IUCN

Carbon Accounting

Best practices in approaches at various scales for forest landscape restoration

GLOBAL FOREST AND CLIMATE CHANGE PROGRAMME

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1. BACKGROUND

Around the world, momentum is growing to restore deforested and degraded lands to enhance the social, economic and environmental benefits of healthy forest cover. The restoration movement is centered on the Bonn Challenge, a global initiative to restore 150 million hectares of degraded land by 2020. Launched by world leaders in September 2011, there are already eleven commitments to reforest over 59 million hectares[1].

Since the first meeting in Bonn, IUCN has been working with countries around the world to promote forest landscape restoration (FLR) – a process that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded forest landscapes.

For restoration to be sustainable and scalable, however, it must have a source of funding. Although this can include derived products such as timbers or agroforestry production, a specific source of funding is needed to stimulate tree planting beyond common practice and to allow natural forest restoration.

Climate funding, with payments for the carbon sequestration achieved by growing forests, provides an opportunity to fill this role. To do so requires the credibility of demonstrated emission reductions to allow access to carbon financing.

Methods to measure and account for carbon stock enhancements associated with forest restoration were developed and piloted starting in the late 1990s for specified restoration project areas. Projects have continued since, following various voluntary and regulatory frameworks. The REDD+ mechanism was developed more recently, broadening the focus from projects to subnational jurisdictions and national jurisdiction boundaries.

Despite the growing interest in FLR, there has been very little focus on the development of methodological approaches for accounting carbon stock changes of restoration practices relative to business as usual (the carbon stock changes that would have occurred in the absence of FLR activities). This is not only because forest carbon stock enhancements can be difficult to measure and monitor over large areas with dynamic land use changes, but also because benefits from carbon stock enhancement activities are often considered marginal when compared to maintaining carbon stocks through avoided deforestation. Forest carbon stock enhancements, however, can be a significant atmospheric carbon sink and present real opportunity to offset emissions; especially for countries with little remaining forest cover or

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[1] As of April 2015.

limited scope to reduce emissions in other sectors. Moreover, FLR can go beyond just carbon stock enhancement providing additional socio-economic and ecological benefits.

1.1. PURPOSE OF THIS REPORT

Forest landscape restoration refers to regaining ecological functionality in deforested and degraded landscapes and consequently enhancing human well-being (IUCN and WRI, 2014)[2], specifically through activities that increase tree cover. In 2011, FLR gained significant momentum with pledges from several countries to the Bonn Challenge (see Box 1).

> **Box 1 – The Bonn Challenge:** The Bonn Challenge was created during a Ministerial Roundtable in Bonn, Germany in September 2011. A global initiative of restoring 150 million hectares of forest landscapes by 2020 was issued to be promoted by the Global Partnership on Forest Landscape Restoration (GPFLR). The Challenge hopes to work alongside other forest restoration initiatives such as the Convention on Biological Diversity's Aichi Target 15, the UNFCCC's REDD+ goal, and the Rio+20 land degradation neutral goal. Entities such as nations, companies, individuals and institutions can make pledges to contribute to the Challenge. These commitments have come in the form of quantities of degraded lands that the entities pledge to restore. Thus far, several countries including the United States (15 million hectares), Ethiopia (15 million hectares), the Democratic Republic of Congo (8 million hectares), Guatemala (3.9 million hectares), Uganda (2.5 million hectares), and Rwanda (2 million hectares) have made commitments. In total, countries have pledged to restore more than 50 million hectares of degraded land. GPFLR partners can provide technical support to determine restoration, political, and financial potential.

One of the key challenges for FLR at any scale is the process of quantifying and monitoring the impact of restoration on carbon stocks, and thus long-term emissions removals, especially given the heterogeneity of floristic composition and management practices in restored forest systems.

This document presents methodological approaches for estimating atmospheric carbon removals from forest landscape restoration initiatives at two scales:

[2] IUCN and WRI. 2014. A guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing forest landscape restoration opportunities at the national or sub-national level. Working paper (Road-test edition). Gland, Switzerland: IUCN. 125pp.

- **Programs** for forest restoration covering the entirety of a national area, or a subnational jurisdiction's area
- **Projects** for forest restoration with defined limited-area boundaries

Each of these scales has a different end-purpose (e.g. political commitment, carbon financing, biophysical goals) as well as development requirements, in terms of best practices/rules for accounting, accounting precision, and monitoring and reporting schemes.

For this document, the following options of FLR outlined in Table 1 are aggregated into two main classes aiming to facilitate operationalization of carbon accounting approaches: an FLR establishment class, and an FLR enrichment class. This aggregation is proposed because approaches for the carbon accounting of newly established forests are technically different than the carbon accounting of forests being enriched. In other words, accounting the carbon sequestration potential of tree planting in non-forest areas (establishment) is different than tree planting in degraded forests (enrichment).

Table 1: FLR options referenced to operational carbon accounting classes. Source: Adapted from IUCN and WRI (2014) (see footnote 1).

Land use	General category of FLR option	Description	Proposed C accounting class
Forest land Land where forest is, or is planned to become, the dominant land use	1. Planted forests and woodlots 	Planting of trees on formerly forested land. Native species or exotics and for various purposes, fuel-wood, timber, building, poles, fruit production, etc.	Establishment
	2. Natural regeneration 	Natural regeneration of formerly forested land. Often the site is highly degraded and no longer able to fulfill its past function – e.g. agriculture. If the site is heavily degraded and no longer has seed sources, some planting will probably be required.	Establishment
	3. Silviculture 	Enhancement of existing forests and woodlands of diminished quality and stocking, e.g., by reducing fire and grazing and by liberation thinning, enrichment planting, etc.	Enrichment
Agricultural land Land which is being managed to produce food	4. Agroforestry 	Establishment and management of trees on active agricultural land (under shifting agriculture), either through planting or regeneration, to improve crop productivity, provide dry season fodder, increase soil fertility, enhance water retention, etc.	Establishment/ Enrichment
	5. Improved fallow 	Establishment and management of trees on fallow agricultural land to improve productivity, e.g. through fire control, extending the fallow period, etc., with the knowledge and intention that eventually this land will revert back to active agriculture.	Enrichment

Protective land and buffers Land that is vulnerable to, or critical in safeguarding against, catastrophic events	6. Mangrove restoration 	Establishment or enhancement of mangroves along coastal areas and in estuaries.	Establishment/ Enrichment
	7. Watershed protection and erosion control 	Establishment and enhancement of forests on very steep sloping land, along water courses, in areas that naturally flood and around critical water bodies.	Establishment/ Enrichment

1.2. FOCAL ACCOUNTING SCALES

Box 2 – REDD+ overview: Internationally, climate change mitigation activities and associated finance for forests has increasingly focused on REDD+, which is officially defined as "reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries". REDD+ was designed to operate at the national level. Advantages of implementing the initiative at this broad scale include decreased risks of displacement of emissions (i.e. leakage) as well as a decreased need to overtly demonstrate business as usual scenarios for discrete parcels of land within the REDD+ area, among others.

While national REDD+ strategies are the intention, subnational REDD+ focusing on specific provinces and/or regions can be developed as interim measures. We expect however, that in most cases subnational regions or projects will ultimately be nested within a reported national system as a means of full national REDD+ implementation.

Commitments to the Bonn Challenge do not trigger financing to countries, subnational jurisdictions, or individuals. As such the pledges do not have the same requirements as a pay-per-performance mechanism, such as REDD+ (Box 2). The commitments themselves are not made in an attempt to seek carbon financing, although restoration activities that support the fulfillment of a pledge to the Bonn Challenge may be eligible to seek such financing.

FLR initiatives seeking carbon financing will need to demonstrate that carbon sequestered is above and beyond a business as usual scenario, and ultimately establish a measurement and reporting system that allows transparent, consistent and accurate accounting of greenhouse gases removed.

Here we focus on best practices for FLR activities attempting to access carbon financing opportunities. The requirements of such financing can be complex and include many initiatives, each with their own specific set of prescriptions (e.g. FCPF Methodological Framework, VCS JNR, ACR Nested Approach, CAR, Gold Standard, etc.). The discussion of scope of various initiatives promoting GHG emission reductions is beyond the goal of this document. Instead we focus on two broad scales of accounting and the commonalities and best practices for each of the two scales.

Box 3 – Understanding terminology: The projection of the GHG emissions and/or removals that would have happened in the future in the absence of REDD+ activities are referred to with different terminologies. The UNFCCC refers to this projection as a forest reference emission level/forest reference level (FREL/FRL), whereas the FCPF refers to it as reference level (RL), and the VCS uses the term baseline. Although confusion exists as a result of this inconsistent terminology, FREL/FRL, RL, and baseline refer to the very same estimation of future GHG emissions that would have occurred should business as usual continue without REDD+ activities.

Note on FREL/FRL: Additional confusion may arise as to how to differentiate between FREL and FRL. Although not specified by the UNFCCC, the common understanding of the difference between the two is that FREL is restricted to emissions from deforestation and forest degradation (emphasis on the term 'emissions'), whereas FRL includes emissions from deforestation and forest degradation, but also removals from forest carbon enhancement activities (UN-REDD, 2014)[2].

In this document, we refer to GHG emissions that would have happened in the absence of REDD+ activities as a FRL to be consistent with the official UNFCCC language.

The two selected scales are:

1. *Programs* implemented at the national or subnational jurisdiction scale
Akin to the international REDD+ movement (see Box 2), this scale would capture policies, laws and measures implemented by governments as well as locally specific implemented activities fostering landscape restoration.
2. *Projects* implemented within specified restoration boundaries

Projects indicate a planting or natural regeneration activity implemented within a specific location that may range from 10s to 1000s of hectares. Projects may be nested within national/subnational accounting programs or may be stand-alone activities with direct financing. Table 2 provides a comparative snapshot of the characteristics of the two spatial scales considered in this report. [3]

Table 2: Comparative analysis of main requirement for the three scales of application for carbon measurement considered in this report.

	National/ Subnational REDD+	Independent Project
Minimum Scale	National or Subnational	Distinct piece of land (~1,000 ha)
Eligible for GHG Finance	Yes	Yes
Suited for Private Sector Financing	No	Yes
Baseline Required	Yes	Yes
Relative Implementation Cost	High	Moderate
Implementation Cost Per Unit Area	Low	High

It is worth emphasizing that FLR activities from both national/subnational REDD+ as well as independent projects may be accounted towards achieving Bonn Challenge commitments and therefore may be eligible for GHG financing.

[3] UN-REDD. 2014. Emerging approaches to Forest Reference Emission Levels and/or Forest Reference Levels for REDD+. 54pp. Available at: www.unredd.net/index.php?option=com_docman&task=doc_download&gid=13469&Itemid=53

2. RESTORATION ACCOUNTING APPROACHES FOR NATIONAL/SUBNATIONAL (REDD+) PROGRAMS

2.1. BUSINESS AS USUAL FOR REDD+

Box 4 – Activity data and emission/removal factors: *Activity data* (AD) is defined by the IPCC (2006)[1] as the data on the extent of anthropogenic activity over a given period of time that results in emissions. Activity data portrays the magnitude of human intervention on the land use/land cover change leading to GHG emissions and/or removals. Activity data is often reported in terms of area of change (e.g. hectares deforested), but it is not limited to spatial extent of changes. Activity data can also be reported as non-spatial metrics, such as volume of timber harvested, kilograms of fuelwood collected, amount of fertilizer applied, or even quantity of animals on grazing land.

Emission factor/removal factors (EF/RF) are defined by the IPCC (2006) as the emission or removal rate of GHG per unit of the activity. EF/RF are directly linked to the activity that results in GHG emissions and along with the activity data, form the basis for GHG emissions/removals accounting. EF/RFs are often derived from ground sampling of carbon dynamics and flows in the landscape.

[1]IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use (AFOLU). Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

To include FLR activities in a national/subnational REDD+ strategy, the increase in the rate of carbon sequestration resulting from such activities relative to a business as usual scenario must be demonstrated. Under the REDD+ mechanism, carbon accounting generally occurs through the pairing of *activity data* with *emission/removal factors* (see Box 4).

For projects a known area is restored and the specific business-as-usual for the area can be determined and carbon stocks associated. For programs, in contrast, a rate is given for (for example), baseline tree planting but the specific hectares are unknown. The typical approach for such “reference levels” (or program baselines) would be to pair the “activity data”, which would be the area of new restoration with “emission factors”, or in this case removal factors, per unit area. Figure1 (a) illustrates a ten-year period of hypothetical new restoration, and Figure 1 (b) shows hypothetical carbon removals per hectare of such restoration effort over the same time period.

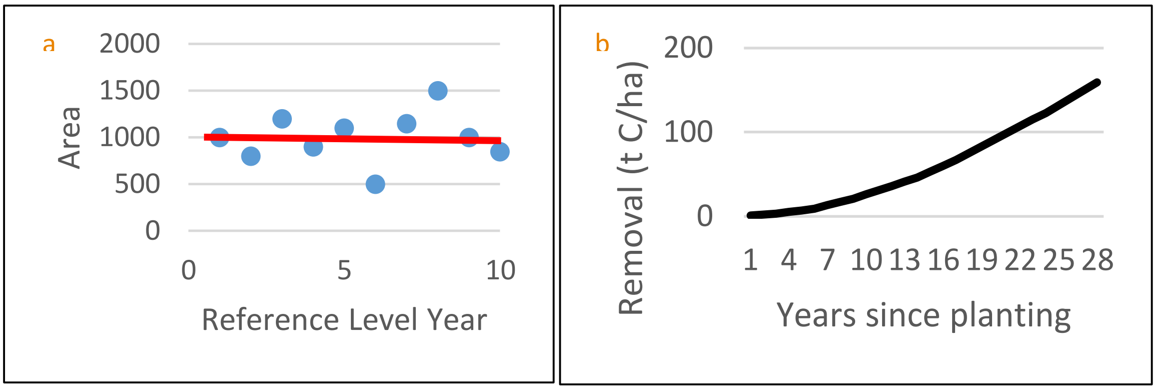

Figure 1: Hypothetical restoration area over a ten year reference period (a), and hypothetical carbon removals over a ten year reference period for such restoration activity (b).

GHG removals from restoration activities present an important contrast in comparison with deforestation/degradation events where emissions happen at one point in time (at the time of the deforestation or degradation event), allowing a single emission factor to be applied per unit of activity data. There is a growing consensus that the principle of committed emissions can be used in carbon accounting whereby all emissions are assumed to occur at the time of the event. However, it is known that for some pools, the emissions occur over time (e.g. the decomposition of carbon stored in soil, dead wood, and harvested wood products). With deforestation and/or degradation those emissions are truly committed, in other words they will occur.

Theoretically it would be possible to apply the concept of committed sequestration to “enhancement” activities. However, with sequestration the removals will not necessarily happen, as restored areas are susceptible to natural or anthropogenic events, where trees can be cut down or lost due to natural events/disasters. In the reference level an area can be assumed to reach a given carbon density, but the reality may be quite different (e.g. much higher or lower). In the implementation case of committed sequestration, the potential consequence could be massive areas of new restoration to achieve immediate crediting benefits, with subsequent lack of management that may lead to die-offs and reversals of sequestered carbon. Thus, the use of the committed sequestration assumption is not really applicable to enhancement activities.

Without this principle we have to look at stocks that accumulate year after year; or in other words, a dynamic reference level. Taking an average over, for example, a ten-year reference period would give one year with ten years of growth, the following year with nine, the next with eight, and so on. This would compare to a dynamic reference level where the actual stocks were applied in each year (Figure 2).

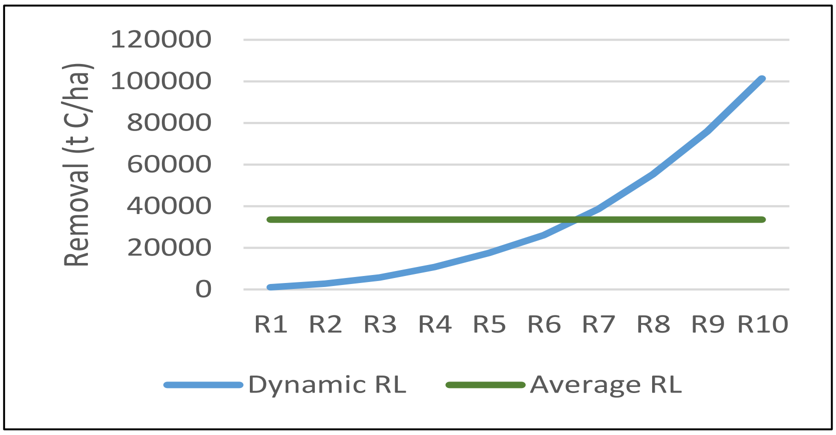

Figure 2: An average reference level versus a dynamic reference level for enhancement over a ten year reference period.

The approaches illustrated above do not come close to representing business as usual because it represents only 10 years of growth for comparison against restoration that will go on for 20, 30 or more years. A fully dynamic reference level would continue for each of the 10 years of the reference period through to maturity for the system. This would be highly complicated and again would require assumptions about the growth and management under business as usual practices.

In Figure 3 below, a hypothetical activity is illustrated. With an average reference level, no net benefit would result for several years but then massive benefits will accrue. With the dynamic reference level something closer to reality is shown at least for the first 10 years, but after the first ten years the reference level and the implementation diverge greatly as implementation starts to introduce years 11, 12, 13, etc. of new restoration while the reference level was capped at only ten years.

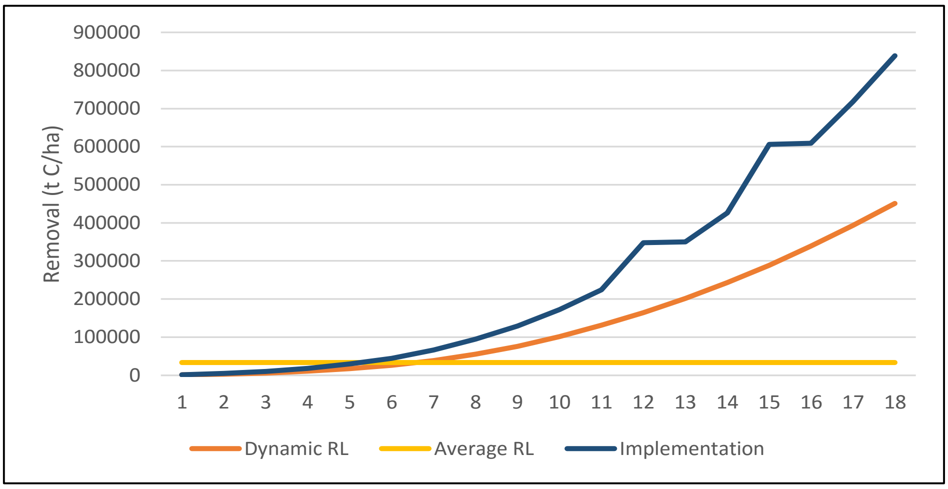

Figure 3: A hypothetical restoration accounting with comparison of implementation against average and dynamic ten year reference levels.

Clearly there is a need for a different solution. For this solution we turn to a concept that has been used under climate change mitigation projects. We will term it a "performance threshold", but it has been termed a threshold for standardized baselines, or an emissions threshold. Under this approach a historical level of restoration is established that must be exceeded before crediting is possible (Figure 4). This reference level then becomes area based with carbon removals only considered when the threshold is surpassed to estimate the creditable sequestration, thus avoiding issues with uncertain fate of restored forests, or misrepresentation of restoration practices under business as usual scenario.

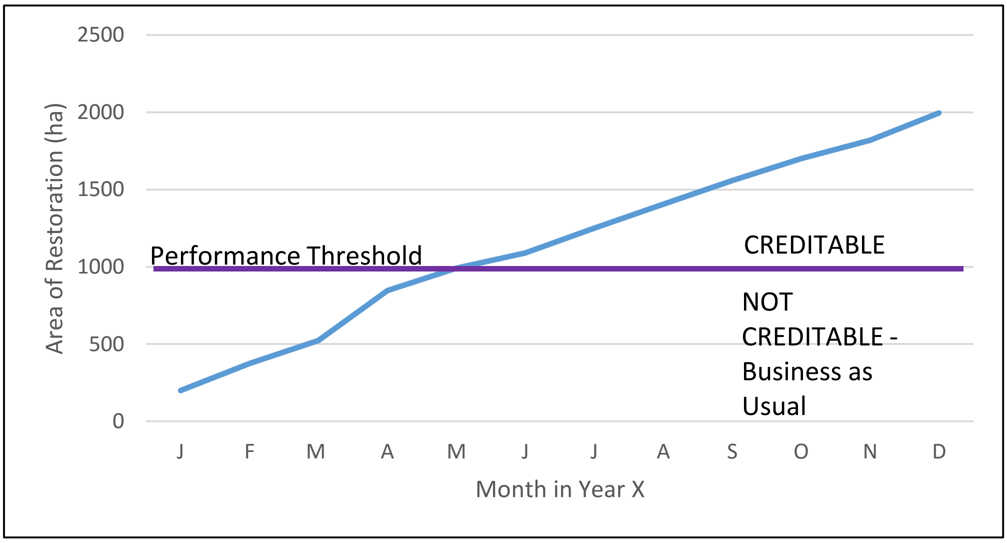

Figure 4: Illustration of the performance threshold concept with crediting possible in each year where the threshold is passed. The threshold represents the historical average annual area of restoration (by restoration class).

The performance threshold reference level would be established by restoration class (e.g. plantation types a, b, c; agroforest types x, y; natural regeneration types, g, h, i, j), so that a historical assessment would estimate performance thresholds for each restoration class.

An example would be a historical assessment that shows that 300 ha/yr of new agroforests in country X are established (the performance threshold), and during implementation only hectares 301 onwards could be credited.

The essential steps for developing a carbon accounting methodology and setting a REDD+ reference level for establishment of new FLR activities are:

- Define restoration classes that will be used (e.g. FLR type, species, or species groups, or crop systems planted)

- Develop a historical annual rate of forest landscapes restored during a specific reference period, generally defined as approximately the last 10 years[4]
- Define the performance threshold for future crediting

2.1.1. Developing Historical Rates of Forest Landscape Restoration

To develop historical rates of forest landscape restoration it is necessary to determine rates of forest enrichment or expansion per forest type over time. This involves assessing new enrichment or expansion at different dates during a historical reference period, and determining the specific area of gain that has occurred between the dates. Different estimates for each point in time can then be stitched together to generate a trend of annual enrichment/expansion (perhaps using categories outlined in Table 1) over the reference period. The projected future annual rate of enrichment/expansion can then be projected from the historical trend.

There are three main approaches to estimate historical rates of forest cover gains: (i) remote sensing analysis, (ii) ground-based survey, or (iii) a mix between remote sensing and ground-surveying. Figure 5 shows different paths that can be taken to estimate a forest reference level for forest landscape restoration.

[4]A reference period of 10 years is a common, generally-accepted length of time for REDD+ activities. Too short a period could capture the influence of short term events and trends, thus failing to capture more meaningful long term trends. In contrast, too long a period can negate meaningful recent trends that are more likely to drive future activity. The FCPF's Methodological Framework states that "the start date for the Reference Period is about 10 years before the end-date" (Indicator 11.2), while the VCS JNR requires a historical annual average over the period of 8 to 12 years, or a historical trend over at least the 10 years, both ending within two years of the start of the baseline (Requirement 3.11.12).

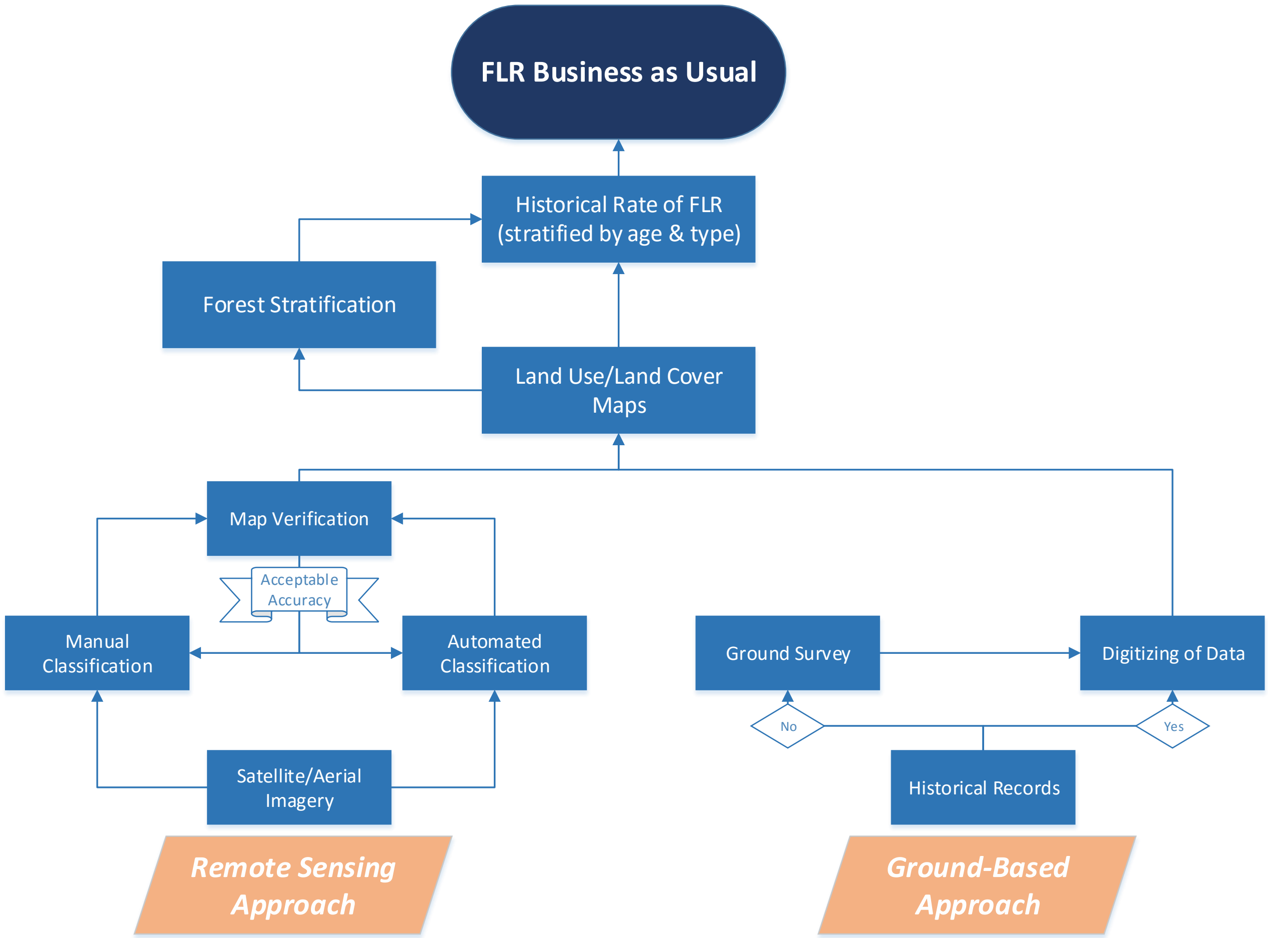

Figure 5: General concept for estimating business as usual rates of historical forest landscape restoration activities.

The best methods for developing historical rates of restored forested landscapes depends on several factors:

- Measurement and monitoring costs (financial resources available to purchase remote sensing imagery, conduct field surveys, train community monitors, etc.);
- Stakeholder expertise (level of technical capacity to conduct spatial analysis, analyze remote sensing products, design field survey campaigns, perform field measurements, and use pertinent technology, etc.);
- Available data and statistics (existence of historical records of FLR, whether spatially-explicit or not; frequency of existing records, access to ancillary data, budget for collecting/acquiring data, etc.); and
- Infrastructure to manage the information adequately (existing remote sensing products and software to assess it, forest and plantation inventories, academic studies, data management/sharing capabilities, etc.).

In general, ground-based approaches can be cost effective if an existing infrastructure for local assessment and reporting is already in place. Remote sensing by definition is distant and can be conducted at any point in time but requires costs and skills, especially when higher resolution imagery is used.

Historical rates of restored forest landscapes using remote sensing

Several remote sensing products are available to measure forest area change. The same products that are used for measuring forest loss (deforestation) can be used to measure forest gain, with a few caveats.

When choosing a remote sensing product, it is important to take into account the forest definition of the targeted area. If the national forest definition determines that areas that are included as forest are smaller than can be determined from the resolution of the imagery used, then actual forest area and changes in forest area may not be fully accounted for using remote sensing products alone. For example, Rwanda's forest definition states that the minimum area of forest is 0.05 ha, which can only be fully detected where the remote sensing product has a cell size of ~22.4 m x 22.4 m or smaller. Broad scale imagery is typically inexpensive or free to attain, and inexpensive to analyze but will not have the resolution to capture small areas of forest restoration. Details on remote sensing products can be found in Annex 1.

The scale of the area to be measured is also an important consideration when computing area of forest change. Ideally, the measurements would take into account the entire area (in the case of a jurisdiction or country, this would be a "wall-to-wall" approach). However, in the case of large jurisdictions or countries, or when using expensive imagery, it may be more appropriate to sample a fraction of the entire study site for measurement. Samples can be selected based on a variety of criteria, but for measuring forest gains it is important to select a representative sample of the targeted area (i.e. that includes the same proportion of area for each stratum, or that present the same dynamics of forest gains across the entire targeted area).

Where the focus is on enrichment rather than expansion of forest areas, significant additional challenges arise for remote sensing. Currently, remote sensing is much more reliable for determining presence or absence of forest rather than the relative crown cover of forest. Using moderate resolution imagery, it may be difficult or at least require highly-advanced analysis to identify enrichment of a degraded forest. Most basic analysis techniques will classify such degraded lands as either non-forest (if highly degraded) or as forest. Recorded "non-forest" areas will subsequently see gain in forest cover as with forest area expansion but for areas recorded as "forest", the enrichment will often not show up in remotely sensed imagery. Even where enrichment shows up in remotely sensed imagery the challenge will remain of determining whether natural forest recovery is being captured or forest restoration as a result of human intervention. Using higher resolution (and therefore higher cost) imagery would resolve some of these issues. Alternatively, enrichment activities may have to have a greater ground survey focus.

Historical rates of restored forest landscapes using ground survey

Historical annual rates of restored forest landscapes can be obtained from ground-based survey if historical records of forest enrichment or expansion exist. The records would need to include historical surveys of areas of forest enrichment/establishment at regular intervals, including the location of restored areas within the larger national/subnational territory. In other words, there must exist records from multiple points in time with a detailed delineation of restored areas, and including the FLR activity type/species planted. The delineation of the restored areas can be done during the survey with a GPS, or by digitizing existing maps depicting historically restored areas. This information must then be aggregated at the national/subnational level into a database, preferably a spatially-explicit database. Over time, the FLR database would contain areas forests restored per period of time (e.g. year) and per type (e.g. species or forest type). This database is necessary to ensure proper accounting of FLR expansion or shrinkage, and avoid either double counting or underestimation of areas restored in the past.

Although not common, particularly in developing nations, yearly statistics on forest area gains can be valuable information for countries that rely upon forest services and goods.

2.1.2. Establishment of FLR versus Enrichment with FLR

No methodological differences exist in the process of developing historical rates of FLR between activities that promote establishment of new forest areas and activities that promote enrichment of existing forest areas.

Technical difficulties in determining and accounting for areas of FLR activities that promote enrichment may arise because of remote sensing limitations and because of complex regeneration dynamics in forested areas. This will both complicate the differentiation of some degraded forest from non-degraded forest, and the differentiation of human-induced FLR activities and natural regeneration within degraded forests. As mentioned before, the rate at which forests can naturally restore and reach canopy closure varies based on a variety of factors, and these factors render differentiation of naturally versus anthropogenically-restored areas difficult to ascertain, especially if monitoring is conducted with remote-sensing techniques only. It is important to mention that only anthropogenically-driven FLR (establishment and/or enrichment) is accounted for in the estimation of historical rates of FLR under a national/subnational REDD+ forest reference level.

2.2. MONITORING FOR REDD+

The monitoring of carbon sequestration/removals as a result of FLR requires the tracking of FLR areas at a regular interval[5], and the association of FLR or even species-specific emission/removal factors (carbon sequestration rates) to each restoration established, thus allowing accounting of carbon sequestered through time. The accounting of carbon removals should only happen for FLR areas that surpassed the performance threshold established when setting the reference levels (e.g. for the example given in Section 2.1. above, the reference level performance threshold was 300 ha/yr of a given FLR type, which means that accounting of carbon removed as a result of FLR establishment should only occur for hectares 301 onwards).

A robust measuring, reporting and verification (MRV) system that is able to accurately: measure (M) the new areas of FLR as well as changes in carbon stocks (increase or decrease) in such areas is required, so that emissions removed can be consistently reported (R) to the UNFCCC and/or any other regulating body, and transparently verified (V) by a third party before payments can be issued to the REDD+ proponent.

A conceptual example of a MRV system tracking FLR activities over multiple years under REDD+ program is given in Figure 6 below (Note: The framework portrays an example of a single forest type, whereas in reality FLR activities may promote various forest types. In such cases, the MRV system would repeat the proposed framework for each forest type covered under FLR activities). The total GHG removals is only required to be estimated for the areas in excess of the FLR business as usual threshold with an additional year of sequestration added for each year completed beyond the initial establishment.

As shown in the conceptual diagram (Figure 6), considering only a single forest type, the GHGs removed in year 1 are calculated by multiplying the FLR area gains (above the threshold) by the carbon sequestered by each during the first year. GHG accounting in year 2, would

[5] UNFCCC currently requires biennial reporting (Decision 14/CP.19 paragraph 6). Available at: http://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=39

include the FLR area gains from year 1 multiplied by the carbon sequestered during two years of growth (since these areas have already been established and growing for two years), plus any additional area of FLR gained in year 2 multiplied by carbon sequestered during first year of growth. In year 3, GHG removed would be the FLR area gains from year 1 multiplied by carbon sequestered during of three years of growth, plus FLR area gains in year 2 multiplied by carbon sequestered during two years of growth, plus the FLR gains in year 3 multiplied by carbon sequestered during first year of growth. The MRV system would capture this repeated cycle of new gains in FLR areas and associate the respective, age-specific, removal factor to each area depending on the time elapsed since its establishment. It is worth remembering that only FLR area gains additional to business as usual can be credited under a REDD+ scheme.

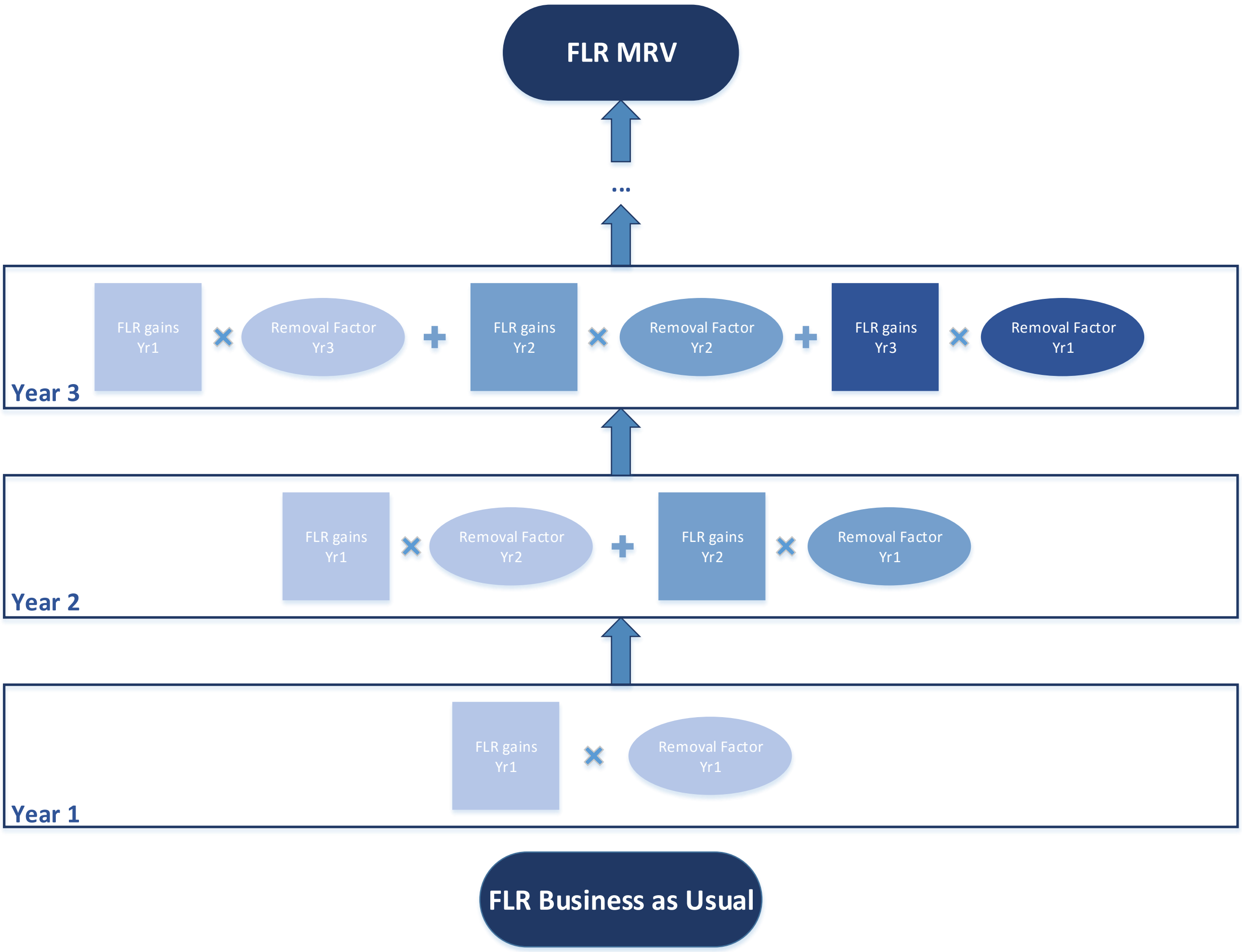

Figure 6: Conceptual framework for MRV system tracking FLR activities over multiple years under a REDD+ Program

2.2.1. Ground-based monitoring

Ground-based monitoring of FLR activities at the national/sub-national REDD+ program requires:

i. Spatially delineated area of forest gains as a result of FLR, and
ii. Estimation of carbon accumulation rates/growth behavior of forests restored.

Delineating FLR areas

A spatial delineation of the boundaries of every FLR area is required. This delineation must be conducted at a regular frequency. This monitoring of areas can be conducted using GPS devices and directly uploaded to a spatially explicit database containing all polygons of FLR areas, or it can be conducted with non-spatially explicit surveying equipment (i.e. theodolite) and later be digitized into a spatially explicit database. It is important that every FLR area surveyed is associated with the year of the monitoring event, and forest type/species established in the area.

Carbon accumulation/growth behavior of FLR

Removal factors are resultant from estimates of carbon accumulation of type-specific FLR activities over time, which can be derived from multiple sources:

- Permanent plots: Establishment of permanent sampling plots in FLR areas can record standing carbon stocks at regular intervals. A set of permanent sampling plots must be established following an appropriate sampling design per forest type stablished. Permanent plots are not recommended for REDD+ as are considered overly costly for the purpose.
- Chronosequence sampling: Establishment of temporary sampling plots in each of the FLR forest types across various ages of development can be used to estimate carbon sequestration. There must exist stands of each forest type considered in the FLR initiative at various ages of development (i.e. years since establishment) to permit sampling each of the forest types at different ages. The age of forest areas being sampled must be known so that carbon stocks data can be associated with a given age for derivation of a curve of carbon sequestration.

- Published models or data: Much similar to using IPCC tier 1 default rates of carbon accumulation IPCC (2006)[6]. Only reliable and published growth models and/or carbon accumulation data, which are representative of the FLR area can be used to estimate the carbon sequestration potential. This presents the lowest cost option but relies on pre-existing data and analyses.

2.2.2. *Remote sensing-based monitoring*

A purely remote sensing-based monitoring program of FLR initiatives at the national/subnational REDD+ program requires:

i. Spatial delineation of FLR area gains, and
ii. Estimation of carbon accumulation rates/growth behavior of forests restored.

The boundaries of every FLR area must be spatially delineated using remote sensing products. To do so there cannot exist in areas of forest landscape being restored that are smaller than the spatial resolution of the remote sensing product[7].

The delineation of FLR areas must be conducted a regular frequency (e.g. if reporting occurs every two years, the monitoring of FLR areas must take place at least at the same frequency).

Carbon sequestration rates would be determined as detailed above (see Ground-based monitoring).

2.2.3. *Mix of ground and remote sensing based monitoring*

An approach that mixes the use of ground- and remote sensing-based monitoring allows the selection of methods based on the best cost-benefit ratio. This mixed approach allows flexibility to monitoring for FLR initiatives with either ground surveying or remote sense mapping.

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[6] IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use (AFOLU). Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[7] Alternatively, there could be a conscious decision to forego accounting of FLR areas that are smaller than the spatial resolution of the remote sensing product (Landsat imagery has a spatial resolution of 0.09 ha).

2.2.4. Monitoring of establishment of FLR versus enrichment with FLR

When it comes to monitoring FLR activities, measuring establishment is different than measuring enrichment.

- For *establishment* new areas of trees are established where none existed before and the accumulation of carbon in these new trees can be captured.
- For *enrichment* there must be a separation between the carbon sequestration rate of the degraded forest in the absence of restoration and the carbon sequestration of the enriched restored forest.

The following options are proposed for assessing the changes in carbon stocks:

1. Establish paired inventory plots in enriched restored forest and in a control non-restored degraded forest to determine the difference. However, experience has shown that a sizeable number of ground plots would need to be established per stratum to determine the increase due to enrichment. This option is likely cost prohibitive.
2. Modeling of carbon sequestration. Many tree growth models exist and are commonly used[8]. Such models would require parameterization according to the number and size of trees prior to and post enrichment, the soil, and the climate conditions of the site. Beyond this initial data collection all that would be required would be limited measurement at each reporting time period to validate that the model is accurately estimating current stocks.

2.3. DATA NEEDS

Data needs for establishing forest reference level under a REDD+ approach:

- Historical rates of FLR
  - Stratified by age and type,
  - Preferably spatially explicit and
- Projection of historical average or trend of FLR rates, based on
  - Statistical significance
  - REDD+ standard[9]

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[8] Examples of models given at: http://models.etiennethomassen.com/

[9] Different REDD+ standards allow different types of projection of historical emissions for development of a forest reference level. See footnote 3.

Data needs for monitoring forest reference level under a REDD+ approach:

- Spatially explicit areas of FLR
  - At regular time intervals
  - Stratified by age and type
  - Preferably derived from land use/land cover maps in digitized format (e.g. shapefile)

AND

- Forest biomass accumulation data
  - Stratified by age and type of FLR
  - For multiple years
  - Estimated with suited allometric equation for region and type of FLR
  - Preferably derived from:
    - Forest inventory data (i.e. permanent sampling plots), or
    - Chronosquence sampling

OR

- Growth curves/look-up tables of carbon accumulation rate
  - For each age and type of FLR
  - Demonstrated suitable for region of FLR

OR

- Particularly for enrichment: parameterized growth models

2.4. ADDITIONAL RESOURCES

Additional information on methods and approaches for national/subnational-level restoration activities can be found at:

- GOFC-GOLD Sourcebook of methods and procedures for monitoring and reporting GHG emissions and removals: www.wmo.int/pages/prog/gcos/documents/Mitigation_GOFC-GOLD_REDD_Sourcebook.pdf
- LEAF-Asia Tools and Guidance: http://www.leafasia.org/tools

- BioCarbon Fund Sourcebook for Land Use, Land-Use Change and Forestry Projects: https://wbcarbonfinance.org/Router.cfm?Page=BioCF&FID=9708&ItemID=9708&ft=DocLib&CatalogID=25802
- US Forest Service's review of selected remote sensing and carbon measurement tools for REDD+: www.fs.fed.us/eng/rsac/programs/monitoringforests/10018-RPT1-Book%201.pdf

3. RESTORATION ACCOUNTING APPROACHES FOR PROJECTS

In the context of this section, FLR projects are the activities that increase tree cover within a specified boundary made possible by financing from greenhouse gas mitigation.

These types of projects have been in existence for more than 20 years with a high point reached between 2005 and 2010 with the implementation of the CDM of the Kyoto Protocol, followed by the establishment of voluntary markets such as the VCS, the ACR, CAR, Plan Vivo and others. Projects have since been in decline given the small market demand for carbon credits, but are seen as an important implementation approach for achieving national and subnational emission reductions under REDD+ or a successor scheme, as well as being a means for direct private industry investment in GHG mitigation activities.

Box 5 – A glance at independent projects: A project-based approach is the finest possible scale for FLR activities and therefore results in strict requirements for carbon accounting with detailed monitoring and precise estimates of carbon sequestration. This approach will also typically result in the higher carbon accounting and monitoring costs per unit area and/or emission offset generated than a national/subnational approach.

The key benefits of a project-based approach are the direct tie between FLR establishment at the property level (private property or not), and resulting climate finance; thus incentivizing independent action and the direct flow of benefits to FLR stakeholders.

3.1. SPECIFIC CONSIDERATIONS FOR RESTORATION PROJECTS

The need to demonstrate actual removals of atmospheric GHG to trigger financing opens an additional set of specific criteria for projects when compared to national/subnational REDD+. These criteria are established to ensure that each project is effectively sequestering GHG additional to what would have happened otherwise (the business as usual scenario), safeguarding the validity of carbon offsets. Although the criteria vary slightly across different standards, they can be summarized as:

1. Proof that an area has not been deforested just to create the opportunity for a FLR activity that will claim GHG removals/carbon credits in the future;
2. Demonstration that an area would not have been restored if not for climate change finance – the concept of project additionality, in which it must be demonstrated that FLR is not legally required nor financially independent from

carbon financing, and there are no excluding economic or market barriers to implementing the FLR project;

3. Determination of the specific baseline carbon stocks and the most likely changes in baseline carbon stocks for the project area in the absence of a project;
4. Direct measurement of carbon stocks and carbon stock changes that occur after FLR establishment (i.e. with use of ground plots or remote sensing techniques[10]) after planting.

Each of the overarching criteria listed requires planning to ensure successful implementation of FLR projects eligible for carbon financing.

3.2. TECHNICAL APPROACH FOR RESTORATION PROJECTS SEEKING CARBON FINANCING

Figure 7 represents the key steps required in implementing a restoration activity at the project scale:

[10] VCS's approved tool: VT0005: Tool for measuring aboveground live forest biomass using remote sensing.

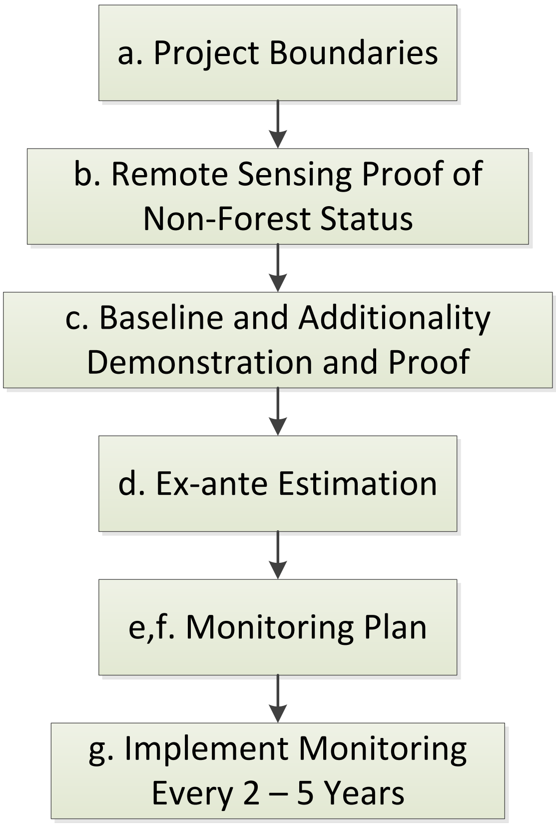

Figure 7: the key steps in implementing a restoration activity.

a) Determine precise boundaries of future tree cover – typically with GPS tracing;
b) Remote sensing analysis to demonstrate area has been non-forest at least ten years (for forest establishment projects not relevant for enrichment);
c) Demonstrate and prove baseline land use, land cover and stocks;
d) Forecast expected project carbon sequestration (ex-ante estimation);
e) Plan plots (typically permanent plots) for measuring trees. Select allometric equation or equations for estimating carbon stocks from tree measurements / enrichment projects would likely select, parameterize and validate a growth model to model carbon sequestration both with and without enrichment activities;
f) Include other pools (belowground biomass, dead wood, litter and soil organic carbon) through calculation approaches rather than direct measurement (or may already be included in the growth model for enrichment activities);
g) Measure trees every 2 to 5 years. Subtract baseline stocks from planted stocks to determine net sequestration (for enrichment activities monitoring using models, only limited measurement will be necessary in order to validate model outputs).

3.3. ESTABLISHMENT OF FLR VERSUS ENRICHMENT WITH FLR

As for national/subnational programs, enrichment activities present a more complex scenario than establishment activities. Again the challenge is establishing both the business as usual rate of carbon sequestration (in the absence of enrichment), and the amount that carbon sequestration that is elevated above this business as usual as a result of enrichment.

As at the national/subnational program level, there are two options to measure carbon stock gains from enrichment with FLR:

1. Establish paired inventory plots in comparable degraded and restored through enrichment forests to determine the difference in carbon sequestration between the two. At the project level, it is expected that operationalization of paired plots is much simpler than at national/subnational program level given the limited spatial extent of projects (Table 2).
2. Modeling of carbon sequestration. Use of tree growth models parameterized to the business as usual and to enriched forest. Parameterization would include site specific factors such as soil type, climate, and the species, size and density of trees. Limited measurements will be needed to validate the model outputs.

3.4. DATA NEEDS

Data needs for a project-based approach to restoration:

- Precise location of expected, and later demonstrated, planted tree boundaries; preferably digitized in electronic format (e.g. shapefile);
- Allometric equations that are demonstrably suited for the planted species;
- OR parameterized model of tree growth (for enrichment activities);
- Remote sensing image of planting area ten years previously proofing absence of forest in proposed project area (for establishment activities);
- Tree species to be planted with estimates of growth rates (either biomass accumulation, basal area increase, or diameter at breast height increase with planting density);
- List of most common land uses that would have taken place in the proposed project area, and if any feature trees, arguments why this should not be expected in the project area.

3.5. ADDITIONAL RESOURCES

Additional information on methods and approaches for project-based restoration activities can be found at:

- World Bank Sourcebook on measurement approaches for carbon projects: http://www.winrock.org/resources/sourcebook-land-use-land-use-change-and-forestry-projects
- ITTO Guidebook providing guidance in developing an afforestation project: http://www.itto.int/direct/topics/topics_pdf_download/topics_id=28630000&no=1&disp=inline
- Winrock Standard Operating Procedures for field measurement of carbon stocks and carbon stock changes: http://www.winrock.org/sites/default/files/publications/attachments/Winrock_Terrestrial_Carbon_Field_SOP_Manual_2012_Version.pdf
- US Forest Service guidebook for measurement of carbon stocks and carbon stock changes in forests: http://www.winrock.org/resources/measurement-guidelines-sequestration-forest-carbon

4. SUMMARY

4.1. KEY FINDINGS

The key findings and differences between the two scales for carbon enhancement accounting through FLR are given in Table 3. Since projects are relatively small with established defined areas, project measurement is typically done on the ground and results are given in precise estimates of the sequestration achieved by restoration. For national or subnational programs, determination of enhancement area in the historical reference period to determine business as usual and subsequent implementation is a key challenge, especially where enhancement occurs on small areas and when enrichment planting occurs. The focus on governments for national and subnational programs reduces the suitability for private sector financing in contrast to projects in which investment can directly occur.

Table 3: Summary of the key differences between national/subnational restoration programs and independent projects

	National/ Subnational REDD+	Independent Project
Scale	National or Subnational	Distinct piece of land (~1,000 ha)
Suited for Private Sector Financing	No	Yes
Relative Implementation Cost	High *(due to large area covered)*	Moderate
Implementation Cost Per Unit Area	Low	High *(due to small scale and high precision)*
What should the business as usual incorporate?	Area *(for enrichment measurement will require an estimate of sequestration in the absence of enrichment planting)*	Baseline sequestration
Recommended method for determining area	Remote sensing / ground data *(Depending on systems already in place and capacity)*	Boundaries known. Derived on ground
Recommended method for determining carbon stocks	Establishment: Literature Enrichment:	Establishment: Measurement Enrichment:

	Modeling	Modeling
Highest cost element	Determination of business as usual	Measurement of stocks
Key challenge	Determination of area of restoration	Minimizing transaction costs

4.2. REMARKS BY FLR TYPE

1. Planted forests and woodlots

Represent the simplest FLR activity from GHG accounting perspective. Usually can be detected from remote sensing and carbon sequestration follows well understood trajectories of the establishment of an even-aged cohort of trees (homogeneous or heterogeneous in composition). Literature (models or look-up tables) or chronosequence plots can determine the rates of carbon sequestration. The recommended GHG approach is likely remote sensing based or a mixed approach, directly influenced by existence and availability of data.

2. Natural regeneration

The rate at which trees establish under natural regeneration is dependent on the seed sources and the suitability of the growth conditions (e.g. nutrient/light/water availability, existing pests, and natural/anthropogenic disturbances). Usually natural regeneration can be detected by remote sensing provided areas are not too small and/or diffuse to be detected by the remote sensing product. Literature (models or look-up tables) or chronosequence plots can determine the rates of carbon sequestration. The recommended GHG approach is likely remote sensing based or a mixed approach, directly influenced by existence and availability of data.

3. Silviculture

Represents forest management and enrichment of existing stocks. A challenge to remotely determine areas (for national or subnational programs) and to determine the rate of carbon sequestration *above* the existing rate without enrichment intervention. These FLR activities are recommended to be monitored on the ground, with direct measurement of incremental areas restored and modeling of carbon sequestered as a result of enrichment.

4. Agroforestry

Highly diverse class of activities that can include a wide mix of planting densities and composition, including both timber and food trees, and even herbaceous understory planting. Agroforestry will usually constitute FLR establishment, but can be FLR enrichment by increasing the number of trees in an existing agroforest and/or enriching an existing forest with agricultural species (food trees and/or herbaceous plants). Challenging to determine business as usual carbon stocks and expected carbon stock changes accurately given the variation in management practices across farmers. Agroforests can be detected by remote sensing; though small agroforests are common and will be difficult to detect remotely. For establishment of agroforests a mix of ground and remote sensing approach is recommended, so small agroforests can be captured. For enrichment with agroforests, a ground approach to GHG accounting is recommended.

5. Improved fallow

Fallow cycles can be difficult to separate from deforestation in remote sensing. It can also be difficult to establish some standardized common practices for particular areas in terms of length of fallow periods. The carbon stocks of fallows are typically described as the average stock across the entire fallow cycle. Increasing the length of the fallow or otherwise improving the fallow increases this mean carbon stock. A mix of ground surveys to determine fallow periods with remote sensing to detect land cover changes is likely the best approach, however a case-by-case assessment is recommended.

6. Mangrove restoration

Mangrove restoration can be usually differentiated in remote sensing and literature exist on mangrove carbon stocks and rates of carbon sequestration. The recommended GHG approach is likely remote sensing based or a mixed approach, but directly influenced by existence and availability of data.

7. Watershed protection and erosion control

Watershed protection can include all elements of forest restoration including establishment and enrichment as well as elements of the conservation of existing forests. This activity captures many or all of the previous six and the technical considerations discussed for all activities above are applicable here.

ANNEX 1: REMOTE SENSING TECHNOLOGIES AND APPROACHES

Commonly used remote sensing products include imagery from satellites such as MODIS, LANDSAT, IKONOS, RapidEye, Quickbird, and SPOT (Table 4). Products vary in temporal (the frequency at which an image is taken of the same location) and spatial (the cell size of the imagery) resolution. The free MODIS products are high in temporal resolution providing daily images, but relatively low in spatial resolution with cell sizes of 500-1000 m. Because of this coarse spatial scale, MODIS products are generally not useful for measuring fine scale forest area change, but still can be useful as a support product, especially at the national/subnational scale. For example, when dealing with large areas, the MODIS land cover product can be used to stratify forest types on the coarse scale which can influence a sampling design using a finer-scale remote sensing product (GOFC-GOLD 2013)[11]. For specifically measuring carbon stock enhancements at any scale, MODIS is unlikely to be useful as anything other than a support product.

Table 4: Overview of select remote sensing products used for REDD+ monitoring and baseline development.

Remote Sensing Product	Temporal Resolution (days)	Spatial Resolution (ha)	Example Studies	Considerations	Cost ($ ha^{-1})[12]
Terra-MODIS	1	6.25-25	Friedl et al. (2002)[13], Hansen et al. (2003)[14]	Free product, very good temporal resolution but poor spatial resolution.	Free

[11] GOFC-GOLD, 2013. A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COP19-2, (GOFC-GOLD Land Cover Project Office, Wageningen University, The Netherlands).

[12]Pricing for remote sensing products can be highly variable based on amount of images purchased, level of preprocessing done before purchase, if images are historical or taken upon user request, among other variabiles. Prices are also constantly changing and the prices listed here are only an estimate and should not be quoted for actual purchasing.

[13]Friedl MA, McIver DK, Hodges JCF, Zhang XY, Muchoney D, Strahler AH, Woodcock CE, Gopal S, Schneider A, Cooper A, Baccini A, Gao F, Schaaf C. (2002). *Global land cover mapping from MODIS: algorithms and early results .* Remote Sensing of the Environment: 83, 287-302.

[14]Hansen MC, DeFries RS, Townshend JRG, Carroll M, Dimiceli C, Sohlberg RA. (2003). *Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm*. Earth Interactions: 7(10).

ETM+ Landsat	16	0.09	Hansen et al. (2013)[15], Gebhardt et al. (2014)[16]	Free product with highest spatial resolution, but temporal resolution is poor.	Free
SPOT 6-7	1	0.000225 -0.0036	Pratihast et al. (2013)[17]	Good temporal and spatial resolutions, but comes with some cost.	0.01-0.025
IKONOS	1-3	0.001024	Gougeon and Leckie (2006)[18]	Great spatial and temporal resolutions that can be used for even small forest definitions. However, very expensive to obtain.	0.10
RapidEye	5-6	0.0025	Magdon et al. (2014)[19]		0.01
Quickbird 2	2-3	0.000467	Hirata et al. (2014)[20]		0.24-0.28

Medium-scale remote sensing products are more commonly used for measuring forest change. The free Landsat product is most commonly used, with a 30 m cell size and images of the same location taken at an interval of 16 days. A global forest change product created by Hansen et al (2013) exists that shows forest gain over the period of 2001-2012. Ideally, a reference period should have more than two dates to show a trend, but this product shows the feasibility of LANDSAT imagery to measure forest gain. Landsat thus far has been the most widely-used satellite product for national/subnational-level REDD+ accounting because it is free to obtain and has good spatial and temporal resolution compared to other free products. However, to date most national/subnational-level REDD+ accounting has been focused on

[15]Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG. (2013) *High-Resolution Global Maps of 21st-Century Forest Cover Change*. Science: 342, 850.

[16]Gebhardt S, Wehrmann T, Muñoz-Ruiz MA, Maeda P, Bishop J, Schramm M, Kopeinig R, Cartus O, Kellndorfer J, Ressl R, Santos LA, Schmidt M. (2014) *MAD-MEX: Automatic Wall-to-Wall Land Cover Monitoring for the Mexican REDD-MRV Program Using All Landsat Data*. Remote Sensing: 6, 3923-3943.

[17]Pratihast AK, Herold M, Avitabile V, de Bruin S, Bartholomeus H, Souza Jr CM, Ribbe L. (2013) *Mobile Devices for Community-Based REDD+ Monitoring: A Case Study for Central Vietnam*. Sensors: 13(1), 21-38.

[18]Gougeon FA, Leckie DG. (2006) *The Individual Tree Crown Approach Applied to Ikonos Images of a Coniferous Plantation Area*. Photogrammetric Engineering and Remote Sensing: 72(11), 1287-1297.

[19]Magdon P, Fischer C, Fuchs H, Kleinn C. (2014) *Translating Criteria of International Forest Definitions into Remote Sensing Image Analysis*. Remote Sensing of Environment: 149, 252-262.

[20]Hirata Y, Tabuchi R, Patanaponpaiboon P, Poungparn S, Yoneda R, Fujioka Y. (2014) *Estimation of Aboveground Biomass in Mangrove Forests using High-Resolution Satellite Data*. Journal for Forest Research: 19(1), 34-41.

forest loss (deforestation) and not on forest gain. As discussed in section 2.1.1, the viability of using Landsat and other medium-scale remote sensing products for enrichment with FLR is limited, but Landsat is a good option for measuring enhancement from FLR at the national/subnational level.

Fine-scale remote sensing products are preferred from a quality standpoint, but are much more expensive to obtain, process, and analyze. Products such as RapidEye, IKONOS, and QuickBird have cell sizes of less than 0.01 ha. Other options such as orthoimagery and LIDAR[21] also have very fine scales, but can be even more expensive to obtain. If budget is limited, one option is to obtain a small sample of high-resolution imagery to train or guide classification algorithms of medium-scale imagery.

For national/subnational-level restoration programs, fine-scale products can be prohibitively expensive. This is especially true for forest reference level development, since many fine-scale imagery is captured on demand, so historical images may not be available (this is not the case for coarser-scale resolution such as Landsat, which captures imagery everywhere along its flight-path regardless of user request). In addition, restoration programs must consider the need for consistency in their monitoring program. REDD+ frameworks generally require that the same methodology be used for forest reference level development and monitoring. This requirement implicates the need for the same remote sensing product to be used in forest reference level development as in future monitoring. Therefore, if a national/subnational program decides to use fine-scale imagery for their forest reference level, they must plan to use (and therefore probably purchase) the same remote sensing product for each future monitoring event. It may be possible for a REDD+ program to change the remote sensing product it uses over the course of time if it can prove the new product increases its accuracy and reduces uncertainty. The frameworks stress the need for consistency in remote sensing products and accounting methodology and so any change in product would need to be accompanied by explanations of how consistency is maintained in results. Due to these issues, it is suggested that national/subnational programs attempt to use medium-level remote sensing products to measure forest gains before purchasing/obtaining fine-scale imagery.

Fine-scale remote sensing products are more feasible for project-level restoration activities since these activities involve small areas. However, projects may have smaller budgets

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[21]Orthoimagery refers to high resolution (normally meter or submeter) aerial images that have been geometrically corrected to give a uniform scale. LIDAR is a lasar-based technology used to make high-resolution maps through measuring the distance to a target of an airborne sensor.

and will receive less benefits because of their smaller size. This means they must consider the associated costs of fine-scale imagery, and may determine that ground-level measurement/monitoring is more feasible than a remote sensing analysis.

ANNEX 2: CASE STUDY OF RWANDA

The country of Rwanda is used here as a case study, and considerations and recommendations of the GHG approach are based on the information available to the authors. This case study aims to facilitate the decision making of those faced with similar challenges and thus assist in the definition of an appropriate approach.

Rwanda and its forests

The Republic of Rwanda is a densely populated, developing country of 10.5 million people with an average annual growth rate of 2.6%[22] and a GDP of 1,302 billion Rwandan Francs G.[23] Rwanda is a small country, encompassing 2.4 million hectares, of which approximately 2 million hectares are under cultivation or permanent pasture.[24] Most of the country is at an altitude above 1,000m, which creates a moderate climate despite being two degrees south of the Equator. The country has two rainy seasons, the first of which occurs from February to June and the second of which occurs from September to December. Rainfall is distributed unevenly across the country with the West and North receiving more rainfall than the South and East.

Land, water, flora, and fauna are the main natural resources Rwanda's population relies on for their livelihoods, which are largely based on subsistence agriculture and energy production. Indeed, an estimated 90% of the population and 70% of the country's land area are devoted to subsistence agricultural production, while a further 16% of land area is allocated to fuel wood and timber production to meet the country's energy needs.[25] With the population's high dependence on the country's limited land resources, degradation, deforestation, soil erosion, and loss of biodiversity pose potential threats to the country's rural population.[26] The primary challenge faced in Rwanda is the management of existing resources to meet the needs of an increasing populace who depend on natural resources for every aspect of their livelihoods.[27]

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[22] NISR (2012). *Population and Housing Census, 2012.* National Institute of Statistics of Rwanda. Kigali.
[23] NISR (2014). *Gross Domestic Product (GDP); First Quarter, 2014*. National Institute of Statistics of Rwanda. Kigali.
[24] Habiyambere , T., Mahundaza , J., Mpambara , A., Mulisa , A., Nyakurama , R., Ochola , W. O., et al. (2009). *Rwanda State of Environment and Outlook.* Kigali: REMA.
[25] Habiyambere , T., Mahundaza , J., Mpambara , A., Mulisa , A., Nyakurama , R., Ochola , W. O., et al. (2009). *Rwanda State of Environment and Outlook.* Kigali: REMA.
[26] Republic of Rwanda Ministry of Lands, Environment, Forestry, Water and Mines . (2003). *National Environmental Policy 2003 .* Kigali: Ministry of Lands, Environment, Forestry, Water and Mines .
[27] Habiyambere , T., Mahundaza , J., Mpambara , A., Mulisa , A., Nyakurama , R., Ochola , W. O., et al. (2009). *Rwanda State of Environment and Outlook.* Kigali: REMA.

The definition of forest in Rwanda requires a minimum crown cover of 10%, minimum tree height of 3 meters, and minimum forest area of 0.05 ha[28]. The total area of Rwanda's forest cover is 553,098 ha, representing 21.5% of the total country area.[29] This includes 8% of natural forest cover and 13% of forest plantations.[30] The forest cover of Rwanda has been shaped by the country's food and energy needs in recent years. The area of natural forests inside of national parks and forest reserves has declined since 1990, largely as a result of increased demand for agricultural land and fuel wood plantations.[31] The government has protected the remaining areas of intact natural forest and has even led efforts to increase their size through afforestation activities.

Rwanda's options

Rwanda has made a commitment to the Bonn Challenge to restore 2 million hectares of forest landscape by 2020. Rwanda will likely finance its restoration activities through several channels, and one of the options is carbon financing. Thus, the approach described under national/subnational REDD+ is applicable to estimate the increase in terrestrial carbon stocks and capitalize on the FLR efforts that it seeks to achieve by 2020. If Rwanda wishes to encourage and facilitate private investors to assist in meeting its domestic targets and commitment to the Bonn Challenge, the guidance described in the Project level section applies.

Technical considerations for Rwanda

Rwanda's current forest definition has a threshold for area that is quite small (0.05 ha). On one hand, this offers Rwanda the possibility of more forest gain by including very small tracts of forest and allows inclusion of a wide range of activities, including small tree plantings around homes for example. However, the threshold for minimum forest area is challenging from a technical perspective, especially when considering continuous monitoring using remote sensing products, because freely available satellite imagery have coarser spatial resolution than Rwanda's minimum forest area threshold, and therefore will not capture areas of tree planting smaller the 0.09 ha (Landsat's spatial resolution). Only high resolution remote sensing products have spatial resolutions that are able to detect areas as small as 0.05 ha (RapidEye or finer spatial resolution imagery – see Table 4 in Annex 1). Thus, Rwanda has three approaches available for accounting GHG removals as a result of FLR activities:

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[28] http://cdm.unfccc.int/DNA/bak/ARDNA.html?CID=180

[29] MINERENA (2010). *National Forest Policy; 2010*. Ministry of Environment and Natural Resources. Kigali.

[30] MINERENA (2010). *National Forest Policy; 2010*. Ministry of Environment and Natural Resources. Kigali

[31] Food and Agricultural Organization of the United Nations. (2006). *Global Forest Resources Assessment 2005* . Food and Agricultural Organization of the United Nations. Rome: Food and Agricultural Organization of the United Nations.

1. Ground-based surveying: This option can have low monitoring costs incurred, especially if community monitoring is implemented successfully. But for forest reference level development, unless Rwanda has historical data on FLR that occurred within the country over the past 10 years or so, ground-based survey alone precludes Rwanda from estimating business as usual rates of forest reference level, and thus developing a forest reference level; which in turns precludes the country from seeking carbon financing.

2. Remote sensing monitoring: Two considerations are important if opting to use remote sensing products for developing its National forest reference level. The decision should be based on a cost-benefit assessment of the inclusion of small areas of FLR (areas between 0.05 and 0.09), balancing costs of utilizing high-resolution imagery and benefits from accounting such areas.
   i. Freely available remote sensing products: This options entails a conscious decision to forego the accounting of FLR initiatives that are smaller than 0.09 ha in the development of the National forest reference level, and during subsequent monitoring – monitoring must be consistent with forest reference level.
   ii. High resolution remote sensing products: This option entails a conscious decision of acquiring and processing high resolution imagery. Considerations to costs of acquisition and processing of imagery, and existing technical capacity and infrastructure to manage this technology are strongly recommended to Rwanda

Beyond the remote sensing points above, it is also important to mention that the spatial resolution of the remote sensing product is not necessarily the same as the minimum mapping unit (MMU) of a map. In other words, features on the ground may not be accurately mapped using the spatial resolution of the remote sensing imagery and therefore the MMU needs to be at a coarser resolution than actual imagery (Figure 8). An example is the Nduwamungu et al. (2008)[32] forest cover map that uses high resolution orthoimagery (6.25×10^{-6} ha), but employs a MMU of 0.25 ha, which means that even with the use of orthoimagery, minimum forest area detected is still larger than the area threshold in the national forest definition; and in fact coarser than the spatial resolution of Landsat imagery (0.09 ha).

[32] Nduwamungu Jean N., Nyandwi Elias, Mazimpaka Jean Damascene, Mugiraneza Theodomir, Mukashema Adrie, Uwayezu Ernest, Rwanyiziri Gaspard and Nzabanita Vital. Rwanda forest cover mapping using high resolution aerial photographs.

Figure 8 demonstrates the difference between spatial resolution and MMU. In this image, we will consider the spatial resolution to be the size of one of the smaller four cells. The forest patch is actually not any larger than one of the cells, but it is split between four cells, meaning it doesn't make up a majority of any of the cells and therefore might not be captured at all. Therefore, the MMU would not be the same as the spatial resolution, but instead would be the size of the larger orange cell, or the area of the four smaller cells combined.

Figure 8: Demonstrating the difference between spatial resolution and MMU.

Recommendations for Rwanda

The selection of ground versus remote sensing approach to develop the national forest reference level should first consider the existence of reliable historical data of forest area gains from multiple points in time, such as national statistics from MINERENA[33] and/or reported to FAO FRA[34], academic studies characterizing historic forest area gains over the entire country (or a specified subnational unit), etc. If reliable records are unlikely to be obtained, remotes sensing products are likely the best options for developing the forest reference level. In this case, we would recommend use of Landsat or similar resolution imagery for the following reasons:

- Cost of imagery acquisition: Landsat images are free
- Cost of imagery processing: High resolution imagery requires more work to process, georeference and ultimately map changes in land cover. This is especially true when compared with Landsat, which is extensively used worldwide and has many products that have already been processed and are publically available[35]. In addition to already-made

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[33] Rwanda Ministry of Environment and Natural Resources.

[34]Food and Agriculture Organization (FAO): Forest Resource Assessment (FRA): http://www.fao.org/forestry/fra/en/

[35] Some of these higher-level Landsat products can be viewed at the US Geological Survey's Landsat archive: http://landsat.usgs.gov/CDR_ECV.php

products, the ubiquity of Landsat means that many researchers have already developed algorithms that could be readily employed, lowering potential costs for new studies.

- Cost of verifying the maps: Verification of maps based on remote sensed products entail use of information at a finer scale that imagery used in the map itself. This means that map verification would require either ground-truthing or imagery at an even higher resolution than the one used to develop the map, which in turns implies increased costs in the two topics discussed presented above.
- Marginal benefits from including small FLR activities: The additional benefits generated by including very small patches of FLR (ranging between 0.05 and 0.09 ha) would likely be small and with high uncertainty, especially given these small patches can have variable management practices and end-uses (e.g. often in case small patches of fast growing tree are planted to provide fuelwood).

To continuously monitor GHG removals as a result of implementation of FLR activities, Rwanda would also need to estimate the carbon accumulation rate/growth behavior of the forest landscapes being restored. As such, the country would need a robust MRV system to accurately map the areas of FLR as well as the carbon sequestered in these areas.

For estimating the carbon sequestration potential, Rwanda should firstly identify published data and models that are representative of the country's geophysical factors (i.e. soils, geography and climate) and the FLR typology being established (i.e. FLR type and species composition). The data and models compiled should be reliable and representative, and in summary be equivalent to IPCC tier 2[36]. After compiling these data and models, Rwanda would have to validate them by collecting a limited amount of ground data and verifying that models are well aligned with primary data collected. If the simpler approach of using published data and models are not possible (i.e. no reliable published data and models representative to Rwanda's FLR exists), then Rwanda would have to collect primary data through sampling, and/or develop its own growth models.

For more direct recommendations to which approach is most suitable to Rwanda more detailed information of data availability, existing capacity, established infrastructure and political context in Rwanda are necessary. This could be achieved by direct interaction with relevant

[36] IPCC (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. 590 pp. Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html

Rwandan stakeholders, including government officials, through an in-country mission, or multiple conference calls.

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