu, S. (Eds.), Carbon Stocks Monitoring in Nunukan, East Kalimantan: a Spatial, Modelling Approach. World Agroforestry Centre, Bogor, pp. 55–77.

Suyamto, D., Van Noordwijk, M., Hadi, D.P., Lusiana, B., 2003. FALLOW model: assessment tool for landscape level impact of farmers land use choices. In: Post, D.A. (Ed.), Proceedings of MODSIM 2003: International Congress on Modelling and Simulation: Integrative Modelling of Biophysical, Social and Economic Systems for Resource Management Solutions, 14–17 July 2003, Townsville, Australia.

Suyamto, D.A., van Noordwijk, M., Lusiana, B., Eka Dinata, A., Khasanah, N., 2006a. Prospects of adoption of tree-based systems in a rural landscape and its likely impacts on carbon stocks and farmers' Welfare: the FALLOW model application in Muara Sungkai, Lampung, Sumatra, in a ''Clean Development Mechanism' context. ICRAF Working Paper No. 14, World Agroforestry Centre, ICRAF, SEA Regional Office, Bogor, Indonesia. http://www.worldagroforestry.org/sea/Publications/searchpub.asp?publishid=1327.

Suyamto, D.A., van Noordwijk, M., Lusiana, B., Eka Dinata, A., 2006b. Way Tenong and Sidrap: tree planting and poverty alleviation, Indonesia. In: Murdiyarso, D., Skutsch, M. (Eds.), Community Forest Management as a Carbon Mitigation Option: Case Studies. Center for International Forestry Research (CIFOR), Bogor, Indonesia, pp. 74–84., In: http://www.worldagroforestry.org/sea/Publications/searchpub.asp?publishid=1508.

Suyanto, S., 2007. Underlying cause of fire: different form of land tenure conflicts in Sumatra. Mitig. Adapt. Strat. Glob. Change 12, 67–74.

Tomich, T.P., de Foresta, H., Dennis, R., Ketterings, Q.M., Murdiyarso, D., Palm, C.A., Stolle, F., Suyanto, S., Van Noordwijk, M., 2002. Carbon offsets for conservation and development in Indonesia? Am. J. Altern. Agric. 17, 125–137.

Tomich, T.P., Cattaneo, A., Chater, S., Geist, H.J., Gockowski, J., Kaimowitz, D., Lambin, E.F., Lewis, J., Ndoye, O., Palm, C., Stolle, F., Sunderlin, W.D., Valentim, J.F., van Noordwijk, M., Vosti, S.A., 2005. Balancing agricultural development and environmental objectives: assessing tradeoffs in the humid tropics. In: Palm, C.A., Vosti, S.A., Sanchez, P.A., Ericksen, P.J., Juo, A.S.R. (Eds.), Slash, Burn: The Search for Alternatives. Columbia University Press, NY, USA, pp. 415–440.

Trenbath, B.R., 1989. The use of mathematical models in the development of shifting cultivation. In: Proctor, J. (Ed.), Mineral Nutrients in Tropical Forest and Savanna Ecosystems. Blackwell, Oxford, pp. 353–369.

Van Noordwijk, M., Tomich, T.P., Winahyu, R., Murdiyarso, D., Partohardjono, S., Fagi, A.M., 1995. Alternatives to Slash-and-Burn in Indonesia, Summary Report of Phase 1. ASB-Indonesia Report Number 4, Bogor, Indonesia, 154 pp.

Van Noordwijk, M., 2002. Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. Ecol. Model. 149, 113–126.

Van Noordwijk, M., Hairiah, K., Sitompul, S.M., 2000. Reducing uncertainties in the assessment at national scale of C stock impacts of land use change. In: Magcale-Macandog, D.B. (Ed.), Proceedings of the IGES/NIES Workshop on GHG Inventories for Asia-Pacific Region. Institute for Global Environmental Strategies (IGES), Hayama, Japan, pp. 151–163., In: http://www.iges.or.jp/cc/napiid/PDF/2_LULUCF2.pdf.

Van Noordwijk, M., Rahayu, S., Hairiah, K., Wulan, Y.C., Farida, A., Verbist, B., 2002. Carbon stocks assessment for a-forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land use change analysis. Sci. China 45, 75–86.

Van Noordwijk, M., Widayati, A., Lusiana, B., Hairiah, K., Arifin, B., 2005. What can a clean development mechanism do to enhance trees in the landscape? Experience with rubber, coffee and timber-based agroforestry systems in Indonesia. In: Murdiyarso, D., Herawati, H. (Eds.), Carbon Forestry: Who Will Benefit? Proceedings of Workshop on Carbon Sequestration Sustainable Livelihoods. CIFOR, Bogor, Indonesia, pp. 92–111., In: http://www.cifor.cgiar.org/publications/pdf_files/Books/BMurdiyarso0501.pdf.

Van Noordwijk, M., Arifin, B., Leimona, B., 2006. Criteria and mechanisms for rewarding upland poor for the environmental services they provide. In: Ai Dairah, Nurida, L., Irawan, Edi Husen, Fahmuddin Agus, (Eds.), Revitalisasi dan Multifungsi Pertanian [Multifunctionality and Revitalization of Agriculture]. Proceedings of Seminar 27–28 June 2006. Bogor, Indonesian Agency for Agricultural Research and Development, Jakarta, Indonesia, pp. 124–154.

Van Noordwijk, M., Leimona, B., Emerton, L., Tomich, T.P., Velarde, S., Kallesoe, M., Sekher, M., Swallow, B., 2007a. Criteria and indicators for ecosystem service reward and compensation mecha-nisms: realistic, voluntary, conditional and pro-poor. Working Paper 37. World Agroforestry Centre, Nairobi.

Van Noordwijk, M., Suyanto, S., Budidarsono, S., Sakuntaladewi, N., Roshetko, J.M., Tata, H.L., Galudra, G., Fay, C., 2007b. Is Hutan Tanaman Rakyat a new paradigm in community based tree planting in Indonesia? Working Paper 45. World Agroforestry Centre, Bogor. http://www.worldagroforestrycentre.org/Sea/Publications/currentpub.asp?publishid=1686.

Verbist, B., Eka Dinata, A., Budidarsono, S., 2005. Factors driving land use change: effects on watershed functions in a coffee agroforestry system in Lampung, Sumatra. Agricult. Syst. 85, 254–270.

Verchot, L.V., Hutabarat, L., Hairiah, K., van Noordwijk, M., 2006. Nitrogen availability and soil N_2O emissions following conversion of forests to coffee in southern Sumatra, Global Biogeochem. Cycles, 20, GB4008, doi:10.1029/2005GB002469. http://www.agu.org/pubs/crossref/2006/2005GB002469.shtml.

Verchot, L.V., Van Noordwijk, M., Kandji, S., Tomich, T.P., Ong, C.K., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K.V., Palm, C., 2007a. Climate change: linking adaptation and mitigation through agroforestry. Mitig. Adapt. Strat. Glob. Change 12, 901–918.

Verchot, L.V., Zomer, R., Van Straaten, O., Bart Muys, B., 2007b. Implications of country-level decisions on the specification of crown cover in the definition of forests for land area eligible for afforestation and reforestation activities in the CDM. Climatic Change 81, 415–430.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken, D.J. (Eds.), 2000. Land Use, Land-Use Change and Forestry. A Special Report of the IPCC. Cambridge University Press, NY.

Worldbank, 2007. Sustaining Economic Growth, Rural Livelihoods, and Environmental Benefits: Strategic Options for Forest Assistance in Indonesia. Worldbank, Jakarta.