Recommendations on the design of national monitoring systems relating the costs of monitoring to the expected benefits of higher quality of data

REDD[+] seeks to establish 'performance based' financial instruments to make forests more valuable standing than destroyed.

Project
Report

World Agroforestry Centre

BOX 1. Overview of the REDD ALERT project

The European Union financed the REDD ALERT project (contract number 226310) 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 greenhouse gas (GHG) emissions. Its specific objectives six-fold.

1. Document the diversity in social, cultural, economic and ecological ***drivers of forest transition*** and conservation and the consequences in the context of selected case studies in Indonesia, Vietnam, Cameroon and Peru as representative of different stages of forest transition in Southeast Asia, Africa and South America.

2. ***Quantify rates of forest conversion*** and change in forest carbon stocks using improved methods.

3. Improve accounting (methods, default values) of the consequences of land-use change for ***GHG emissions in tropical forest margins including peat lands***.

4. Identify and assess 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.

5. Analyse scenarios in selected case study areas of the ***local impacts of potential international climate-change policies*** on GHG emission reductions, land use and livelihoods.

6. Develop ***new negotiation support*** tools and use these with stakeholders at international, national and local scales to explore a basket of options for incorporating REDD into post-2012 climate agreements.

Recommendations on the design of national monitoring systems relating the costs of monitoring to the expected benefits of higher quality of data
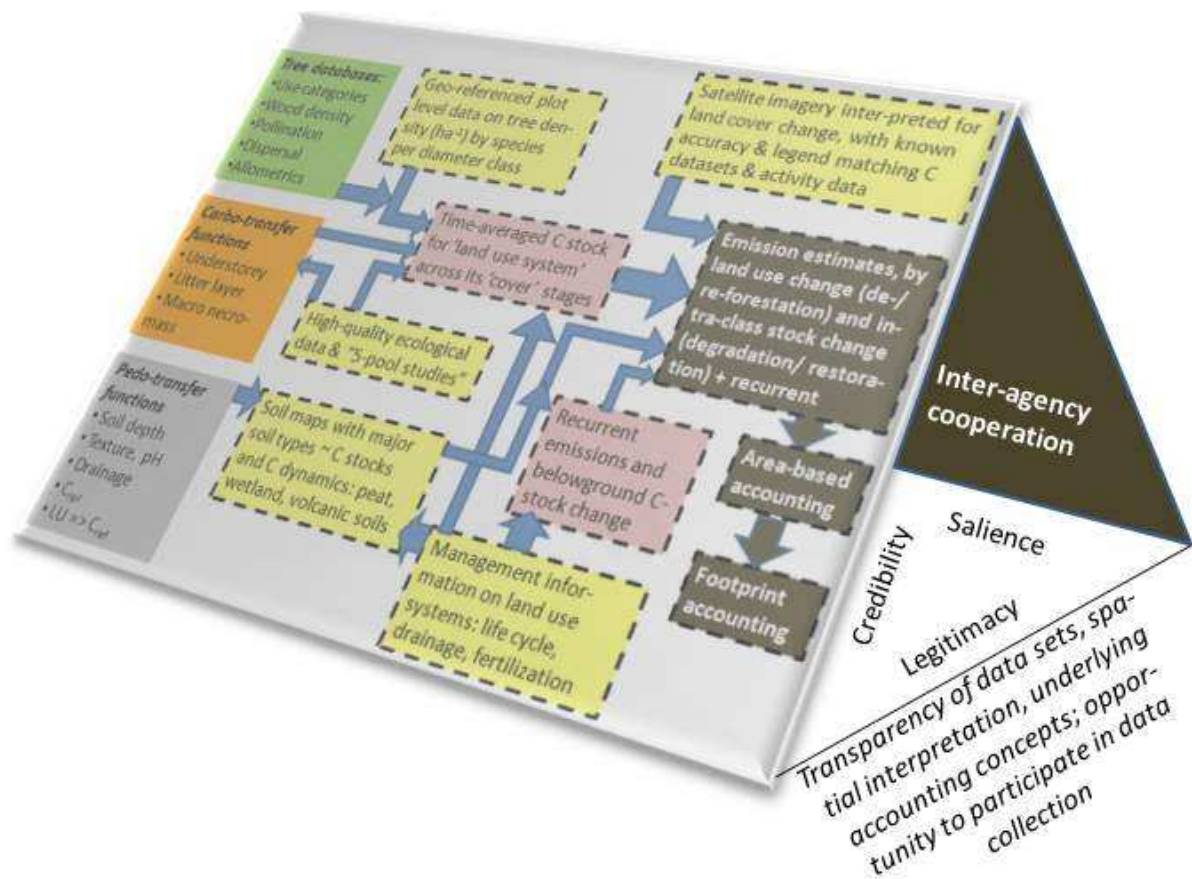
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2012

World Agroforestry Centre (ICRAF)

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Synopsis: REDD+ seeks to establish 'performance based' financial instruments to make forests more valuable standing than destroyed. A trustable, reliable and transparent C accounting system at national scale is thus essential. Accuracy of C stock and emission estimates depends strongly on scale: approaches that are sufficient for reliable national accounting may not be accurate at site ('pixel') level. The proposed REDD implementation mechanisms thus influence the required levels of precision at specific scales, and the benefits that stakeholders can obtain from investment in better data. Within a general scheme of the type of tree, forest, soil and land management practices that are needed to estimate emissions, we review a number of datasets to assess sources of bias and random error, linked to the level of replication that is needed to achieve specified precision. We also summarize data on costs of data collection at a number of scales, with different levels of precision. In combination, the costs and benefits of investment in data quality can be weighed and a balance achieved between achievement and 'transaction costs' (to which the costs of designing a monitoring system contribute). To be cost effective, national monitoring systems can build on existing forest inventory and soil data, but they need to be analyzed for bias components and variability to assess adequacy for carbon stock appraisals. Examples for Indonesia are given of the gap between these data and intensive ecological studies: reconciliation of the data sources requires reanalysis of the site selection for ecological studies and of pre-1990 logging across the country. We provide a list of 10 recommendations and summarize the current situation in Indonesia, Vietnam, Cameroon and Peru relative to these suggestions that combine biophysical and institutional dimensions of system design.

Recommendations:

1) Start with what you have; forest departments, agricultural statistics, land cover studies, spatial planning zones, existing use rights, soil maps and soil fertility databases can all contribute important information;

2) Expect gaps and mismatches between data sets especially where institutional and biophysical concepts use the same terms (e.g. "forest");

3) Analyze quality of a national monitoring system as dependent on three characteristics:

   A) Salience (does it address key policy issues and respond to policy implementation at relevant time scale?)

   B) Credibility (are the methods up to date and consistent with international standards, are confidence intervals of key parameters known, is error propagation towards final estimate traceable with realistic degrees of confounding of component errors)

   C) Legitimacy (is the work done by agencies and individuals that are, through their combination and cooperation, seen to represent the specific and valid concerns of:

   - Local, subnational and national governments (aligned with reporting obligations)

   - Local people and indigenous group representatives

- Local, national and international private sector with interest in the 'footprint' of land use associated with commodity value chains

- Environmental NGO's at local, national and international level)

4) Involve local stakeholders in data collection and international expertise in consistency and validity checks

5) Invest in methodology, harmonization of legends (operational classification scales), 'one-map' consistency of spatial data across government agencies, and clarity of operational definitions from a local perspective before investing in new data collection

6) Tier 2.5 AFOLU accounting is a feasible and realistic goal for any country wanting to participate in REDD+ debates; it involves stock change accounting with subnational land use classes, C-stock (activity) data that are adjusted to eco-climatic zones, major soil types (incl. peat and volcanic soils as special classes), and the typical management practices across the life cycle of land use systems. It also requires area data of land cover change **with matching legend** (more than 20 map units may be needed); for Indonesia most of this was achievable with an external investment of about 1 Million Euro plus data and staff capacity of national agencies

7) The protocols for "RApid Carbon Stock Appraisal" (RACSA) allow local data collection and reporting at a cost level of 10,000-20,000 Euro for areas of 20x20 km^2 to district scale, if carried out by competent national universities and NGO's, in cooperation with local governments. High-precision, location-specific data (e.g. following VCS protocols) are only useful if **nested within** the national system and its hierarchical legend units, and when possible sampling bias (selective focus on high C stock or high emission areas) can be assessed

8) **MR:** The quality of interdepartmental coordination between custodians of various data sets that contribute to the national accounting system determines the quality of the national accounts; it requires considerable effort and adjustment of institutional incentive systems

9) **V:** Basic data on soils and tree cover need to be open to public scrutiny in sufficiently high resolution to allow public scrutiny and corrections; an appropriate system for obtaining feedback, verifying local discrepancies and adjustment of databases is needed, and may require appropriate budget

10) The primary accounting precision target for REDD+ and NAMA is the national scale, consistent with National Communications on Greenhouse Gas Emissions; this implies that **bias** issues (systematic error) are prominent and require attention in temporal consistency, while **random error** is less problematic for national reports; local-scale confidence levels at the finest spatial scale that is publicly accessible, however, influence the fraction of local stakeholders that will see their area as misrepresented.

Contents

1. Introduction: costs of (not) having good data

Obtaining information has a cost, reliable information a higher cost, and information where we can estimate the reliability of data an even higher one. Lack of information on carbon stocks and emissions implies lack of opportunity to participate in "carbon markets" – if the latter will at some point emerge. Investment in understanding the basic concepts of carbon storage and in collecting locally relevant data of know reliability is a relevant step towards a future where land-based emissions will be an issue in public debate, whether under NAMA or REDD+ headings of policy instruments (NAMA = Nationally Appropriate Mitigation Actions; REDD+ = Reducing Emissions from Deforestation and (forest) Degradation, plus rebuilding of forest carbon stocks). It is, however, relevant to judge what level of investment may optimize rather than minimize uncertainty. Current investments are tens of millions of dollars per year for countries with large forest areas, and without reliable data such investments will not continue or increase.

A number of commodity markets, e.g. palm oil, start to be restrictive for participants without proper data: exclusion of palm oil by the US EPA from biodiesel markets may have been based on incorrect or at least incomplete data. Even though the biodiesel use is only a few percent of total, palm oil is a multi-billion dollar per year value chain, so the costs of not having good data is worth tens of million dollars per year. Seen in that light, investments of a few million dollars per year in systems that support multiple commodity chains plus area-based C accounting across the country are probably economically justified at this point of the international debate on climate change mitigation. At the level of a smallholder farm, however, the costs of a single soil analysis may be higher than any carbon-market benefit it might give access to. Scale matters in the cost/benefit ratio of data collection, but also in the nature of the variability issue sampling has to address.

The estimate of terrestrial carbon stock at a given time, which can be contrasted with that at an earlier time to estimate net sequestration or emission levels, is typically obtained by adding over 5 "IPCC pools" of terrestrial carbon stocks, each with its own bias and random error jointly contributing to uncertainty:

- Aboveground tree biomass, understorey and other vegetation,
- Roots of trees and other vegetation,
- Dead wood (macro necromass),
- Litter and other necromass,
- Soil carbon.

Uncertainty in the overall emission estimates does not follow directly from the uncertainty in the basic data – we need to understand all the steps involved in deriving the final values and the covariance between components before we can look at error propagation. It is possible that variability is dampened, and is smaller in the aggregated results than in the components; it is also possible that variation in specific factors has a more than proportional effect on the uncertainty in the final result. Only by tracing the steps in carbon stock and emission accounting, we can identify the weakest parts of the current data chain and focus efforts on strategic investments of higher quality (or simply more) data where it really matters.

Uncertainty is conventionally partitioned over two components: bias (systematic error) and random error. Random error can be controlled by increasing the number of replicate samples, as the confidence interval decreases inversely proportional to the square root of the number of samples. Bias will not be reduced by increasing sample size; it will only show when a combination of methods is used that would supposedly provide the same answer and it doesn't do so in reality. If one of the methods has the status of 'standard' the discrepancy of the others is considered bias; in other cases all the divergent methods are suspect, until the differences can be reconciled with independent other information about the performance of the methods.

Bias and random error have a very different impact on efforts to reduce emissions. The paper published by Nogueira et al. (2007) on the carbon content and wood density of the deforestation arc in the Amazon reduced the estimated national emissions from Brazil by about 10%, as it clarified that the forests that are actually converted had lower carbon stocks than was previously assumed. This type of emission reduction, as cost effective as it may have been, is, however, not replicable – once a bias term is removed it cannot be further reduced.

Tiers in national GHG accounting

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use (http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html) provided a framework 3-tiered structure for AFOLU (Agriculture, Forestry and Other Land Use is the name for historical reasons; it might just as well be called 'all land use') methods:

"Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided in this volume. Country-specific activity data are needed, but for Tier 1 there are often globally available sources of activity data estimates (e.g., deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.), although these data are usually spatially coarse."

"Tier 2 can use the same methodological approach as Tier 1 but applies mission and stock change factors that are based on country- or region-specific data, for the most important land use or livestock categories. Country-defined emission factors are more appropriate for the climatic regions, land use systems and livestock categories in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land use or livestock categories."

"At Tier 3, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land use and management activity data, integrating several types of monitoring. Pieces of land

where a land use change occurs can usually be tracked over time, at least statistically. In most cases these systems have a climate dependency, and thus provide source estimates with inter-annual variability. Detailed disaggregation of livestock population according to animal type, age, body weight etc., can be used. Models should undergo quality checks, audits, and validations and be thoroughly documented."

Who cares? What accuracy is needed at what scale for various alternative REDD implementation pathways?

Specifically in the case of emerging REDD mechanisms there is no consensus yet at what scale accurate C stock data are needed. If the primary focus is on accurate national scale emission assessments relative to Reference Emission Levels (or Reference Levels), uncertainties at lower, contributing scales is acceptable, **as long as errors can be expected to be symmetrical** (over and under estimates balancing out). Random error will be small at a national aggregation scale, but sensitivity to **bias** is high.

If on the other hand the primary action will be at 'project' level with 'pixel' level performance contracts, accuracy is needed at pixel scale. For example, it is generally considered acceptable in remote sensing image interpretations have a pixel level accuracy of at least 85%. This implies that 15% is misclassified: if the error is symmetrical (an assumption to be tested, see below), 7.5% may get more money than they deserve (and they will keep quiet), and 7.5% too little (and they will complain or feel mistreated). Depending on circumstances, this level of error and uncertainty can be unacceptable, and more investment in higher quality imagery that can be interpreted with higher accuracy, say 95%, may seem justified (even so, 2.5% of pixel right-holders have reason to complain...).

The Voluntary Carbon Standard (VCS) that is emerging as a quality standard in voluntary REDD projects as well, requires adequate replication of samples to control the random error in C stock assessment for fine-grained application. The efforts needed add to the transaction costs, but increase probability of fund access and may still be worthwhile for project developers. Will all these additional data also contribute to accuracy of national emission estimates? Not unless the 'sampling bias' of locating all these samples in a relatively small area can be quantified and controlled for.

An alternative REDD benefit distribution mechanism can be envisaged (Fig. 1) that combines three paradigms (van Noordwijk and Leimona, 2010; van Noordwijk et al., 2012):

❑ '**commodification**' of carbon credits at national scale (with narrow confidence intervals of data, internalization of 'leakage' concerns and bottomline accounting solutions to the 'permanence' issue),

❑ a '**compensation**' paradigm between provinces and districts that ties government funding to C stock performance along other parts of formulaic approaches (e.g. number of inhabitants, poverty levels, education and health care scores), and

❑ a '**co-investment**' paradigm that provides incentives for high-C stock development pathways on the ground.

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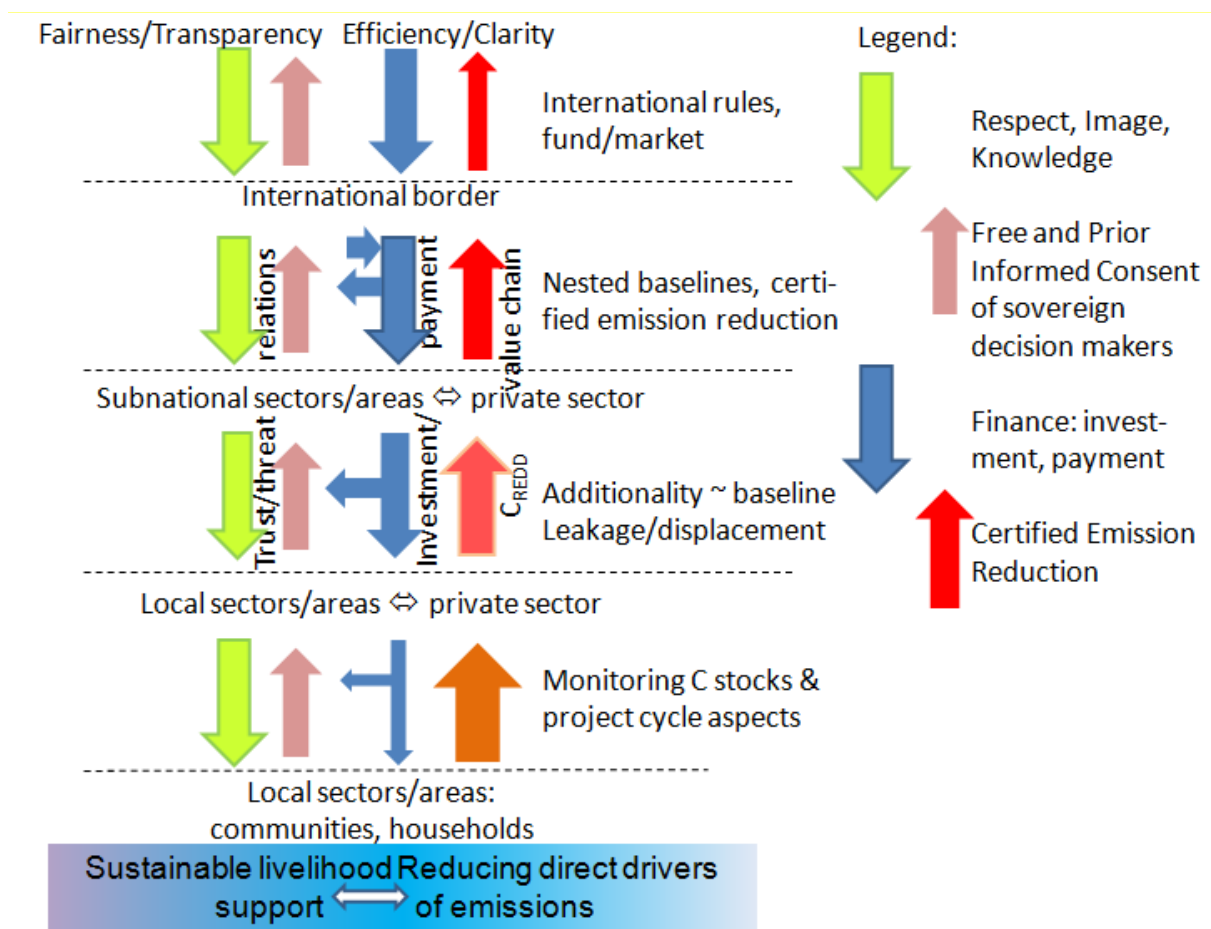
Figure 1 (identical to REDD-ALERT D2.2 Figure 7). Two-way exchanges in both the fairness and efficiency domains of a nested REDD process that links performance from local to national scales with support for sustainable livelihood options that reduce emissions compared to the 'normal' development pathway

for REDD. An alternative approach is currently in discussion where private funds will be channelled in new ways towards 'investments in sustainable development' – which may have emission reduction as a co-benefit, rather than as primary rationale (Fig. 2). With the emergence of environmental standards for 'footprint' calculations of commodity flows, two scales have emerged:

- Some standards (such as EPA biofuel) are for the global weighted average of production conditions of that commodity,

- Others allow companies to get 'certified' at plantation level (potentially true for the EU biofuel standard).

The consequences for scale dependence of accuracy is similar as that discussed for REDD projects.
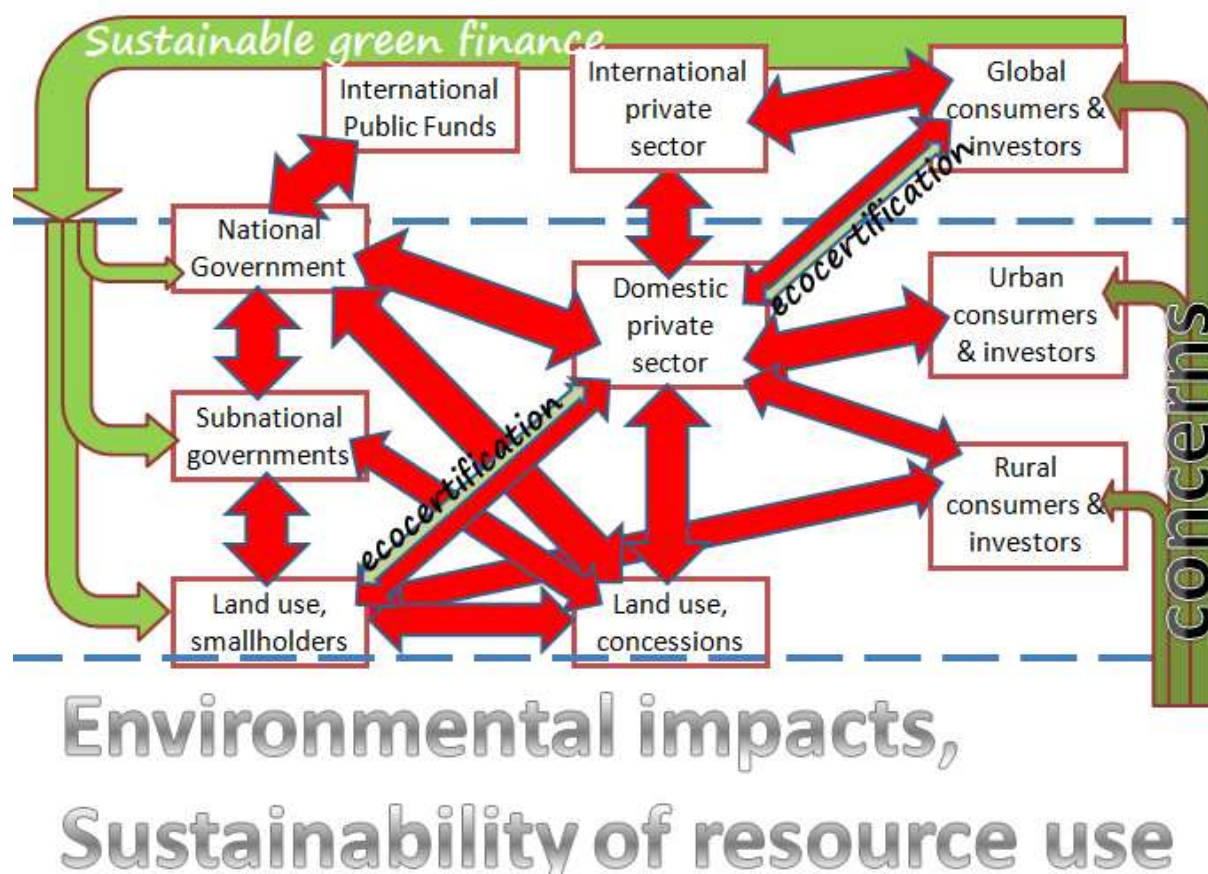
Figure 2. Linkage of local stakeholders in tropical forest margins to local and national governments as well as a private sector with international reach; new 'sustainability finance' options are under discussions for which sustainability aspects, including the 'emission footprint' will influence investment decisions, without targeting C credits as such

In such an approach the level of accuracy required would increase from pixel to national scale, alongside the levels of 'replication' over which random error can be expected to balance out.

The slow pace at which international commitments to reduce emissions have been obtained has led to disappointment in expectations that a 'carbon market' will soon be the major source of funding

What does data collection cost?

Most of the experience so far with data collection has been supported by research projects with limited objectives and scope regarding C accounting, combined with other tasks. For a number of projects we have information about the scale at which they operated, the type of data that they achieved, and the level of costs (including project management, partnerships, capacity development and similar activities to start up). Table 1 provides examples, ranging from a national scale effort at a 1 M Euro cost level, to rapid C stock appraisals of a limited area at a cost level of 10,000 Euro. Relative to the costs of opportunities lost by not having reliable data described at the start of this chapter, these levels of investment are reasonable.

A separate but related discussion is who should be involved, and in what role, in the measurements:

- ❑ Local people who know the area, know the forests and trees, and have a direct stake in what happens with their landscapes?

- ❑ Professionally trained foresters and ecologists who have good understanding of statistics, bias and error prevention (quality control on data),

- ❑ International experts who can contribute to international compatability and internal consistency of data between countries and components of the global carbon cycle.

While their involvement comes with different cost structures and levels per unit time, clarity on roles and potential for synergy and complementarity is needed on the institutional side before economic cost/benefit calculations can be brought to closure in recommendations about their role in a national C accounting system.

Table 1. Examples of cost levels for C stock appraisals and emission estimates

What it takes: cost level and time frame	What you get	Example
1 M Euro	Indonesia (193 M ha)wall-to-wall Landsat imagery analyzed with object-based classification for land cover change (1990, 2000, 2005, 2010) + analysis of national forest inventory data for typical C stock estimates; 85% accuracy at pixel level in ground-truthed locations ➔ emission estimates per 5 year at national & provincial scale; district level needs further work	AllREDDI Indonesia, EU supported
10,000 Euro	Rapid C-stock appraisal (RACSA) on typically 20*20 km2 (40,000 ha): local C stock data + satellite image interpretation ➔local emission estimates	About 10 RACSA application in Indonesia, Philippines, Vietnam
20,000 Euro	District-level RACSA subcontracted by provincial government to national university	E. Java (Indonesia) Kalahan (Philippines) RACSA + PIN development

Key questions for this report

In view of the above, we will in chapter 2 explore technical aspects of uncertainty, bias and random error propagation, and consider the type of data that need to be combined in order to arrive at national C accounting for the land-based sectors. In chapter 3 we will discuss the institutional side of ways to organize such efforts, by getting existing departments and institutions to cooperate, be critical about data quality, and be jointly responsible for an accounting system that stands up to

critical reviews. Combining insights from chapters 2 and 3, we will formulate a list of ten recommendations in chapter 4, review status in the REDD-Alert countries in chapter 5, followed by some final discussion on ways forward.

2. Biophysical and statistical uncertainty on C stock changes in the landscape: databases, bias and error propagation

Basics of stock change accounting

At any point in time the total terrestrial C stock can be obtained by summation over the total land area of the products of area and typical C stock for any class of a classification system, provided the classification system is comprehensive ('no orphans') and has no overlap:

$$Stock_t = \Sigma_i (A_{i,t} C_{i,t})$$

Where A equals area, C carbon stock density, and the indices t and i refer to time and classes of a a land use classification system. Much of the land area may not change over a (short) accounting period, so the focus can be on areas that *did* change. The IPCC Good Practice Guidance recommended a simple approach by combining 'activity data' (AD - information on the extent to which a human activity takes place, typically in area changed per unit time) with 'emission factors' (EF - emissions or removals per unit activity, typically in CO_2e/ha):

$$Emissions = \Sigma_j AD_j * EF_j$$

Three types of 'activity data' and associated 'emission factors' can be distinguished:

1) Areas that changed from one land use class to another one, with higher or lower C stock density, and an emission factor derived from this stock difference,

2) Areas within a class that, on average, changed its typical C stock density

3) Areas that involve recurrent emissions, such as drained peat soils that continue to lose C or non-carbon greenhouse gas (GHG) emissions counted at their CO_2e equivalents.

Each of these three emission categories may associate with a specific set of policy options and levers; thus reporting under separate headings is relevant, as long as the system does not have gaps or overlaps. If we have a land use classification that covers the total land area without overlaps and orphans, we can describe land use change over a time period t➜t+1 as a matrix, sorted by associated typical ('time-averaged') C stocks for each land use type, that may themselves vary with time (Table 3).

Table 2. Schematic representation of land use change matrix in relation to typical C-stock estimates per class

	LU_1	LU_2	LU_3	LU_4	...	...	LU_n	
LU_1	0							$A_{LU1,t}$
LU_2		0						$A_{LU2,t}$
LU_3			0					$A_{LU3,t}$
LU_4				0				$A_{LU4,t}$
...					0			$A_{LU..,t}$
...						0		$A_{LU..,t}$
LU_n							0	$A_{LUn,t}$
	$A_{LU1,t+1}$	$A_{LU2,t+1}$	$A_{LU3,t+1}$	$A_{LU4,t+1}$	$A_{LU..,t+1}$	$A_{LU..,t+1}$	$A_{LUn,t+1}$	A

C_t	C_{t+1}
$C_{LU1,t}$	$C_{LU1,t+1}$
$C_{LU2,t}$	$C_{LU2,t+1}$
$C_{LU3,t}$	$C_{LU3,t+1}$
$C_{LU4,t}$	$C_{LU4,t+1}$
$C_{LU..,t}$	$C_{LU..,t+1}$
$C_{LU..,t}$	$C_{LU..,t+1}$
$C_{LUn,t}$	$C_{LUn,t+1}$

We can split the total stock change in terms that relate to the first and second type of 'activity':

Stock change $_{t=>t+1}$ = Σ_i ($A_{i,t+1}$ $C_{i,t+1}$) - Σ_i ($A_{i,t}$ $C_{i,t}$) +{ Σ_i ($A_{i,t+1}$ $C_{i,t}$) - Σ_i ($A_{i,t+1}$ $C_{i,t}$)}

= Σ_i (($A_{i,t+1}$ -$A_{i,t}$) $C_{i,t}$) + Σ_i ($A_{i,t+1}$ ($C_{i,t+1}$- $C_{i,t}$))

Area changed, C density not	C density changed

The first term indicates the sum of area change *between* the various land use classes ('deforestation', 'reforestation'), the second shifts in typical C stock density *within* each class ('degradation', 'restoration'). These are the first two types of 'activity' listed above. For the third type, recurrent emissions, we can use a midpoint area estimate for the interval (e.g. ($A_{i,t+1}$ +$A_{i,t}$)/2 for linear interpolation) to be fully consistent.

In this approach, the choice of an appropriate land classification system is key to the success and remaining uncertainty of this approach.

The IPCC Good Practice Guidance suggests the following high level ***land use*** classification:

(i) Forest land: all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystem type as specified in the IPCC Guidelines. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.

(ii) Cropland: arable and tillage land, ***and agro-forestry systems*** where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.

(iii) Grassland: rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and ***silvo-pastoral systems***, subdivided into managed and unmanaged consistent with national definitions.

(iv) Wetlands : land that is covered or saturated by water for all or part of the year (e.g., peatland) and ***that does not fall*** into the forest land, cropland, grassland or settlements categories. The category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

(v) Settlements: all 'developed' land, including transportation infrastructure and human settlements of any size, ***unless they are already included under other categories***. This should be consistent with the selection of national definitions.

(vi) Other land, including bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

While this categorization avoids overlaps, it may not directly match existing data that use a similar terminology. For example, forest data tend to be defined by institutional mandates of a forestry department, rather than by the presence of a woody vegetation; the inclusion of 'forests without trees' in the definition caters for this, in part, but does not match general parlance that links loss ot tree cover to 'deforestation'. While crop land can include agroforestry and pasture silvo-pastoral systems, there is no guidance on how to account for the tree cover in these land categories – although it can be substantial (Zomer et al., 2009).

As discussed in REDD-ALERT D2.2, the primary challenge is to reconcile 'land cover' data, objectively derived from remote sensing, and 'land use' perspectives that relate to economic activities\ and stakeholder perspectives.
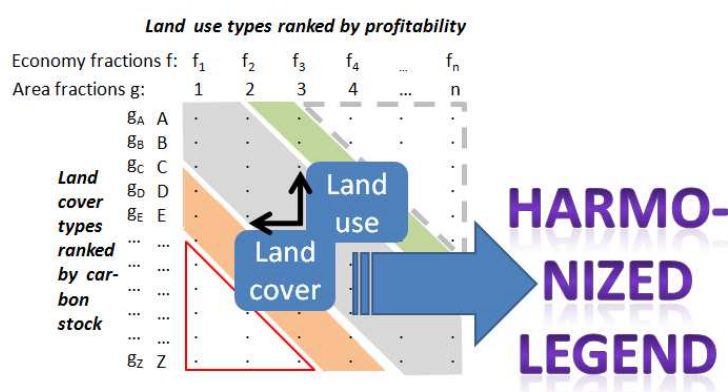
Figure 3. A harmonized legend (classification system) is needed that relates what is observable (land cover) to its economic attributes (land use)

Table 3. Relationship between land cover classifications, as observable in remote sensing imagery, and the various aspects of a land use system across its typical life cycle; a consistency check between land cover and land use data requires comparison of the sums of rows and columns

Land cover type and associated C stock	Land use system 1	Land use system 2	Land use system 3	...	Land use system n	Total
1. Bare	$T_{1,1}$ % of time	$T_{1,2}$ % of time	$T_{1,3}$ % of time		$T_{1,n}$ % of time	T_1 % of land area
2. Low vegetation (grass, crop)	$T_{2,1}$ % of time	$T_{2,2}$ % of time	$T_{2,3}$ % of time		$T_{2,n}$ % of time	T_2 % of land area
3. Shrub, young trees	$T_{3,1}$ % of time	$T_{3,2}$ % of time	$T_{3,3}$ % of time		$T_{3,n}$ % of time	T_3 % of land area
4. Planted forest	$T_{4,1}$ % of time	$T_{4,2}$ % of time	$T_{4,3}$ % of time		$T_{4,n}$ % of time	T_4 % of land area
5. Tree crops	$T_{5,1}$ % of time	$T_{5,2}$ % of time	$T_{5,3}$ % of time		$T_{5,n}$ % of time	T_5 % of land area
6. Mixed tree cover ('agroforest')	$T_{6,1}$ % of time	$T_{6,2}$ % of time	$T_{6,3}$ % of time		$T_{6,n}$ % of time	T_6 % of land area
7. Heavily logged forest with remnant trees	$T_{7,1}$ % of time	$T_{7,2}$ % of time	$T_{7,3}$ % of time		$T_{7,n}$ % of time	T_7 % of land area
8. Secondary forest	$T_{8,1}$ % of time	$T_{8.2}$ % of time	$T_{8,3}$ % of time		$T_{8,n}$ % of time	T_8 % of land area
9. Logged-over forest	$T_{9,1}$ % of time	$T_{9.2}$ % of time	$T_{9,3}$ % of time		$T_{9,n}$ % of time	T_9 % of land area
10. Old-growth forest	$T_{10,1}$ % of time	$T_{10.2}$ % of time	$T_{10,3}$ % of time		$T_{10,n}$ % of time	T_{10} % of land area
Area per land use system	A_{LU1}	A_{LU2}	A_{LU3}	$A_{LU..}$	A_{LUn}	A
Time-averaged C stock density	$C_{LU1} = \Sigma_j\, T_{j,1}\, C_j$	$C_{LU2} = \Sigma_j\, T_{j,2}\, C_j$	$C_{LU3} = \Sigma_j\, T_{j,3}\, C_j$	$C_{LU..}$	$C_{LU4} = \Sigma_j\, T_{j,4}\, C_j$	

Summation of area via the rows and summation via the columns must lead to the same result.

For example, a swidden system of land use may be 'bare land' for half a year, cropped (low vegetation) for 2 years, shrub (fallow) for about 5 years, and secondary forest for the rests of its cycle. Plantation forestry may also involve a bare land phase, and progress from low vegetation to shrub and planted forest aspects over time. Logging may alternate between old-growth and (high-density) logged forest if done carefully at low extraction rates, or operate in the lower ranges of land cover types if done more aggressively. The challenge is partly one of wording where certain terms can refer to both a land cover and a land use type.

BOX. Accuracy: bias and precision (Hairiah et al. 2011)

The final value calculated from any sampling or accounting method will probably differ from the actual value at the time of assessment. While this is unavoidable, it is important to realize the consequences of inaccurate answers and the costs involved in getting better and better approximations. It is useful to distinguish between two sources of 'inaccuracy' (the difference between the estimate and the actual value)—namely, bias (systematic error) and incomplete sampling (random error)—as shown in Figure. 1. Only incomplete sampling can be dealt with by increasing the sampling effort. Bias can derive from the use of inaccurate or wrongly calibrated methods and equations, or from sampling schemes that give a higher probability of inclusion in the sample to areas with either a relatively low or a relatively high value.
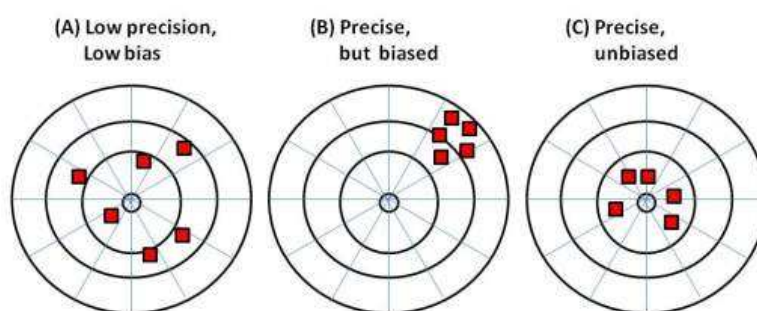

RACSA Figure 1. . Lack of precision and bias can both lead to inaccurate estimates but only the first can be dealt with by increasing the number of samples. Assuming the objective is to sample the bulls eye in the centre of the target: (A) all sampling points, while close to the centre, will have low bias, but they are widely spaced and therefore have low precision; (B) all points are closely grouped indicating precision but they are far from the center and so are biased and inaccurate; (C) all points are close to the center and closely grouped, so they are precise and unbiased or in a word, accurate.

The variation between replicates can be used to estimate the precision of the sample mean, but it does not reflect its accuracy, as any bias is not revealed. Bias may only show up if data from multiple sources are compared with measurements at another scale. When the first estimates of the global C cycle were made, there were large amounts of 'missing carbon' due to inconsistencies in methods used by the various data sources. A number of sources of bias in the data collection have since been identified and the data gap is smaller but it still exists. In the context of policies and international regulation, bias and precision play different roles. Relative, (rather than absolute) changes in emissions and stocks are the targets of such policies. Thus, as long as bias is consistent in space and time, it does not affect the policy process. However, inconsistencies between the outcomes of different methods can be used as an excuse for inaction ("the scientists don't yet agree, so we had better wait"). Random error tends to be smaller at a national scale of data aggregation than at sub-national units where fewer samples are involved. This is important for the scales of policy instruments. If changes in C stocks in relatively small areas are the target of a project, a substantial sampling effort will be needed to quantify those changes in C stocks for the area. If the target changes at a national scale, a similar effort spread over a much larger area might suffice to obtain the same precision at much lower cost per unit change in the C stock measured. The emphasis on precision at project scales may have contributed to the impression that C accounting at the national scale will be complicated and expensive. It does not have to be, if efficient sampling schemes are used. Political processes, however, don't readily appreciate statistical arguments, and may want to see detailed 'wall-to-wall' evidence before action is taken. The psychology and art of communication are as important as the accuracy and precision of the data.

The transition of land cover types (which can be observed in remote sensing) and land use systems (that can combine various land cover types during a typical production cycle, for specified %'s of time) is not trivial and requires a consistency test that is rarely made (or at least rarely reported).

Linking up component databases

C stock accounting over land areas, e.g. at (sub)national scale, requires the combination of different types of data and observations (Fig. 4). These data require different types of expertise and institutional mandates.
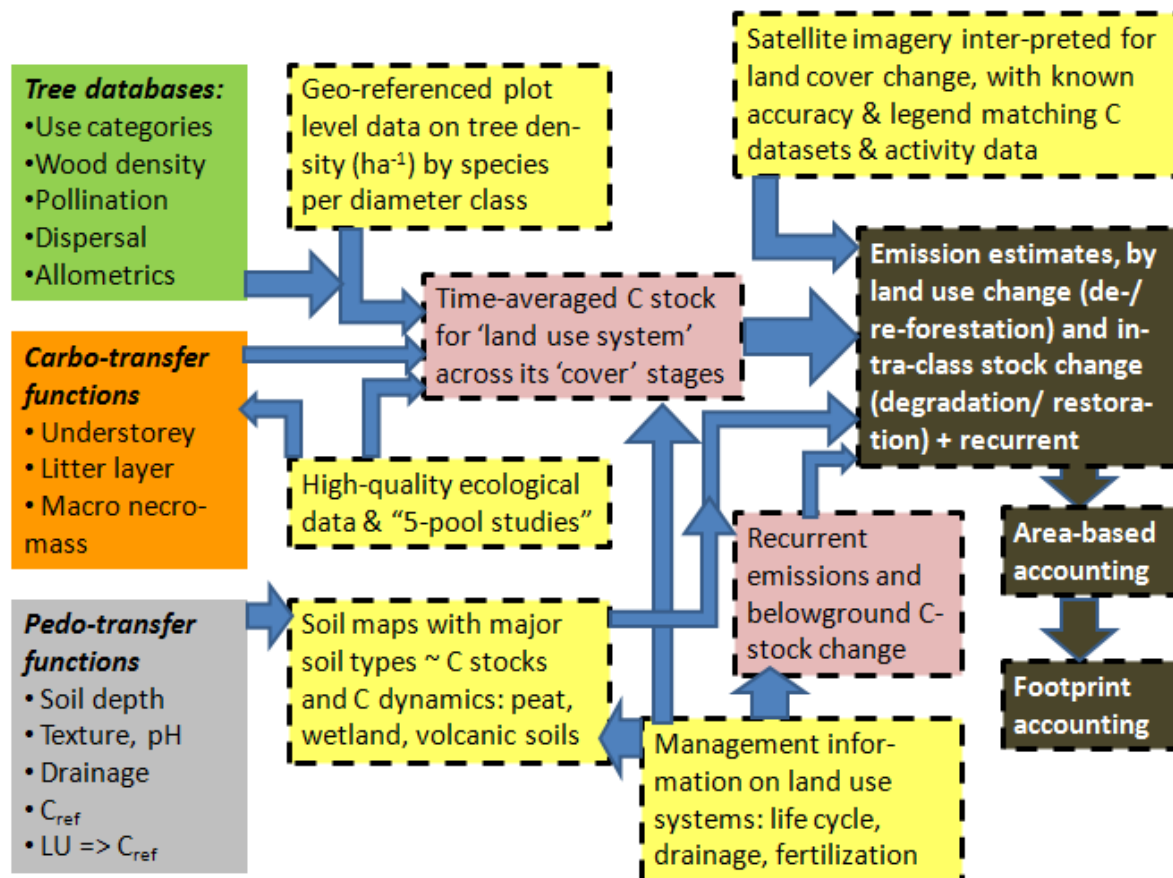
Figure 4. Schematic flowchart of the types of data and databases that are needed to derive time-averaged C stock of the main land use systems, that match the definitions of the land use change matrix derived from remote sensing, plus soil information systems that allow recurrent emissions (e.g. in the case of drained peatlands) to be added

A major challenge, as stated before, is to ensure that the operational definitions that accompany data sets are matching – or in case they are not, that bias corrections can be derived that allow them still to be used.

What do we know and need to know of soil carbon changes linked to land use change?

With agriculture finally finding its place on the global Climate Change agenda at the Durban UNFCCC COP, the level of uncertainty in changes in soil carbon stocks linked to land use change is likely to get

renewed attention. Lipper et al. (2011) suggest soil carbon sequestration benefits can be 'harvested'. In the special case of peatlands the emissions linked to land use change are large (ten's of t CO_2e ha^{-1} y^{-1} over decades) and attention is warranted and forthcoming, as these still are large fluxes with large uncertainties and controversies over prospects of restoration activities. There are some rough edges to the peat issues in terms of definitions: soils with less than 50 cm of peat don't classify as peatlands, yet can cause large emissions; peatlands gradually merge into other wetland issues of greenhouse gas fluxes, which merge into temporarily flooded riparian zones. Mangrove soils with C_{org} levels of around 10% down to several m's depth have recently gained attention, as little is known about C dynamics in these soils or of the fate of C-rich sediments under coastal abrasion. Lack of clear definition of such 'special cases' may be an argument to include all soils to avoid the type of definitional confusion that has considerably slowed down REDD efforts.

The IPCC AFOLU accounting frameworks require that changes in soil carbon stocks across all land uses are part of a 5-yearly (non-Annex-I) or annual (Annex-I) reporting cycle at national scale. Is there scope for monitoring at subnational or 'project' scales as well?

Table 5. Arguments pro and con inclusion of soil carbon stocks in subnational and project scale C accounting efforts

Arguments in favour	Arguments against
Soil carbon stocks have longer residence times and cumulative changes with time are less vulnerable to change than aboveground C stocks	Small annual changes in a pool that has high spatial variability which is only partially attributable to easily measurable covariates (Don et al., 2011; Braimoh, 2012?)
Beyond peat and wetlands, the case for recovery of C_{org} in overgrazed and degraded drylands is sufficiently strong to warrant action, as the areas involved are large (Wang et al., 2011)	Evidence of changes in relative Corg distribution with depth that are uncorrelated with the more readily observable change in topsoil Corg; this relates to changes in soil tillage (VandenBygaart and Angers 2006), shifts between grasslands and tree-based vegetation (Jobbágy and Jackson, 2000)
Dynamic process-based models of C_{org} continue to improve and can be used for refined and downscales national estimates (van Wesemael et al., 2011; Smith et al., 2012)	Sample bias in current published data of paired-plot comparisons as explored by Powers et al. (2011) and internal contradictions (both forest=> grassland and grassland=>forest changes are reported to increase Corg)
New methods based on spectral analysis reduce the costs of analysis and correlations with standard (wet chemistry or dry combustion) analysis are pretty good (***no peer-reviewed use for C_{org} temporal monitoring, though***)	Costs of sample analysis with the required levels of replication that can overcome spatial variability can take up >100% of the economic value of increased certainty about C stock changes over short time intervals
Enhancing C_{org} has co-benefits for agricultural productivity and CC adaptation, so there are win-win opportunities	Soil C stocks have been shown to recover spontaneously with agricultural intensification (Minasny et al., 2010), undermining 'additionality'

The Rapid Carbon Stock Appraisal (RaCSA) protocol

The RACSA research protocol (Hairiah et al., 2011) on measuring C stocks was developed as part of the global ASB (Alternatives to Slash and Burn) project to estimate C stocks at various levels in

mineral soils and peat soils. It was developed as a carbon accounting tool with stakeholders, contributing to national accounting systems, but the basic data for RaCSA must come from efforts at a more local level to measure the carbon stocks in the landscape. The basic steps of data collection and measurement of trees are not particularly difficult and do not require expensive or complex equipment, but consistency and attention to detail are necessary. So far, much of the cost of carbon measurements has been in the design of the system and the costs for external experts to travel to remote locations rather than on the time spent actually measuring trees. Different ways of organizing these efforts can be substantially more cost effective if local expertise can be developed and standards of reporting and verification can be maintained.

The RaCSA protocol includes three types of knowledge: local ecological knowledge (LEK), public/policy knowledge (PEK) and scientific/modeling knowledge (MEK) (Figure 5). Comparing and contrasting these knowledge types involves the classification/stratification schemes as much as the measures of carbon stock density. The public/policy domain tends to focus on institutional categories and associated departmental divisions rather than the actual vegetation and carbon stocks involved. In using existing data sources, such as 'forest cover', the lack of clarity in operational definitions used is a major problem. The main output of RaCSA is landscape carbon estimates under various scenarios of land use change, taking into account ways to measure activities that are expected to improve local livelihoods and alleviate rural poverty.
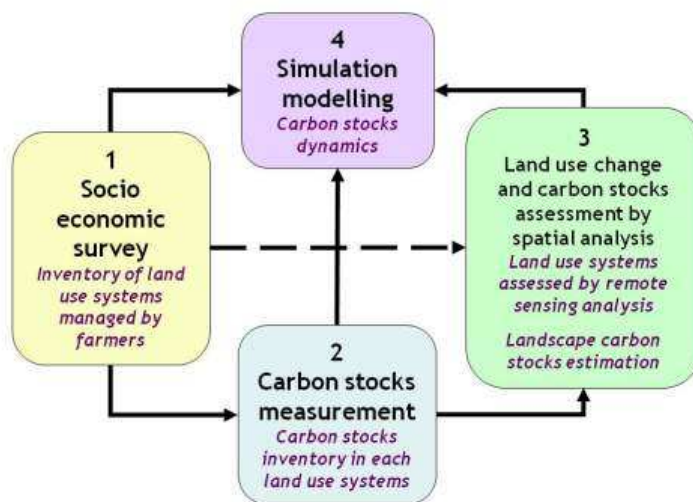
Figure 5. Four main components and outputs under RaCSA approach (Hairiah et al., 2011)

The four levels of measurement covered by RaCSA are:

Tree level: assessing the current carbon stock of an individual tree, that is, aboveground (shoot) and belowground (roots) biomass;

Plot level: estimating the current carbon stock in aboveground and belowground pools of trees and understory, in necromass (dead plant parts) and in the soil in a plot of a particular land use system;

Land use system level: calculating the time-averaged C stock of a land use system from plots of various ages within the same land use system; and

Landscape level: extrapolating the time-averaged C stocks of all land use systems to the whole landscape by integrating them with the area of land use/cover changes obtained from satellite image analysis.
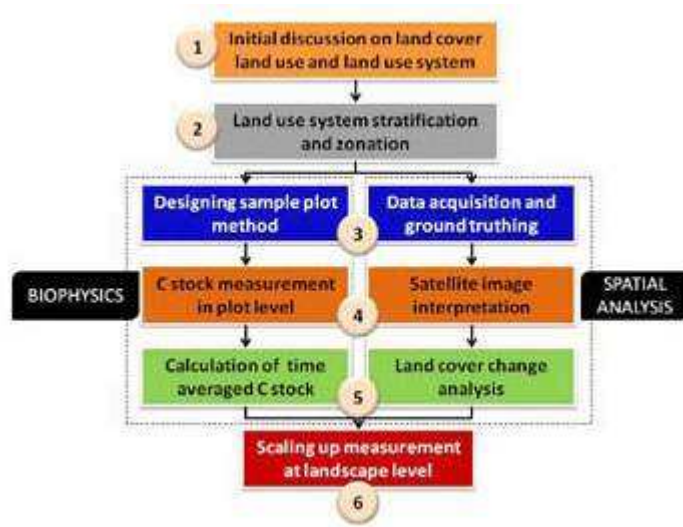
Figure 6. RaCSA in 6 practical steps (Hairiah et al., 2011)

RaCSA involves six steps (Fig. 6):

The assessment team should be composed of people with skills covering a multidisciplinary range—social scientists, ecologists/botanists/foresters, spatial analysts/remote sensing specialists, statisticians and modelers. In collecting and analyzing data, RaCSA uses semi-structured interviews, focus group discussions, spatial analysis using GIS and remote sensing data, landscape assessment through reconnaissance and groundtruthing, statistical analysis, field measurements and laboratory analysis.

Step 1. This is targeted to understand LEK through the identification and discovery of histories, trends and the drivers of land use and land cover changes in the study area.

Step 2. The knowledge obtained in step 1 is then reconciled and combined with the PEK and MEK to produce stratification, zonation and a lookup table of land cover, land use and land use systems. The three terms refer to different aspects of land:

Land cover refers to vegetation types that cover the earth's surface; it is the interpretation of a satellite (digital) image of different land cover. In simple terms, it is what can be seen on a map, including water, vegetation, bare soil, and/or artificial structures.

Land use refers to human activities (such as agriculture, forestry and building construction) at a particular location that alter land surface processes including biogeochemistry, hydrology and biodiversity; of course, the uses interact strongly with land cover, however they are not always identical: the same land cover can be used differently and the same uses can be applied to different land cover.

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Land use systems combine land cover and land use with the addition of the cycle of vegetation changes and management activities (planting and harvesting, among others); this needs more on-ground information of LEK and sometimes PEK.

The differences among the three terms are often subtle and in some cases they converge, such as for primary forest. In many tropical parts of the world, where swidden practices and other land uses of a rotational nature are common, the land use system (LUS) approach is a key solution to address difficulties in accounting for medium timescale fluctuations of carbon stocks. LEK is the most important information source to indicate LUS, which allows for accounting of carbon stocks at the landscape level rather than partial accounting. However, when a particular LUS has not yet reached equilibrium in the landscape, such as the new trend of oil palm establishment in some areas, the age distribution of the plots can be skewed toward young vegetation so that carbon stocks can be overestimated. In such cases, calibrating the typical or time-averaged C stock into spatial-averaged C stock needs additional information on the fraction of the area in each class of the plantation in the landscape.

Beyond the second step of RaCSA, other than in the satellite image analysis, the consistent use of LUS is encouraged with the lookup table among land cover (LC), land use (LU) and land use systems (LUS) being revisited from time to time. Steps 1 and 2 are landscape level activities.

Step 3. The multidisciplinary team of MEK will discuss and determine the legend, strata or classification system based on the inputs from step 2. The legend and stratification will be used by the ecological team conducting field measurements and by the remote sensing team interpreting satellite images and producing time series maps of LU/LC.

Step 4. This step is by far the biggest step consuming most of the resources; it comprises field work to address tree and plot level activities, and desk analysis to convert the field measurement into time-averaged C stock for each LUS.

Steps 5. This is the second largest step comprising groundtruthing to collect geo-referenced information on LUS and satellite image analysis to produce time series maps of LU/LC to be linked with the LUS through the lookup table produced from step 2. Image processing is beyond the scope of this Manual; however some concepts and tips drawn from the experiences of the ASB and more recent studies will be shared here. While step 4 is described in most detail in a standardized manner, the other steps mostly involve guidelines to be used flexibly to fit the specific needs and conditions in the study area and to suit the composition of team that will conduct the C-accounting.

Step 6. This step is mostly a desk study, comprising analysis and reporting. This step integrates all levels from the tree to the landscape. For a full cycle of RaCSA, the ultimate step will be developing a simulation modeling of the carbon dynamics based on land use decision making process used by farmers. This simulation modeling part is beyond the scope of this Manual. Interested readers are encouraged to check http://www.worldagroforestrycentre.org/af2/fallow.

A separate manual (Agus et al., 2011) specifically guides the RaCSA applications in peatlands.

National Forest Inventory data for Indonesia interpreted for C stock

Indonesia's forests were inventoried from 1989 to 1996 (phase 1) and from 1995 to 2000 (phase 2) by the Forest Planning Agency at the Ministry of Forestry as part of a collaboration between the Government of Indonesia and the United Nations Food and Agriculture Organization. The objective of this National Forest Inventory (NFI) was to assess stocks, growth rates and tree diversity across the landscapes of Indonesia. An improved version of the NFI became known as the Forest Assessment and Monitoring System. This data set was used to estimate aboveground tree biomass and carbon stock in Indonesia by the ALLREDDI project (Harja et al., 2011); it had not previously been done, as quality control of the data had not been completed. Harja et al., (2011) provided an overview of the data and derived carbon-stock densities for different forest types and locations that can be used for estimating historical, aboveground CO_2 emissions from deforestation and forest degradation across Indonesia and its various forest types.

Table 6. Issues and opportunities involved in using Indonesia's NFI data for C stock estimates (Harja et al., 2011)

ISSUES	OPPORTUNITIES
The NFI was not initially designed for carbon-stock assessment. The data have not been in the public domain and available for scrutiny. Several experts are sceptical about the quality of the data, especially regarding botanical identification	The inventory was comprehensive and well-designed, using proper techniques of data collection. Tree data (diameter, height) allow use of allometric equations to estimate aboveground tree biomass, a dominant component of total carbon stock. Botanical identity only influences carbon-stock estimates via wood density attributes
The systematic sample design, in contrast to a stratified random design, meant that less frequent forest types are poorly represented	The data allow assessment of the shape of statistical distributions of carbon-stock density in the main (lowland) forest types of Indonesia
Data validation for quality assurance was itself of variable quality, but involved consultants from a number of universities and research institutions during and shortly after the inventories	Internal data consistency tests and comparison with other data sources can indicate weaker parts of the data set

Based on the analysis of weaknesses and challenges in reinterpreting the data for C accounting purposes, Harja et al. (2011) concluded that the NFI data is the richest and largest database of forest inventory across Indonesia, based on systematic sampling and consistent, well designed, protocols of field measurement. The database has been well maintained by the Forest Planning Agency of the Ministry of Forestry but its accessibility to other stakeholders has been severely restricted, preventing peer review and improvement. Several sources of error were addressed by the ALLREDDI analysis: errors due to field measurement and data entry; errors from applying allometric equations; and errors in plot samplings. The ALLREDDI team conducted consistency checking and data cleaning of the NFI dataset and visited several plots in the field. After filtering out the data that were inconsistent and did not fulfill data-cleaning criteria, a total of 1595 plots was retained.

The NFI plots were designed systematically across Indonesia, every 20 x 20 km, rather than stratified. This causes data gaps in some forest categories and eco-regions, which are small in area and not very well represented in the current NFI dataset. The uncertainties in carbon-stock estimates within those becomes very high. Within this dataset the tree diameter/height relationship was partially related to climatic variation across Indonesia: trees of any diameter tend to be taller in wet areas compared to those in dry areas. Both diameter and height therefore need to be included in estimating tree biomass, as provided for in the Chave (2005) allometric equation. Typical aboveground carbon-stock of forests in Indonesia ranged from 16.92 to 92.73 Mg/ha, with the highest in the Sumatran peat-swamp forests eco-region and the lowest in the Lesser Sundas'

deciduous forests. The non-forest carbon-stock ranges from 3.5 to 99.4 Mg/ha. The uncertainty was higher on fewer numbers of plots sampling such as the Sunda Shelf mangroves eco-region, which associates with 10% error. Concerning the huge potential of the dataset to be the single biggest dataset for determining carbon stocks in Indonesia's forests—on which will be based the estimates of emissions from land use, land-use change and forestry (LULUCF) , baseline estimation and any additionality of climate-change mitigation actions—more rigorous and more systematic validation and verification of the existing plots and data, including field checks, needs to be carried out. Filling data gaps in some eco-regions should also be considered when redesigning the NFI. In addition, the current NFI was not designed to cover all carbon pools; adding a set of protocols to be inclusive of necromass, litter and soil carbon in NFI data collection for the next round of monitoring would be ideal. There have been many efforts at compiling plot inventories by other institutions in Indonesia. The ALLREDDI project established a prototype of a platform for data sharing through an integrated webbased database, accessible online. This will enrich the dataset at the national level and will enable people to cross-validate the data and contribute significantly to the monitoring, reporting and validating system to be developed for Indonesia. A screenshot of the web-based interface of the database is shown in Figure 7.
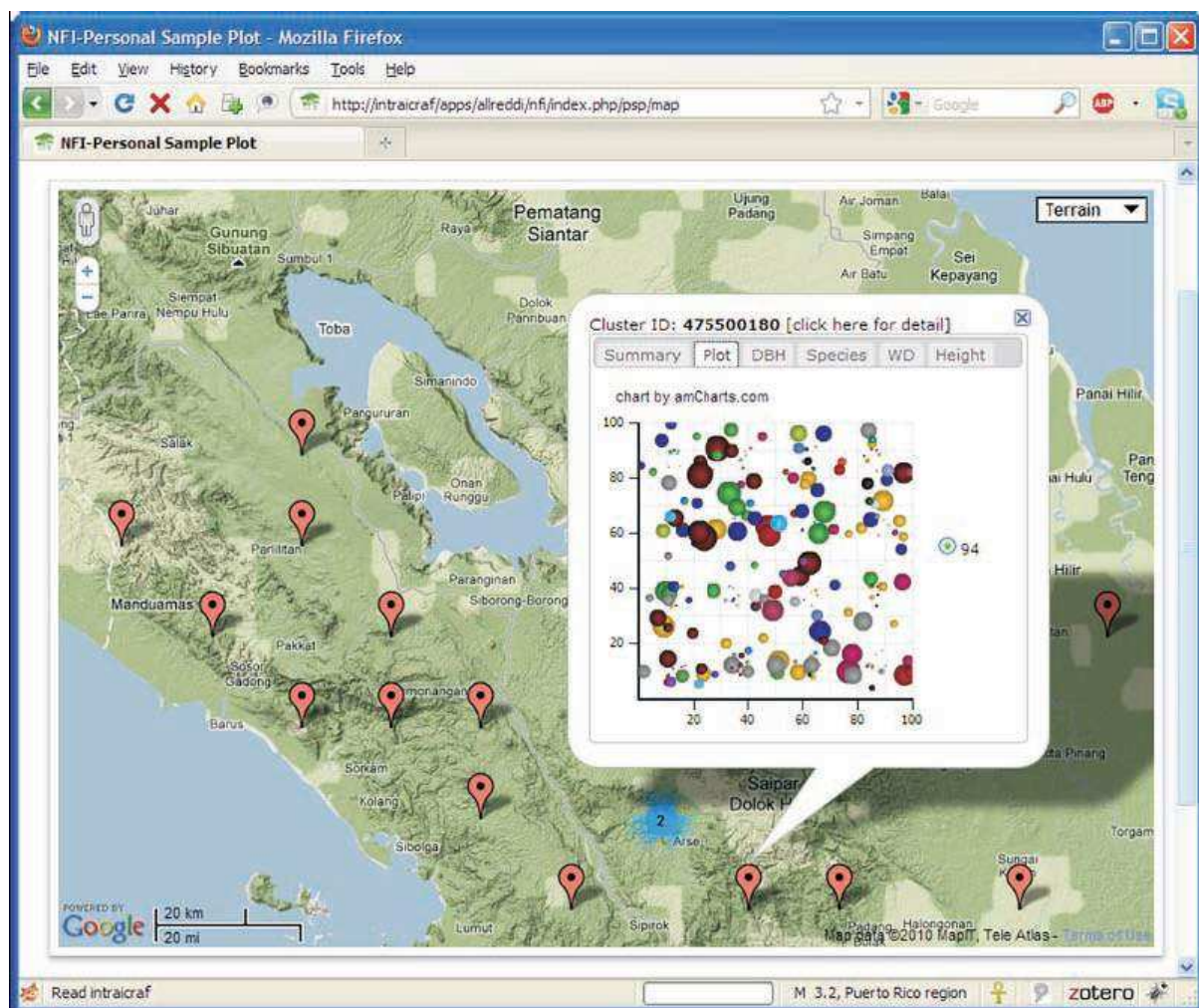
Figure 7. Web-based graphical user interfaces of NFI database overlaid on Google Maps; the platform was used as the analysis tool and stores the user data (Harja et al., 2011)

3. Institutional aspects of reliable monitoring systems
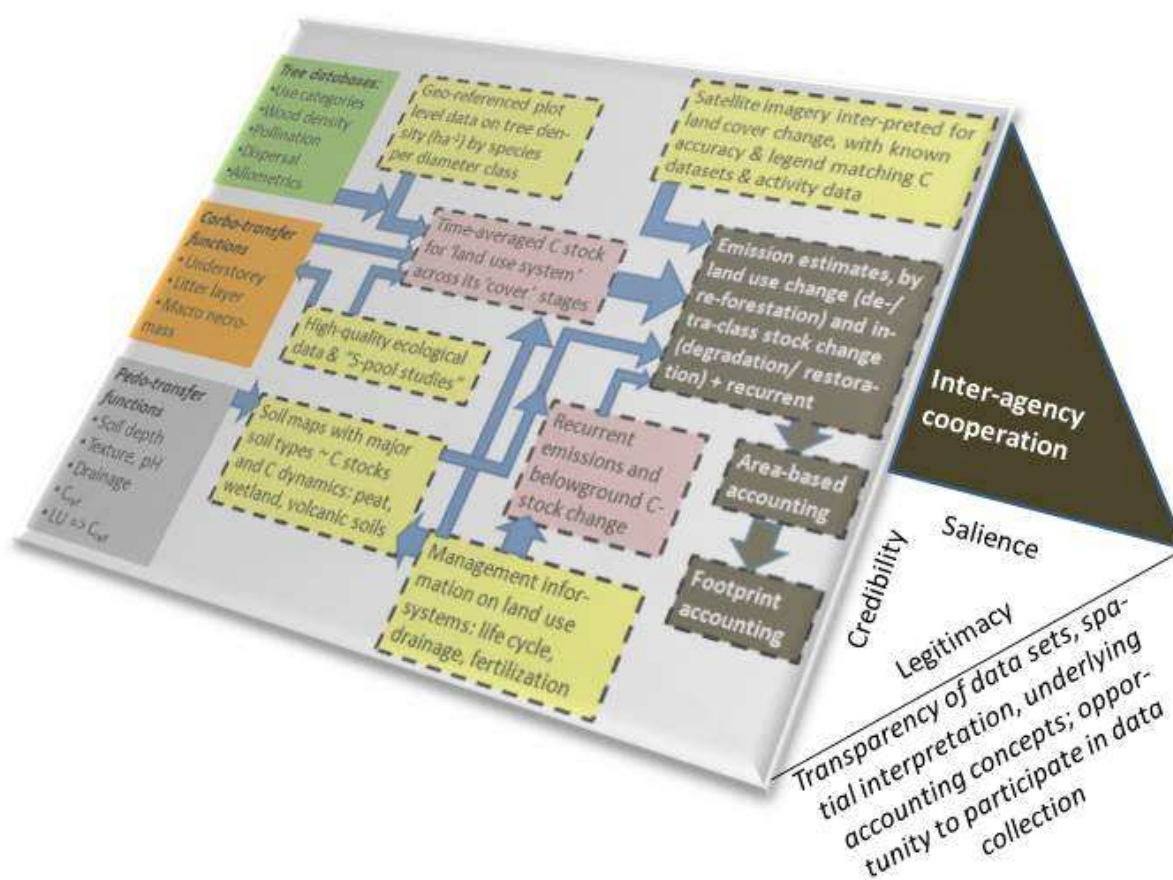
The IPCC 2006 Guidelines for National Greenhouse Gas Inventories contain the necessary clarifications regarding Quality Control (QC) and Quality Assurance (QA) for GHG inventories. QC procedures are internal to the process of inventory preparation, while QA consist in an external (independent) assessment of the quality of the reported estimates.

Following Clark et al. (2011) the interaction on local forest and carbon dynamics between local communities and external agents or intermediaries can be seen as 'boundary work'. It creates 'boundary objects' in the sense of datasheets reflecting local C stock dynamics in a mutually agreed protocol for sampling design (number of plots per stratum), sample selection (location of plots within a stratum) and measurements at plot level. The relevance of these 'boundary objects' for negotiating designs of REDD+ that can effectively link local, national and international objectives, can be analyzed under three criteria of 'science quality': salience, credibility and legitimacy (Table 7).

Table 7. Grouping of main arguments *pro* and *con* to directly involve local communities in monitoring, using the salience, credibility and legitimacy framework of Clark et al. (2011)

Arguments based on perspectives of	Local stakeholders	National stakeholders	International stakeholders
Salience (relevant to decision making)	• Local drivers and management options are key to achieving REDD+ goals • 'Buy-in' by local stakeholders is needed to define and achieve REDD+ targets • Local job creation for MRV brings some direct benefits	• REDD+ depends on national scale land use plans and regulations, fiscal policies and law enforcement • 'Buy-in' by national policy framers is needed, as leakage & emission displacement is intractable at lower scales	• Effectiveness requires targeting all major drivers of status quo and pulling all levers of change • FPIC commitment is part of internationally agreed 'safeguards', needed to attract funding
Credibility (technically adequate in handling of evidence)	• Effective use and integration of local knowledge can help stratify sampling • **Negative:** lack of quantitative skills can lead to errors • **Negative:** vested interest in reporting desired results	• Nesting of local data in the stratified national accounting is needed to deal with all scales of variability • **Negative:** vested interest in reporting desired results • Sub-national verification must be independent of monitoring and reporting	• Global consistency and integrity of C accounting systems requires control of bias *plus* random error through adequate stratification, sufficient replication and quality control on data chains • National verification must be independent of monitoring and reporting
Legitimacy (fair, unbiased, respectful of stakeholders)	• Local stakes in landscapes under discussion are high • Motivation, recognition and respect for local 'sovereignty' need concrete steps and actions • FPIC is seen as vehicle for local control over changes in the landscapes that affect livelihoods	• Depending on the 'unity in diversity' policies of nation-states, local representation is tolerated/ required • Countries upwardly claim 'sovereignty' in climate policies	• Fairness of international rules of the game is needed as UNFCCC requires consensus decisions

4. Recommendations

Based on the above considerations, we developed a set of ten recommendations, that we tested for their applicability across the four REDD-ALERT countries in the next chapter:

1) Start with what you have; forest departments, agricultural statistics, land cover studies, spatial planning zones, existing use rights, soil maps and soil fertility databases can all contribute important information;

2) Expect gaps and mismatches between data sets especially where institutional and biophysical concepts use the same terms (e.g. "forest");

3) Analyze quality of a national monitoring system as dependent on three characteristics:

    A) Salience (does it address key policy issues and respond to policy implementation at relevant time scale?)

    B) Credibility (are the methods up to date and consistent with international standards, are confidence intervals of key parameters known, is error propagation towards final estimate traceable with realistic degrees of confounding of component errors)

    C) Legitimacy (is the work done by agencies and individuals that are, through their combination and cooperation, seen to represent the specific and valid concerns of:

    - Local, subnational and national governments (aligned with reporting obligations)

    - Local people and indigenous group representatives

    - Local, national and international private sector with interest in the 'footprint' of land use associated with commodity value chains

    - Environmental NGO's at local, national and international level)

4) Involve local stakeholders in data collection and international expertise in consistency and validity checks

5) Invest in methodology, harmonization of legends (operational classification scales), 'one-map' consistency of spatial data across government agencies, and clarity of operational definitions from a local perspective before investing in new data collection

6) Tier 2.5 AFOLU accounting is a feasible and realistic goal for any country wanting to participate in REDD+ debates; it involves stock change accounting with subnational land use classes, C-stock (activity) data that are adjusted to eco-climatic zones, major soil types (incl. peat and volcanic soils as special classes), and the typical management practices across the life cycle of land use systems. It also requires area data of land cover change ***with matching legend*** (more than 20 map units may be needed); for Indonesia most of this was achievable with an external investment of about 1 Million Euro plus data and staff capacity of national agencies

7) The protocols for "RApid Carbon Stock Appraisal" (RACSA) allow local data collection and reporting at a cost level of 10,000-20,000 Euro for areas of 20x20 km^2 to district scale, if carried out by competent national universities and NGO's, in cooperation with local governments. High-precision, location-specific data (e.g. following VCS protocols) are only useful if *nested within* the national system and its hierarchical legend units, and when possible sampling bias (selective focus on high C stock or high emission areas) can be assessed

8) **MR:** The quality of interdepartmental coordination between custodians of various data sets that contribute to the national accounting system determines the quality of the national accounts; it requires considerable effort and adjustment of institutional incentive systems

9) **V:** Basic data on soils and tree cover need to be open to public scrutiny in sufficiently high resolution to allow public scrutiny and corrections; an appropriate system for obtaining feedback, verifying local discrepancies and adjustment of databases is needed, and may require appropriate budget

10) The primary accounting precision target for REDD+ and NAMA is the national scale, consistent with National Communications on Greenhouse Gas Emissions; this implies that *bias* issues (systematic error) are prominent and require attention in temporal consistency, while *random error* is less problematic for national reports; local-scale confidence levels at the finest spatial scale that is publicly accessible, however, influence the fraction of local stakeholders that will see their area as misrepresented.

5. Current practice in the four REDD-ALERT countries

Indonesia

As much of the underlying analysis reported here was based on Indonesia, the guidelines reflect an informed perspective on the opportunities – but not one that is necessarily shared by all stakeholders. Major challenges still are that:

The Ministry of Forestry has a mandate and data sets that relate to the institutional forest domain ('*kawasan hutan*') but is less clear beyond that. Biophysically tree cover and forest types don't change abruptly at the *kawasan hutan* boundary, and remote sensing data apply to the whole landscape, but there are challenges in mandate and responsibility. Before changes in forest cover had the prospects of direct financial incentives linked to them, these issues did not matter; but if changes in forest cover inside and outside forest have consequences for financial incentives, with the reporting agency more directly related to changes within than outside forests, a potential conflict of interest emerges.

The Indonesian Soils Research Institute, by contrast, resides under the Ministry of Agriculture, and most of its data and expertise relate to agricultural land; however, soils under forest lands that were considered as targets for future agricultural expansion *do* exist; they tend to be focussed on the soils of higher agricultural potential, as noted globally by the meta analysis of Powers et al. (2011). Current data sets of background conditions for Indonesian soils are most detailed for the islands of Java (Minasny et al., 2011) and Sumatra (van Noordwijk et al., 1997); areas of uncertainty include

- the effects of land cover change on volcanic soils (Andisols) of high carbon content, but potentially high erosion rates where they occur in the terrain (Verbist et al., 2010),

- the effects of land cover change on karst (limestone) soils, with generally high sensitivity to physical degradation,

- general applicability of the recovery of soil carbon described by Minasny et al. for Java, across the different water management regimes involved in rice production, with various degress of tree cover and agroforestry practices,

- the fate of mangrove soil carbon after mangrove conversion: it is likely that recorded 'on-site' losses include abrasion and transport of carbon rich material in marine environments (with the opportunity of 'safe' carbon storage), as well as decomposition and release to the atmosphere; a similar debate on the fate of soil C involved in erosion has led to a conclusion of near-neutral net effects, but the issue has not yet been addressed for SE Asian mangroves, as far as we know,

- peatland issues of current carbon stock (depth, density, maturity, mineral content) as well as time course of change in density (compaction) and atmospheric release after conversion and fertilization.

The last issue is probably of greatest quantitative importance and is currently addressed by research efforts of the Ministry of Agriculture and national universities, as well as international cooperation

efforts, acknowledging a 'legitimacy deficit' of earlier international efforts. The field has a reputation for emotionally charged discourse, sometimes slowing down scientific progress, but over the years there is improvement and convergence towards acceptable 'default' estimates.

Discussions on a national MRV system have focussed on the need to deal with potential conflicts of interests of the partners with the strongest data sets and track records, versus the challenges for any new institution to establish effective cooperation. High level support, through a presidential task force, brings in a mandate to move forward, but actual data sharing protocols have yet to be formalized. Overall the institutional aspects have proven to be more challenging than the technical data collection.

Viet Nam

In Viet Nam forest resources assessment started in 1990 and is carried out every 5 year, by the Forest Planning and Inventory Institute (FIPI) under VNForest. For REDD+, a new National forest monitoring system (NFMS) is considered to improve to comply with international MRV standards. NFMS be provided by:

- Forest land management system - FLMS (for activity data);

- National forest inventory (forest & biomass) - NFI

- Green house gases inventory - GHGI

The NFMS be set up in three steps:

1. Development of the MRV including technical support and capacity building;

2. Operationalization and testing of the system with its three elements FLMS, NFI, and GHGI;

3. Functioning of integrated MRV system and provision of information for National REDD+ Program

There has been little effort to bring in more local perspectives on forests, trees outside forest and agroforestry. As noted before (Hoang et al., 2010), forest data maintained by different agencies differ substantially and further efforts are needed to reconcile them. The guidelines as developed here can help inform a more inclusive process towards further data collection.

Cameroon

Cameroon has developed its steps towards a national carbon accounting system as part of its FCPF support for REDD+ readiness. A national accounting unit or coordination has not yet been established, but a design of an integrated monitoring systems of changes in forest cover and carbon stock has been proposed. That design is endorsed by the technical ministries responsible for the coordination and management of the readiness process in the country, the MINEPDED-Ministry of Environment in charge for the national REDD+ coordination and hosting the CC focal point, and the Ministry of Forestry (MINFOF).

Cameroon targets the reduction of emissions based on deforestation and degradation through options identified in the respect of national priorities for economical growth and poverty reduction. The plan is to involve in all the 5 REDD+ activities discussed internationally, through cross-sectoral

interventions aimed at 1) enhancement of present conservation measures; 2) sustainable forest management; 3) village level land use planning to increase carbon stock at the landscape level – agricultural technologies, fallow management, community forests, while reducing the impact of agro-industries; 4) management of the firewood/charcoal sector; and 5) reforestation: small- and large scale, firewood/timber.

Targeting the five interventions puts a priority on the definition of forest and forest degradation and on the understanding and monitoring of conversion trajectories of other land use categories to develop a consistent/operational hierarchical land use/cover classification system.

At the present however the MRV does not clearly refer to all the components indicated in the strategy (there is actually not clear identification of the categories to report), nor does it give any guidance about how to make use of existing knowledge to stratify among the considered categories and develop and operational legend. Cameroon plans to initially target a *tier 2* approach to move towards a *tier 3* once the system evolves.

In the present version of the MRV planning document, existing information is not adequately inventoried no action flow is designed so that it is difficult to figure out what actions will lead to meet the monitoring and reporting standards even for a *tier 2* level. A minimum level of information for the establishment of REL and an adequate monitoring and reporting is not defined.

Useful information exists so in order to optimize its use data from different sources have to be integrated/harmonized to design a cost efficient and targeted sampling strategy. A step-wise sampling strategy with various levels of local accuracy might be defined with identified priority areas of risk of carbon loss (areas that are more at risk of conversion/ degradation -including degradation of the agricultural matrix-, definition of areas with potentials for intensification and reforestation-or identification of areas with high carbon stock (both biomass and soil).

FOREST DEFINITION issues in Cameroon

Forest definition is certainly a crucial aspect in the setting up of the national accounting strategy. In Cameroon at the present two different definitions of forest are used. One is presented in the Forestry Code of 1994, Section 2: "*Under this law, forest means any land covered by vegetation with a predominance of trees, shrubs and other species capable of providing products other than agricultural produce*". The second definition was adopted in 2008 in the context of CDM but has not yet been submitted to UNFCCC CDM executive board for approval. According to that definition: "*Forest is a tract of land with a minimal surface of 0.1 hectare, with tree canopy cover of more than 30% (or with an equivalent stand density). The trees or arborescent vegetation should be able to reach a minimum height of 5 m.*" Under this definition anything that has a tree cover lower than a minimum 30% is non-forest. However the definition includes also agricultural land use systems where tree coverage could potentially reach the threshold value. In the UNFCCC system the forest use should be the predominant one to identify forest land. The decision of adopting the higher threshold of tree canopy cover (choice was between 10-30%) reflects the objective of promoting reforestation projects at the forest/savanna interface and in the northern regions of Cameroon, making trees and woody savannah land eligible for CDM. However in the forest zone that definition would include most of land under cocoa and coffee agroforests and fallow where secondary regeneration is occurring, creating biases in the understanding and definition of both deforestation and degradation processes in relation to small-scale agriculture and selective logging (Robiglio et al. 2010).

NATIONAL LAND COVER MAP

A key step in the readiness process in Cameroon is the production of a national land cover map against which activity/changes will be assessed over a 1-5ha of minimum mapping unit. The time interval to be used to calculate national deforestation rates (each 5 years starting from 2000) presents several inconvenient due to the lack of cloud free images. The difficulties encountered by the REDD_PILOT project (KFW-GAF project) in defining a REL and assessing the deforestation rates based on LANDSAT images for the last decade, seems not to have been taken into account. Also the importance of the size of a minimum area is underestimated in particular in relation to the type of intervention the country is planning to be rewarded for (that includes smallholders' agricultural systems).

It is proposed that the map will be based on Remote Sensing information integrated with information on agro-ecological zones and phyto-geographical domains. In order to create sub-national land use classes, we suggest that further bio-physical strata are included based on the IRD soil maps (to be digitized, 1:500000, or 1:1.000.0000, the FAO SOIL MAP (or the global map of terrestrial soil organic carbon stock in preparation by UNEP), the Digital Elevation Model, rain and temperature (cite-source) and preliminary information on peatland (see IRAD). The team should also consider how to make use of the data derived from the most recent FAO Forest Inventory (based on phytogeographical strata) that includes also biomass/carbon estimates.

There is no specific indication about the use of other existing spatial data set on socio-economic and management data (transport, forest management) to be used to identify areas at risk of forest loss or degradation and prioritize intervention including the setting up of the MRV for those hot spot areas. That same information should be used to propose a zoning for sub-national REL.

Existing databases produced by national agencies (census data and agricultural production/surfaces) that could be easily integrated in a geo-referenced Data Base are ignored. Any reference to tenure is missing. The participation of institutions outside government is not yet well apparent in the description of the MRV, therefore the use of an operational legend that includes local perspectives and expert knowledge is not yet considered at this point.

Since the mapping effort has still to start and is part of the readiness process there is the opportunity for the technical REDD+ team to design an operational classification system and define a hierarchical nested legend with sub-national classes that integrate relevant information/ land use and carbon sensitive.

CARBON STOCKS AND EMISSIONS

The section on carbon stock assessment suffers from the same lack of a coherent and rigorous structure of the section on the establishment of a REL and activity data for the MR. Standard IPCC methodological guidelines are reported.

The lack of an integrated legend is reflected in the absence of strategic information about the land use classes for which carbon stocks will be assessed. The inventory of survey method and available data is poor and not well referenced (see the lack of information about the national forest inventory!). No mention is made to the sampling framework and the expected reliability of results (precision, accuracy, mean square error or bias and for which classes.

A strategy to complement existing carbon data set (public data from ASB + grey literature for the area) with additional studies (also in relation to other ongoing efforts in the region: ASB/REALU, FORAFMA etc...) should be defined but it is not yet clear how the readiness process will benefit of the ongoing external efforts.

Against this general background, comments from Cameroonian stakeholders on the ten recommendations were:

Recommendation	*Comments from Cameroon REDD-ALERT*
• Start with what you have...; forest departments, agricultural statistics, land cover studies, spatial planning zones, existing use rights, soil maps and soil fertility databases can all contribute important information;	✓ Not yet taken into account but it is on the way towards.... since we are assisting the technical team and reviewing some bits of the R-PP (on REL/MRV)
• Expect gaps and mismatches between data sets especially where institutional and biophysical concepts use the same terms (e.g. "forest");	✓ Not yet applicable, will depend on how far we will go in 1. See also the section above on forest definition.
• The quality/efficiency of a national monitoring system is dependent on three characteristics: • Salience (does it address key policy issues and respond to policy implementation at relevant time scale?) • Credibility (are the methods up to date and consistent with international standards, are confidence intervals of key parameters known, is error propagation towards final estimate traceable with realistic degrees of confounding of component errors) o C) Legitimacy (is the work done by agencies and individuals that are, through their combination and cooperation, seen to represent the specific and valid concerns of: • Local, subnational and national governments (aligned with reporting obligations) • Local people and indigenous group representatives • Local, national and international private	✓ The structure of the MRV proposed is not yet consistent with the strategy (e.g. categories to accounted for- see comments above) ✓ Not yet applicable ✓ C1) It is applicable but not yet specifically addressed as a concern for the MRV ✓ C2) It is applicable but not yet specifically addressed as a concern for the MRV ✓ C3 and C4) No, too sophisticated we are not yet there....but it is something we should work on...

sector with interest in the 'footprint' of land use associated with commodity value chains • Environmental NGO's at local, national and international level)	
• Involve local stakeholders in data collection and international expertise in consistency and validity checks	✓ This has not yet been taken into account but could be proposed based on existing pilot projects (CED)
• Invest in methodology, harmonization of legends (operational classification scales), 'one-map' consistency of spatial data across government agencies, and clarity of operational definitions from a local perspective before investing in new data collection	✓ This might specifically focus on defining the terms for the new national land cover map. One main issue is cloudiness, but a part from Remote Sensing info there are other data to include and a lot of work that has to be done on the definitions/harmo-nization.
• Tier 2.5 AFOLU accounting is a feasible and realistic goal for any country wanting to participate in REDD+ debates; it involves stock change accounting with subnational land use classes, C-stock (activity) data that are adjusted to eco-climatic zones, major soil types (incl. peat and volcanic soils as special classes), and the typical management practices across the life cycle of land use systems. It also requires area data of land cover change *with matching legend* (more than 20 map units may be needed)	✓ Progress in Cameroon on this issue will depend on a ranking of the options presented in the strategy
• The protocols for "RApid Carbon Stock Appraisal" (RACSA) allow local data collection and reporting at a cost level of 10,000-20,000 Euro for areas of 20x20 km^2 to district scale, if carried out by competent national universities and NGO's, in cooperation with local governments. High-precision, location-specific data (e.g. following VCS protocols) are only useful if *nested within* the national system and its hierarchical legend units, and when possible sampling bias (selective focus on high C stock or high emission areas) can be assessed	✓ Little experience yet beyond earlier efforts of the ASB team
• **MR:** The quality of interdepartmental coordination between custodians of various	✓ This issue is really crucial in Cameroon. The structure of the national REDD+

data sets that contribute to the national accounting system determines the quality of the national accounts; it requires considerable effort and adjustment of institutional incentive systems	steering committee reflects a certain willingness to develop a strong coordination between government, (and ministries within the government- 12, and non government agencies-civil society, indigenous people, logging companies- however the list is not yet exhaustive). Technical coordination will be assured by the REDD+ technical team that includes a secretariat and 5 thematic groups of experts from the ministries, research centres, and universities (also should be more exhaustive /inclusive).
• **V:** Basic data on soils and tree cover need to be open to public scrutiny in sufficiently high resolution to allow public scrutiny and corrections; an appropriate system for obtaining feedback, verifying local discrepancies and adjustment of databases is needed, and may require appropriate budget	✓ Not yet realistic
• The primary accounting precision target for REDD+ and NAMA is the national scale, consistent with National Communications on Greenhouse Gas Emissions; this implies that *bias* issues (systematic error) are prominent and require attention in temporal consistency, while *random error* is less problematic for national reports; local-scale confidence levels at the finest spatial scale that is publicly accessible, however, influence the fraction of local stakeholders that will see their area as misrepresented.	✓ Cameroon has so far focussed on REDD$^+$ rather than NAMA. Quantification of bias and uncertainty has not progressed yet.

Peru

In Peru, as in other REDD-ALERT countries, a number of different agencies have developed forests and deforestation maps, without technical reconciliation efforts as to their content, while the institutional mandates of the various agencies has only recently been clarified. The Ministry of the Environment now has the responsibility to monitor land-use and land cover change for the country within the national REDD program.

The Ministry of Environment's capacity has been improved through collaborations with the Moore Foundation and with researchers from different universities. The Moore Foundation has supported the development of a program that will analyze satellite imagery every year to produce an annual

assessment of deforestation. The project will work at different levels, including basic data on area deforested (annually) and a more detailed program on all land use changes within the country. The latter program has not yet defined the periodicity of the effort, but it will not be annual. Collaborations with University researchers have been an important component of the national MRV planning. These collaborations include work with Carnegie Mellon University, where an active program in light detection and ranging (LIDAR) is providing detailed estimates of forest degradation in the Amazon region of Peru. The results from this work are not yet in the public domain. However the early conclusion is that this work is going to prove cost-effective and provide the country with detailed picture of carbon stocks in degraded forests.

Soils research has traditionally focussed on the more densely populated highlands, rather than the Amazon forest landscape, and there are substantial challenges to reconcile the existing data in a national C accounting framework. REDD-ALERT efforts in the Ucayali landscape have yielded basic data at local level, but not yet at a national scale. One issue related to soils that will need much more focus in the future is how to deal with organic soils in the Peruvian Amazon. These soils are not the same as the peatlands that are found in Indonesia, but do have distinctive characteristics and are found in substantial areas. They tend to be associated with wetland forests that are very high and biodiversity. Unfortunately, there has been very little carbon stock assessment in these wetland soils. Much more work will be needed to identify the extent of these areas and the carbon stocks held within them.

One issue that is only now gaining attention is how MRV systems can operate in a nested framework between local, national and international levels of operation. The ministry of environment has been reaching out to local governments to see how they can work together in the development of MRV systems. One goal is to build on comparative advantages between the national government and the local governments. The national Ministry of Environment now has very good capacity, capacities that local governments will not likely be able to replicate. Many of the land-use assessments and carbon stock evaluations at local level do not match the quality of those developed at the national level. For local officials to take advantage of work done at the national level, it will require better protocols for data sharing and the capacity for the Ministry of Environment to take time to respond to local requests. The advantage of local governments is their ability to conduct fieldwork, especially validation work to estimate the accuracy of land-use maps derived from remote-sensing. Despite the recognition of these comparative advantages, much better coordination will be needed to build efficient programs for MRV at both local and national levels.

In November 2012, the local government of ex-department held a MRV workshop for agencies working in any aspect of deforestation mapping and monitoring. The workshop was cosponsored by ASB researchers working in Peru. Six different agencies presented their deforestation mapping initiatives for the department, include a presentation by REDD-Alert researchers on the visual interpretation mapping done for the Aguaytia region. One of the most important presentations was from the Ministry of Environment, focusing on all aspects of their program and how they want to reach out to local governments. An important outcome of the workshop was an agreement by all the partners to share data and knowledge on deforestation dynamics in the region. They also agreed to share validation information such as photographs and GPS points that could be used by anybody to assess the accuracy of land-use maps.

6. Discussion and next steps

The recommendations developed here for the design of national monitoring systems, have revealed large differences between the countries, linked to differences in institutional and research culture. Our recommendations explore the institutional dimensions and procedural steps, as well as the technical aspects, as experience has shown that non-technical issues may in fact be the hardest to resolve.

Our analysis of supply and demand for precision on national monitoring systems has raised further questions on the scale at which precision is in fact required. While it is hard and costly to get precision at a fine-grained pixel level, the aggregated C stock estimate for a country (or any large subnational entity within it), will benefit from the large number of pixels involved, effectively dealing with random error and shifting the focus to 'bias' or systematic error (which is independent of the level of replication).

In ongoing efforts, we are quantifying the scale relationship of uncertainty, and try to derive a spatial scale at which technical uncertainty of estimates of C stock change will drop below a level of error that is tolerable for a government agency that assigns 'performance based' incentives to the actors involved. Using data for Jambi province in Indonesia, initial estimates (Lusiana et al., in prep.) suggest that a 1 km^2 scale (100 ha) is needed to bring the uncertainty (based on classification errors plus C stock uncertainty per class) to a level of less than 5%, with existing data sources. The choice of 5% is arbitrary, and tolerance of error for subnational REDD+/NAMA implementation cannot yet be tested empirically. Nevertheless, the 1 km^2 scale may offer an interesting intermediate level for action: it is small enough that local stakeholders can apply their own knowledge of what is going on to differentiate at local level; it is small enough for institutions of collective action to have a chance; and yet, it retains most of the geographical differentiation of patterns within a province or district and the associated efficiency of targeting incentives towards performance enhancement.

Analyses of this type, linking supplky and demand for precision with the institutional models develop-ed for REDD[+]/NAMA implementation, across stakeholder concerns, may well be needed in multiple situations. They are, however, likely to be salient and point towards intermediate positions, where further data collection does not have to focus on 'project scale' precision, but rather contribute to a nested system approach to national accounting systems that allow fairness and efficiency of C accounting and incentive systems to be reconciled.

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Attachment 1. Soil-based C emissions due to land use change in Jambi province (Sumatra, Indonesia)

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Abstract (250 words)

Land use change affects soil carbon more slowly than changes in the visible aboveground carbon stock. Due to large inherent variability of soil C_{org}, effects are not readily measurable. We tested a pedotransfer function developed for topsoil across Sumatra on its validity for soil profile data from Jambi province, after incorporation of a power function (Depth/2.2265)$^{-0.528}$ that relates C_{org} to sampling depth (weighted midpoint of a sample layer). Separate power functions for natural, logged-over, secondary and rubber agro-forest, and a combined shrub + food-crops + *Imperata* grasslands land use group showed that differences are most pronounced in the surface layer; below a depth of 30 cm the hypothesis of no differences could not be rejected. Compared to natural forest, logged forest in these data has lost 16 Mg C/ha in the 0-30 cm depth layer. Rubber agroforest 26, secondary forest 29 and a combination of perennial crops, annual food crops, shrub and *Imperata* grassland 14 Mg C/ha. Data for non-peat wetland sites did not show consistent patterns with depth and impacts of land use change could not be ascertained. Some 41% of variance in Corg across soil layers and land uses remained unaccounted for. Overall LU-dependent C stock in soil$_{0-30}$+litter+necromass pools is only 6% of aboveground biomass (ABG) across land use systems (y = 0.06ABG+80, Mg/ha; R^2=0.29), root carbon 25%; total system C loss from a natural forest starting point is 1.31ABG-293 Mg/ha; R^2=0.995). Remaining uncertainty on soil C_{org} relates to wetland and mineral/peat transitions.

Attachment 2. Carbotransfer functions or default values for litter, understorey and dead wood of forest-derived land uses in Indonesia: safely simplifying data collection?

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Abstract

Forest inventory data only cover one of the five carbon stocks prescribed in international accounting rules. Soil carbon can be estimated from soil maps and pedotransfer functions. We targeted "carbotransfer" functions for the three remaining pools: understorey vegetation, surface litter and dead wood (necromass). This requires expected average values and recognition of conditions where these pools are important, either relative to the total pool size, or in absolute value. Among 715 five-pool measurements across land uses in Java, Sumatra, Kalimantan, Sulawesi, Lombok and Papua 58, 71 and 70% indicated that litter, understorey and dead wood biomass, respectively, were less than 5% of total carbon stock; in 5, 4 and 1% of cases, however, either of these pools were more than 50% of the total. The pool sizes were not significantly correlated with tree biomass across land use systems. As default values we suggest 3.2 ± 0.56 and 3.3 ± 0.50 Mg ha^{-1} for litter in undisturbed and disturbed forest, respectively, and 5.1 ± 1.7 and 1.2 ± 0.2 Mg ha^{-1} for understorey vegetation. In other land use systems the contribution of these pools can be 10 – 100%, and measurements are necessary. Dead wood data is highly variable and further measurement is desirable as the types of disturbance that increase tree mortality and/or decrease standing necromass stock need to be better understood.

Keywords: carbon accounting, carbon stock, forest disturbance, MRV systems, necromass,

Attachment 3. Tropical peatland issues: Mud, muddle, models

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Abstract

Tropical peatlands have become recognized for their high area-based carbon emissions in response to land-use change, and as hot spots of debate on how emission reduction can be achieved. A long and complex knowledge-value-chain links fundamental understanding of peat and peatland processes to actions at local, national and global scale that effectively provide rules, incentives, and intrinsic motivation to reduce emissions. Based on our direct involvement along this chain in Indonesia, Vietnam, Peru and Cameroon we here describe our understanding of this value chain, its stakeholders and issues that (still) remain (partially) unresolved. A number of existing models span part of the chain, but transitions of units of analysis from area to commodity flows and opportunities for emission reduction require specific attention.

Attachment 4. Spatial aggregation of C emission data for a forest frontier district in Indonesia: a fairness-efficiency trade-off in designing nested REDD+ systems

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Abstract

Performance-based rewards for environmental services (ES) gain in efficiency of targeting with higher spatial resolution, but require accurate ES-change data, or risk the reputation for fairness of the agency in charge. Spatial data gain in accuracy with aggregation as the random "noise" level goes down, but lose precision and signal strength in targeting, posing a fairness versus efficiency tradeoff in the design of ES reward schemes. Reduction of emissions from deforestation and (forest) degradation (REDD+) depends on efficiently targeting of incentives to agents of changes in terrestrial carbon stocks, plus fair and long-term support of alternative livelihood options that align with high terrestrial carbon stocks, both at minimal transaction costs. For a high emission district in Jambi province (Indonesia) we assessed the spatial aggregation needed to meet a set threshold of accuracy, through Monte Carlo simulation using known inaccuracy of land cover classification and uncertainty in carbon stocks per land cover type. When the unit of analysis for performance measures is 1 km^2, errors drop below 5%, while much of the spatial signal in areas of high and low emissions is retained. Fairness, efficiency and transaction cost issues in the design of REDD+ mechanisms are readily recognized by local stakeholders, who converge on an equal allocation to short-term efficiency and long-term fairness aspects, while aiming at reducing transaction costs to less than 30%. Feasible measures for emission reduction in the district, as derived from a participatory planning process, are compatible with the 1-km^2 aggregation level of spatial performance data.

REDD+ seeks to establish 'performance based' financial instruments to make forests more valuable standing than destroyed. A trustable, reliable and transparent C accounting system at national scale is thus essential. Accuracy of C stock and emission estimates depends strongly on scale: approaches that are sufficient for reliable national accounting may not be accurate at site ('pixel') level. The proposed REDD implementation mechanisms thus influence the required levels of precision at specific scales, and the benefits that stakeholders can obtain from investment in better data. Within a general scheme of the type of tree, forest, soil and land management practices that are needed to estimate emissions, we review a number of datasets to assess sources of bias and random error, linked to the level of replication that is needed to achieve specified precision. We also summarize data on costs of data collection at a number of scales, with different levels of precision. In combination, the costs and benefits of investment in data quality can be weighed and a balance achieved between achievement and 'transaction costs' (to which the costs of designing a monitoring system contribute). To be cost effective, national monitoring systems can build on existing forest inventory and soil data, but they need to be analyzed for bias components and variability to assess adequacy for carbon stock appraisals. Examples for Indonesia are given of the gap between these data and intensive ecological studies: reconciliation of the data sources requires reanalysis of the site selection for ecological studies and of pre-1990 logging across the country. We provide a list of 10 recommendations and summarize the current situation in Indonesia, Vietnam, Cameroon and Peru relative to these suggestions that combine biophysical and institutional dimensions of system design.