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Development of Liberia's REDD+ Reference Level

Final Report for Republic of Liberia Forest Development Authority

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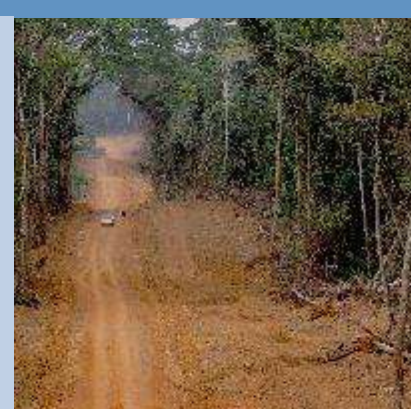

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EXECUTIVE SUMMARY

Reducing Emission from Deforestation and Forest Degradation, and enhancing forest carbon stocks (REDD+) in developing countries is a valuable mechanism for countries that aim to mitigate the impacts of climate change by cutting carbon dioxide emissions originating from the destruction of forests. In Liberia, REDD+ is viewed as an opportunity and a viable source of sustainable finance for investment in forest management, forest conservation, and forest restoration. Additionally, Liberia recognizes the multiple benefits REDD+ may offer, including but not limited to biodiversity conservation, watershed management, enhanced resilient capacity and poverty reduction. The performance based climate financing REDD+ may provide Liberia with is seen as a viable opportunity that will enable Liberia to financially benefit from its forests without degrading them.

Vast tropical forests cover nearly half of Liberia's land mass, which are essential to the livelihoods of Liberia's peoples as well as the health of its ecosystems. While Liberia's forests have historically been subject to exploitation, it has had relatively low deforestation rates compared to many of its neighbors. In fact, according to some estimates, the country contains over half of West Africa's remaining rainforests[1]. Nevertheless, given the fact that over half of Liberia's forest land has been allocated either as commercial concessions or is designated for conservation as protected areas, the potential for significant land use change and associated emissions in Liberia should be considered high. To date, most of the concession areas have yet to be developed and protected areas are not yet well established, leaving the future of Liberia's forests unknown.

The Government of Liberia has already made strides in forest governance as well as in other particular requisites for REDD+. Advancements include the creation and mobilization of necessary institutions and frameworks with the mandate of supporting the development of REDD+ in the country, including the National Climate Change Steering Committee (NCCSC), REDD+ Technical Working Group (RTWG) and REDD+ Implementation Unit (RIU). Additionally, the Government has enacted laws and policies to advance REDD+ strategy and submitted a Readiness Preparation Proposal (R-PP) to the Forest Carbon Partnership Facility (FCPF), approved in March 2012. Liberia's Voluntary Partnership Agreement (VPA) for Forest Law Enforcement, Governance, and Trade with the European Union further supports transparent and sustainable forest management. In addition, the partnership between the Governments of Liberia and Norway announced in September 2014 further provides the financial and technical foundation for successful implementation of REDD+ in Liberia. Liberia has also received assistance from the World Bank's

[1] http://www.euflegt.efi.int/liberia

Forest Carbon Partnership Facility (FCPF) to develop and apply strategies to reduce emissions from deforestation and forest degradation.

This report describes a recommended REDD+ Reference Emission Level for Liberia. Sections 1-5 represent information directly related to REL development needed for submission of a proposed REDD+ Reference Level to the UNFCCC or the FCPF. Section 6 provides recommendations for next steps and improvements.

International Guidance on RL Development

There are two main sources of guidance on the development of a REDD+ Reference Level: the United Nations Framework Convention on Climate Change (UNFCCC) and the World Bank Carbon Fund's Methodological Framework. The UNFCCC provides general recommendations for the development of an internationally acceptable Reference Level, while the Carbon Fund's Methodological Framework provides more explicit requirements for receiving funding under the Carbon Fund. Both refer to accounting methods described by the Intergovernmental Panel on Climate Change (IPCC).

UNFCCC Conference of Parties (COP) decisions contain modalities that guide the development of forest reference levels, particularly decision 12/CP.17 and its Annex. According to these modalities, Parties must be transparent in establishing RLs, taking into account historical data and, if appropriate, adjusting for national circumstances[2]. While forest RLs can be developed sub-nationally as an interim measure while transitioning to a national scale, Liberia has chosen to develop its RL at a national scale. A step-wise approach may be used, allowing Parties to improve the forest RL by incorporating better data, methodologies and additional pools, if appropriate. Forest RLs are expressed in units of tons of CO_2 equivalent per year and must maintain consistency with a country's greenhouse gas inventory (according to 12/CP.17, Paragraph 8). In response to the guidelines for submissions of information on RLs provided in decision 12/CP.17, a summary of Liberia's decisions on these modalities is given in Table ES-1.

Table ES-1. UNFCCC modalities relevant for Liberia's national Reference Level

Reference to Guideline	Description	Liberia's Proposal
Decision 12/CP.17 Paragraph 10	Allows for a step-wise approach	• REL is at national scale, and includes all drivers of deforestation • Degradation will be added as a stepwise improvement, as additional data become available.

[2] Decision 4/CP.15, paragraph 7.

Decision 12/CP.17 Annex, paragraph (c)	Pools and gases included	• Pools: (activity specific) - Aboveground and belowground biomass - Dead wood - Litter - Soil carbon • Gases: - Include CO_2
Decision 12/CP.17 Annex, paragraph (c)	Activities included	• Include deforestation caused by agriculture, mining, forestry infrastructure, and other infrastructure • Other activities will be included in step-wise improvements of the REL
Decision 12/CP.17 Annex, paragraph (d)	Definition of forest used is same as that used in national GHG inventory	• Minimum tree cover: 30% • Minimum height: 5 m • Minimum area: 1 ha
Decision 12/CP.17 Annex	The information should be guided by the most recent IPCC guidance and guidelines,	• All data are gathered using best practices and integrated to estimate emissions using IPCC 2003 and 2006 guidelines[3] • Where country specific data are not available, they will be developed
Decision 12/CP.17 II. Paragraph 9	To submit information and rationale on the development of forest RLs/RELs, including details of national circumstances and on how the national circumstances were considered	• Liberia proposes an upward adjustment to its reference level, as due to national circumstances, historical emissions likely do not accurately reflect future emissions. However, additional data are needed to identify a justifiable number for adjustment.

In addition to the decisions described in Table ES-1, it is necessary to establish a Reference Period, the period from which data on past changes in forest area are established, analyzed, and projected into the future. This is used to determine the average annual level of emissions against which future years are

[3] The two IPCC reports used are the IPCC 2003 Good Practice Guidance for the LULUCF sector (IPCC 2003 GPG) and the IPCC 2006 Guidelines for National GHG Inventories, Volume 4 AFOLU (IPCC 2006 AFOLU)

compared. There are a number of factors that must be considered in determining an appropriate reference period, though it is dictated in part by available data. In the case of Liberia, there are reliable data available on forest loss from 2000 through 2014.

Liberia's national circumstances have significantly influenced historical deforestation rates, including a decade of civil war ending in 2003, timber sanctions enacted between 2003 and 2006, economic decline through 2005, and the Ebola outbreak in 2014. These events have heavily influenced historical rates of deforestation, and as the country's economy begins to improve, land use and land cover change patterns will likely shift. As such, based on the recent history of Liberia, a reference period of 2005-2014 is recommended.

Estimating land cover change

Land cover change was estimated using three main sets of spatial data – the 2014 Land Cover Map produced by Metria/Geoville (2016), a 2000 Percent Forest Canopy Cover map (Hansen et al 2013), and a Forest Loss product for 2000-2014 (Hansen et al 2013). The 2014 Liberia Land Cover Map developed by Metria and Geoville (2106) is a high resolution (10m) map based on RapidEye and Landsat 8 data. This map serves as the best and most recent forest classification for Liberia, and will therefore be used as the minimum level of stratification of forest cover in the Reference Level.

In 2013, Hansen et al published a set of global spatial products that span 2000 to 2013. This includes a global 30-meter resolution '2000 Percent Forest Canopy Cover' map and a 30-meter resolution 'Annual Forest Loss' product produced annually from 2000 onwards. The Hansen et al (2013) '2000 Percent Forest Canopy Cover' precisely matches the 'Annual Forest Loss' product produced from 2000 onwards (Hansen et al 2013), which can be used to create a series of land cover change products and thus create annual deforestation activity data. The Annual Forest Loss product analyzes all available Landsat imagery and combines training data from across the planet to estimate forest loss from (currently) 2000 to 2014 (Hansen et al 2013).

These data have been freely released by the University of Maryland[4] and will be annually updated. The datasets have been widely publicized through Global Forest Watch[5] and the use of such datasets is recommended in the Global Forest Observations Initiative's Methods and Guidance Document "Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests"[6] (referred to as 'MGD'). GFOI MGD explicitly encourages the use of this

[4] http://www.earthenginepartners.appspot.com/science-2013-global-forest
[5] http://www.globalforestwatch.org/
[6] http://www.gfoi.org/methods-guidance/

dataset and now has a module advising on how this dataset can be used in the development of country-level reference levels[7]. However, the MGD and various research indicates that the Hansen et al (2013) can have significant local biases in its canopy cover estimates, and thus need local correction before being used for Liberia.

Based on this evaluation, it was concluded that the Hansen et al dataset provides the highest resolution data available to identify forest loss on an annual basis. As recommended by the GFOI MGD, the data was first processed to create a 'Liberia-Corrected 2000 Percent Canopy Cover' map, stratified by forest class (30-80% Canopy Cover; >80% Canopy Cover), using a combination of information from the Metria/Geoville map and the published Hansen et al (2013). This dataset was used to produce annual forest strata maps and annual deforestation estimates for the reference period, 2005-2014 (Table ES-2). These were based on the Hansen 2000 canopy cover map, corrected for Liberia using the 2014 Metria Geoville classifications, with annual forest loss calculated from that date onwards.

In general, deforestation appears to follow two patterns: large clearings associated with the creation of plantations, visible as five clusters each 20-50 km from the coast stretching down the whole coastline, and a network of tiny clearings located broadly throughout the country, though focused around roads and settlements. The small clearings are likely associated with agriculture and logging, and are relatively evenly spread throughout the time period, whereas the plantation clearings seem to be focused from 2011 onwards.

[7] http://www.gfoi.org/wp-content/uploads/2015/03/MGDModule2_Use-of-Global-Data-Sets.pdf

Table ES-2. Annual rate of forest loss over reference period 2005-2014, by forest cover class

Year deforested	Forest >80%	Forest 30-80%	Combined forest loss
	percent loss		
2005	0.06%	0.20%	0.08%
2006	0.19%	0.73%	0.26%
2007	0.26%	0.93%	0.35%
2008	0.20%	0.82%	0.28%
2009	0.50%	1.71%	0.67%
2010	0.16%	0.42%	0.19%
2011	0.24%	0.70%	0.30%
2012	0.48%	1.34%	0.60%
2013	0.85%	2.48%	1.07%
2014	0.71%	1.92%	0.87%
Average annual loss	0.36%	1.07%	0.46%

Activity data were developed to reflect the magnitude of conversion from each forest class to six post-deforestation land uses: shifting cultivation, oil palm plantations, rubber plantations, non-forest mixed vegetation, mining, and settlements.

Options for additional stratification of Liberia's forests were also examined, indicating that it would be useful for stratification based on concession areas, as these areas experience a higher rate of deforestation than the rest of the country. It would also be beneficial to stratify by road access, as most deforestation occurred within 2 kilometers of roads, and focusing sampling efforts in these areas would increase efficiency.

While the current focus of the REL is on deforestation, emissions from forest degradation are likely to make a substantial contribution to land use emissions in Liberia, and so two possible methods for estimating degradation were examined. Due to a lack of suitable data for either method, the results from the two varied widely, indicating a need for more reliable data, and a future step-wise addition of degradation in the REL, as such data become available.

Emission Factors

Various sources of data may be used to estimate forest biomass and develop emission factors, including carbon measurement inventories, forest inventories, research studies, and global default values. Currently there are limited data available for Liberia, and emission factors were developed using existing global datasets. Three available pantropical maps of aboveground biomass were assessed for appropriateness in producing carbon stocks for each of Liberia's forest cover classes identified in the Metria/GeoVille map: Avitabile et al. (2015), Saatchi et al. (2011), and Baccini et al. (2012). The carbon stocks for aboveground biomass from Avitabile et al. (2015) match most closely with existing data from Liberia and neighboring countries, and the differences between forest classes are most realistic. However, for this Reference Level, we have used carbon stocks from Baccini et al (2012) to develop provisional emission factors, because they provide more conservative estimates and will result in a lower reference level. Additional, smaller carbon pools – belowground biomass, leaf litter, and deadwood – are included using default IPCC values.

Post-deforestation biomass carbon stocks have been estimated based on land-use, but these should be improved where possible, to be based on country-specific data. Soil carbon stocks were sourced from the Harmonized World Soil Database, with the amount of soil carbon emitted as CO_2e estimated as a function of land-use practices that follow forest loss, according to IPCC guidelines. Provisional deforestation emission factors are shown in Table ES-3.

Table ES-3. Deforestation emission factors by forest class and post-deforestation land use, using forest carbon stock data from Baccini et al (2012)

Stratum	EF (t CO_2e ha^{-1})					
	Shifting cultivation	Oil palm plantation	Rubber plantation	Non-forest mixed vegetation	Mining	Settlement
Forest > 80% Canopy Cover	356.9	390.4	225.4	528.8	553.7	500.4
Forest 30-80% Canopy Cover	303.2	446.3	171.3	472.9	497.5	446.3

Historical Emissions

Historical emissions were estimated as the product of activity data and emission factors (Table ES-4).

Table ES-4. Historical emission estimates for Reference Period, by forest class and post-deforestation land use, based on emission factors from Baccini et al dataset.

Sum of All Forests							
	Shifting Cultivation	Oil palm Plantations	Rubber Plantations	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Emissions (t CO_2e)						
2005	853,775	324,969	17,344	816,644	212,855	2,535	2,228,122
2006	2,715,457	1,048,722	55,763	2,613,782	680,629	8,019	7,122,372
2007	3,634,450	1,393,931	74,250	3,487,838	908,643	10,762	9,509,874
2008	2,871,385	1,115,441	59,221	2,770,917	721,273	8,461	7,546,699
2009	6,895,987	2,630,404	140,312	6,602,159	1,720,588	20,462	18,009,913
2010	1,978,554	739,695	39,664	1,877,985	490,057	5,915	5,131,871
2011	3,096,437	1,165,064	62,369	2,947,113	768,726	9,235	8,048,944
2012	6,158,690	2,307,277	123,655	5,850,861	1,526,567	18,397	15,985,448
2013	10,950,159	4,114,790	220,350	10,416,335	2,717,229	32,674	28,451,538
2014	8,856,326	3,304,035	177,270	8,398,617	2,191,904	26,497	22,954,649

Recommended Reference Level

The average historical emissions over the reference period 2005-2014 are 12,498,943 t CO_2e/year based on Baccini et al (2015) data and estimates of land use change. This represents a Reference Emission Level, without adjustments for national circumstances.

The World Bank Carbon Fund allows the Reference Level to be based on an adjustment of the average annual historical emissions over the Reference Period, not to exceed 0.1% of carbon stocks, if a country can demonstrate that historical emissions from land use change do not adequately represent anticipated increases in future emissions. In order to use an adjusted Reference Level, it is necessary to develop a defensible number that can be used to adjust the historical average emissions. This requires additional information on planned or expected development in the country. An initial justification is based on the draft Land Use Analysis report (LTS, 2016) and indicates that expected land use change without REDD activities would result in emissions exceeding the 0.1% cap. Therefore, an initial adjusted Reference

Emission Level could be proposed at 15,343576 t CO_2e/yr. It is important to note, however, that it is not known whether the FCPF would allow Liberia to use an adjusted Reference Level.

Uncertainties

The FCPF Carbon Fund Methodological Framework Section 3.2 requires that sources of uncertainty in Reference Level setting are systematically identified and assessed; and further managed/reduced to a feasible extent. This applies to all potential sources of uncertainties in both Activity Data and Emission Factors. A lack of ground data and local layers led to the use of global/pantropical and IPCC Default values for various components of the Activity Data and Emission Factor calculations: this not only increases uncertainty, but also reduces our ability to estimate these uncertainties. We consistently chose data and approaches that reduced uncertainties and potential biases as much as possible, but nonetheless systematic as well as random errors will inevitably remain, and their degree will be hard to estimate.

We conducted a field campaign in order to estimate the accuracy of the 2014 landcover map and give 95% confidence intervals for the forest cover strata for 2014, following the Olofsson et al. (2013)[8] method as recommended by the GFOI MGD[6]. Unfortunately, it was not possible to set up the number of plots advised by this method, nor place these in a stratified random manner across the country, and thus the 95% confidence intervals themselves have high uncertainty. Further, no suitable ground data on past landcover or the location of deforestation/degradation were available, despite extensive discussions with stakeholders in country and searches of the published and grey literature. This meant that while we could produce confidence intervals for the 2014 strata, it was not possible to backdate these through time using national data.

We did provide an estimate of the 95% confidence intervals for the deforestation data, and thus the minimum and maximum ranges of strata, using the generic tropical validation data provided by Hansen et al. (2013). These data are not specific to Liberia, and not stratified by forest type, and thus only provide an indication of the potential errors caused by a combination of errors of commission (where change is recorded when in fact no change occurred), and errors of omission (where a change is missed).

Uncertainty estimates for Emissions Factors are impossible to estimate without any ground data, and thus error estimates for this side of the RL/REL calculations will require ground plots to be set up, ideally as part of a full National Forest Inventory.

[8] Olofsson, P., Foody, G.M., Stehman, S.V., & Woodcock, C.E. (2013). Making better use of accuracy data in land change studies: estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment* 129:122-131

Next Steps

The Reference Emission Level described in this report was developed following relevant guidance so that it could be submitted to the UNFCCC and/or the FCPF as a proposed REL. However, there are a number of items that should be addressed to improve the REL in a stepwise fashion:

- A full ground-truthing effort should be conducted for the land cover and land cover change maps
- Areas of active plantations must be identified and likely stratified out of the country's forests
- A forest inventory or forest carbon sampling plan should be developed and implemented, so that country-specific emissions factors can be established.
- A Monitoring, Reporting, and Verification System should be developed, consistent with the methods used to develop the REL.
- In the longer term, a reliable approach for estimating degradation should be chosen, and data should be collected to implement such an approach.

1. INTRODUCTION

Reducing Emission from Deforestation and Forest Degradation, and enhancing forest carbon stocks (REDD+) in developing countries is a valuable mechanism for countries that aim to mitigate the impacts of climate change by cutting carbon dioxide emissions originating from the destruction of forests. In Liberia, REDD+ is viewed as a potential opportunity and a viable source of sustainable finance for investment in forest management, forest conservation, and forest restoration to enhance multiple benefits of REDD+, including but not limited to biodiversity conservation, watershed management, enhanced resilient capacity and poverty reduction[9].

Liberia hosts a large percentage of the remaining forests within the Upper Guinean Forest Ecosystem that stretches from Guinea to Togo. It covers an area of 111,369 square kilometres (43,000 sq. mi) and is home to 4,503,000 people. Liberia possesses about forty percent of the remaining Upper Guinean rainforest. The landscape is characterized by mostly flat to rolling plains with a thin strip of mangroves and swamps along the coast and the plains rise to a rolling plateau and low mountains in the northeast. Liberia experiences a conventional rainfall pattern and is kept wet for the most part of the year. The heaviest rainfall occurs in June while the lightest rainfall is in December, with relative humidity between 90- 100% during the rainy season and 60- 90% for the dry season. The geographical location of Liberia from the equator makes the sun over head at noon throughout the year. The average temperature ranges between 28° C to 32°C in November and June respectfully.

Currently, around 85% of Liberians live below the international poverty line[10] as they continue to recover, economically and socially, from a decade of civil war that ended in 2003 and most recently from an Ebola outbreak that took the lives of over 11,000 people. With a large percentage of the country forested, the forestry sector has the potential to assist in the development of the country.

Deforestation and degradation drivers in Liberia include selective logging; pit-sawing; mining activities; fuel wood and charcoal collection; the spread of shifting cultivation; permanent agriculture; and anticipated increases in rubber and palm oil plantations[11]. Performance based climate financing may provide Liberia with an alternative land use opportunity that will enable Liberia to financially benefit from its forests without degrading them.

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[9] FCPF Readiness Assessment (2014): Mid-Term Report for Liberia. https://www.forestcarbonpartnership.org/liberia

[10] Republic of Liberia Ministry of Internal Affairs. 2015. Overview of Liberia. Available at http://www.mia.gov.lr/2content.php?sub=210&related=40&third=210&pg=sp

[11] R-PP Country Submission for Liberia – 2012 http://www.forestcarbonpartnership.org/sites/fcp/files/2014/MArch/March/Liberia%20grant%20agreement.pdf

The Government of Liberia has already made strides in forest governance, in general, as well as particular requisites for REDD+. Advancements include the creation and mobilization of necessary institutions and frameworks with the mandate of supporting the development of REDD+ in the country, including the National Climate Change Steering Committee (NCCSC), REDD+ Technical Working Group (RTWG) and REDD+ Implementation Unit (RIU). Additionally, the Government has enacted laws and policies to advance REDD+ strategy and submitted a Readiness Preparation Proposal (R-PP) to the Forest Carbon Partnership Facility (FCPF), which was approved in March 2012. Liberia's Voluntary Partnership Agreement (VPA) for Forest Law Enforcement, Governance, and Trade with the European Union further supports transparent and sustainable forest management. The historic partnership between the Governments of Liberia and Norway announced in September 2014 further provides the financial and technical foundation for successful implementation of REDD+ in Liberia. Liberia has also received assistance from the World Bank's Forest Carbon Partnership Facility (FCPF) to develop and apply strategies to reduce emissions from deforestation and forest degradation.

Since the Readiness Preparation Proposal (R-PP) was signed in 2012, the RIU have partnered with several organizations to complete components of the Readiness Package. This report serves as an input into this effort through the development of a recommended REDD+ Reference Level. The report is structured with the following sections:

Section 1: Explains Reference Levels and their technical components and provides further context of REDD+ activities in Liberia.

Section 2: Provides an overview of the basic decisions required for the establishment of a reference level, and identifies the most appropriate options for Liberia.

Section 3: Details the methods used to develop Liberia's activity data, the extent of change in forests, for deforestation.

Section 4: Details the methods used to estimate carbon stocks and develop emission factors for Liberia.

Section 5: Combines activity data and emission factors to provide an estimate of historical emissions and describes the projection of these historical emissions into the future to develop a REDD+ Reference Level.

Section 6: Identifies the next steps that should be taken to implement and improve the recommended Reference Level.

Box 1. Overview of REDD+ Reference Levels and MRV

In order for countries to receive credit for reducing net emissions under a REDD+ system, a benchmark must be in place against which total emissions and removals are evaluated. Both the benchmark and the evaluated emissions must be measured using internationally accepted methods.

The benchmark is referred to as a Reference Emission Level (REL) or Reference Level (RL). RELs represent gross emissions from deforestation and forest degradation in a given time period, while RLs represent both emissions and removals for all REDD+ activities. The REL/RL is based on historical greenhouse gas emissions and removals, projected into the future under a Business as Usual (BAU) scenario in which no actions are taken to reduce net emissions. Figure 1 provides a graphical depiction of historical emissions used to develop an average reference level, which is compared to monitored emissions, the total emissions and removals that are being evaluated against the reference level.

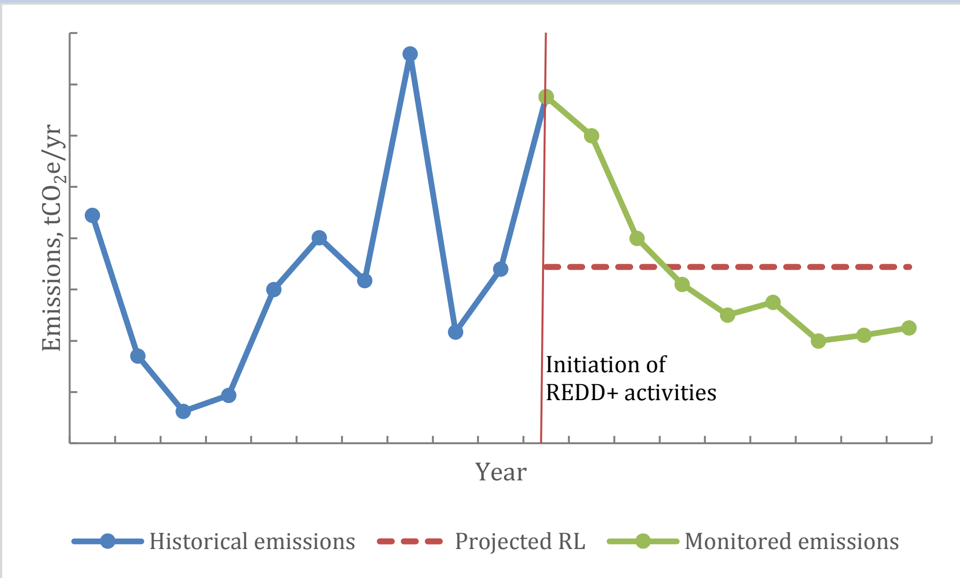

Figure 1. Hypothetical historical emissions (blue) used to develop an average reference level (red) that can be compared to future monitored emissions (green).

REL/RL under the UNFCCC

This approach of measuring (MRV) against the benchmark (REL/RL) is established at the international level. According to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) "forest reference emission levels and/or forest reference levels expressed in tons of carbon dioxide equivalent per year, are benchmarks for assessing each country's performance in implementing [REDD+] activities".

The UNFCCC, in decision 4/CP.17 "invites parties to submit information and rationale on the development of their forest reference emission levels and/or forest reference levels including details of national circumstances."

The UNFCCC calls for the development of a national reference level (RL) or reference emission level (REL) for REDD+, based on decision 4/CP.15, which states:

> *"… in establishing forest reference emission levels and forest reference levels should do so transparently taking into account historic data, and adjust for national circumstances."*

This was further elaborated in decision 4/CP.17 as follows:

> *"…modalities for the construction of forest reference levels and forest emission reference levels to be flexible so as to accommodate national circumstances and capabilities, while pursuing environmental integrity and avoiding perverse incentives."*

The development of RL/RELs can be seen as a two-step process. First is to produce estimates of historical emissions and removals. These estimates are then projected into the future, and the projections can potentially be adjusted, taking into account both national circumstances as well as national capabilities.

The creation of forest RELs/RLs is guided by modalities contained in the UNFCCC COP decisions:

- Use of historical data and adjustment for national circumstances should be transparent, complete, consistent, and accurate
- A step-wise approach is allowed to improve the forest RELs/RL by incorporating better data, improved methodology, and additional pools where appropriate
- Forest RELs/RLs are expressed in units of tons of CO_2 equivalent per year (t CO_2e yr^{-1}) and must be consistent with the country's GHG inventory

MRV

Once the RL/REL is established, it is compared against actual emissions, monitored under the Monitoring, Reporting, and Verification (MRV) system. An MRV system must be in place to evaluate the effects of REDD+ implementation in terms of emissions (green line in Figure 1) against reference levels (red dotted line in Figure 1). In other words, the net emissions under REDD+ must be estimated within an acceptable level of certainty in order to determine the difference between reference emissions and actual emissions.

Internationally accepted methods to estimate REL/RL and MRV

The IPCC (Good Practice Guidance 2003, and Guidelines for National Greenhouse Gas Inventories Agriculture, Forestry, and Other Land Uses [AFOLU] 2006) provides the framework for estimating emissions and removals of CO_2 in the AFOLU sector. The IPCC Guidelines refer to two basic inputs with which to estimate greenhouse gas emissions and removals for the REL/RL and the MRV: activity data and emissions factors.

Both historical emissions and emissions monitored under the MRV are estimated based on these inputs.

- "**Activity data**" refer to the extent of an activity over a known time period. In the case of deforestation, this is usually measured in terms of the change in areal extent of forest land, presented in hectares over a known time frame (usually per year). This activity data can be estimated separately for differing specific types of activities.
- "**Emission factors**" refer to emissions/removals of greenhouse gases per unit of the activity data. For deforestation, this would be per unit area, e.g. tonnes of carbon dioxide emitted per hectare of deforestation.

"Activity data" combined with "emission factors" estimates the total amount of emissions/removals taking place in a given year as a result of that activity. Emissions/removals resulting from land-use conversion are manifested in changes in ecosystem carbon stocks, and for consistency with the IPCC framework, we use units of carbon dioxide, specifically tonnes of carbon dioxide equivalence per hectare ($t\ CO_2e\ ha^{-1}$), to express emission factors.

Three **Approaches** (Approaches 1-3) are presented as options in the IPCC guidance documents for obtaining activity data, and three **Tiers** (Tiers 1-3) are presented as options for obtaining emission factors (Table 1). Higher Approaches and Tiers correspond to greater detail in the underlying data, whereas lower tiers rely extensively on generalized default factors. Different tiers can be used for different components of RL/REL development, however for the most significant components it is recommend that Liberia pursue a tier 2 or 3 in order to reduce uncertainty, while for less significant components a tier 1 may be suitable.

For example, above ground tree biomass is by far the most significant carbon pool in forests, therefore Liberia should seek tier 2 or 3, while litter and dead wood are not very significant carbon pools where default factors could be the best option.

Table 1. IPCC Approaches and Tiers (note that it is not necessary to use the same level for activity data and emission factors)

Level	Approach for activity data	Tier for emission factor
1	Total area for each land use category, but no information on conversions (only net changes)	IPCC default factors
2	Tracking of conversions between land-use categories	Country specific data for key categories
3	Spatially explicit tracking of land-use conversions	Detailed national inventory of carbon stocks for key categories, repeated measurements of through time or modeling

While moving from Tier 1 to Tier 3 reduces the uncertainty range of GHG estimates, it also increases the complexity and costs of measurement and monitoring. Likewise, achieving greater completeness and certainty in a measurement and monitoring system means higher costs as it is likely that more carbon pools would need to be monitored and that the monitoring would need to result in accurate and precise estimates of emissions and removals.

1.1 Liberia's Unique National Circumstances

Vast tropical forests cover nearly half of Liberia's land mass, which are essential to the livelihoods of Liberia's peoples as well as the health of its ecosystems. While Liberia's forests have historically been subject to exploitation, compared to many of its neighbors, it has had relatively low deforestation rates. In fact, according to some estimates, the country contains over half of West Africa's remaining rainforests[12]. Nevertheless, given the fact that over half of Liberia's forest land has been allocated either as commercial concessions or is designated for conservation as protected areas, the potential for significant land use change and associated emissions in Liberia should be considered high. To date, most

[12] http://www.euflegt.efi.int/liberia

of the concession areas have yet to be developed and protected areas are not yet well established, leaving the future of Liberia's forests unknown.

The country's historically low deforestation rates can in part be attributed to political instability, which slowed introduction of infrastructure and foreign investment that often accelerate land use change. Liberia's brutal civil war lasted over a decade and claimed 250,000 lives, and while the conflict was in large part financed by natural resources including timber, the war prevented large-scale development and agricultural expansion. During the country's two civil wars, the economy collapsed, with the GDP declining 90% between 1987 and 1995 (Radelet, 2007). Although the economy saw a slight rebound after the first civil war ended in 1996, it declined again during the second civil war. The second war ended in 2003, but elections were not held until 2005. At that time, Liberia's average income was one-quarter of the country's income in 1987, and one-sixth of that in 1979 (Radelet, 2007). After the 2005 elections, and the installation of the new government, there was an acceleration in the pace of economic recovery.

As part of the country's post-conflict development strategies, the Liberian government sought to develop its forestry industry by offering tax incentives and issuing large timber concessions. However, corruption and a lack of transparency resulted in unsustainable rates of timber harvesting and international scrutiny. Following a reform process where significant efforts were made to regulate the logging industry and establish a framework for sustainable forest management, a UN ban introduced to counter conflict timber was lifted in 2006. Nevertheless, legal timber exports were slow to resume and commercial viability is often challenged by the lack of roads and infrastructure to get timber to market[13].

While historical rates of deforestation in Liberia have been relatively low, recent developments may be altering this trend. Despite efforts made by national authorities to revoke illegally issued timber contracts and control illegal exploitation of timber resources, loopholes in the system have been exploited by large timber companies and enforcement of laws remains a key challenge in fostering a strong, well-regulated timber industry. Furthermore, as Liberia's post-war economy continues to stabilize, foreign investment has grown, along with and expanded agricultural concessions for palm oil, rubber, mining, and timber. In particular, there has been a significant rise in palm oil operations across the country through government leases of land memorandums of understanding between international companies and local communities[14].

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[13] USAID Liberia. 'Liberia – Environmental Threats and Opportunities'. 119/119 Assessment. 2014

[14] http://www.theguardian.com/global-development/2015/jul/23/palm-oil-golden-veroleum-liberia-land-deals-ebola-crisis

The deadly Ebola outbreak in Liberia primarily between 2013 and 2014 also likely had a significant impact on deforestation rates in Liberia. The scale of the outbreak, claiming thousands of lives across the country, brought the national economy, foreign investment, and infrastructure initiatives to a standstill. The World Bank estimated that the fiscal impact to Liberia was a loss of $93 million, reducing GDP by 3.4 percent.[15] In response to this economic impact and foreseen loss of development momentum generated over the past decade, a large amount of funding is being pledged to countries hardest hit by the disease. As of April 2016, the World Bank alone mobilized $385 million for Liberia's recovery effort, which in addition to facilitating the rebuilding of the country's public health system, includes financing for economic recovery and commercial financing to enable trade, investment and employment.[16] While these investments will likely contribute to the improved livelihoods of Liberia's crisis-afflicted populations, it may ultimately result in increased rates of deforestation associated with development of the country's economic resources in years to come.

As Liberia strives to stabilize in the wake of the Ebola outbreak, current drivers of deforestation and forest degradation are likely to persist and intensify. In particular, deforestation and degradation activity is likely to increase among forest concessions and palm oil concessions. Forest concessions comprise the largest official category of land use by area in Liberia, and 29% of these areas are located in dense, carbon-rich forests (LTS International 2016)

Palm oil dominates industrial agriculture land use, and current concessions make up 5% of the total forest area. These concessions lands are overwhelmingly operated by a small set of large multinational companies (Sime Darby, Golden Veroleum (GVL), Equatorial Palm Oil (EPO), and Maryland Oil Palm Plantations (MOPP)), and according to the LTS International Forest Cover and Land Use Analysis Draft Report (2016), this serves as the basis for the scale and location of the industry for the next century. The same report stated that the area of land cleared for oil palm plantation in the next 10-15 years is estimated to reach 250,000 ha based on current industry plans and the pace and scale of development among these concession areas is predicted to accelerate to ensure profitability of these large land acquisitions.

In addition, mining activity is likely to intensify as interests seek to exploit the country's rich mineral resources, as was also highlighted in Liberia's R-PP. Mineral exploitation licences have been granted over 4.6 million hectares of land and the extraction of iron ore in Liberia is accelerating. At least six iron ore concession agreements have been signed with a total estimated investment value of $13 billion, and the future area impacted by mining is estimated to be between 137,200 and 200,800 hectares (LTS

[15] https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/Runde_Savoy.pdf
[16] http://www.worldbank.org/en/topic/health/brief/world-bank-group-ebola-fact-sheet

International 2016). This figure accounts only for the formal mining sector, and not artisanal mining, which is common in Liberia and may have a significant cumulative impact.

All of these factors – war, the Ebola outbreak, and recent and projected economic development – indicate that the past circumstances of Liberia's economy and land use do not serve as representative indicators of its future.

Box 2. REDD+ Efforts in Liberia

Since the Readiness Preparation Proposal (R-PP) was signed in 2012, the RIU have partnered with several organizations to complete components of the Readiness Package (R-Package), including the Development of Reference Scenario for REDD+ Readiness. Below are summaries of other components of the R-package, MRV development efforts, and the existing REDD+ pilot project in Liberia.

Land cover mapping – Metria/Geoville

In February 2014, the Forestry Development Authority signed a contract JV Metria/GeoVille to conduct a comprehensive land cover and forest mapping in Liberia. The Land Cover and Forest map is based on satellite imagery from Landsat 8 and RapidEye. The integrated mapping results are now prepared for delivery to FDA in digital formats as well as printed maps. JV Metria/GeoVille has now completed the final phase of integrating the mapping results of Liberia´s Land Cover and Mapping performed under contract from the Forestry Development Authority.

Liberia-National REDD+ Strategy Consultation

In July 2014, the Forestry Development Authority signed a contract with LTS International and NIRAS to develop the National REDD+ Strategy. The objective is to develop an integrated national REDD+ strategy through a participatory and transparent consultative process with REDD+ stakeholders. The REDD+ Strategy will be prepared in conjunction with a Strategic Environmental and Social Assessment (SESA). The key output of this assignment is to provide analysis on Land Use Options, REDD+ Strategy Options and the Policy, Legal and Institutional Framework, national REDD+ strategy, REDD+ road map and action plan. A draft REDD+ strategy options report was submitted for stakeholder review, and a final draft has been submitted to the RIU.

Strategic Environmental and Social Assessment (SESA)

In May 2014, the Liberian Forestry Development Authority (FDA) signed a contract with Tetra Tech ARD assist in the preparation of a Strategic Environmental and Social Assessment (SESA) and a draft REDD+ Environmental and Social Management Framework (ESMF). The technical oversight and coordination of the SESA and ESMF is provided by the Environmental Protection Agency (EPA) of Liberia, in accordance with the environmental law, through a SESA coordinator and a stakeholder SESA working group. The SESA is to contribute to the REDD+ Readiness process in Liberia by assessing how REDD+ strategy options address environmental and social priorities associated with current patterns of land use and forest management. Gaps identified through this assessment would lead to adjustments in the REDD+ strategy options to close the gaps. Also, the SESA will provide an Environmental and Social Management Framework (ESMF) that will outline the procedures to be followed for managing potential environmental and social impacts of specific policies, actions and projects during the implementation of the REDD+ strategy that is finally selected. The SESA Inception Phase and Report were completed in September 2014, and the team is in the process of completing the remaining deliverables.

REDD+ Communication Strategy and Information Sharing

In March 2014, the Liberian Forestry Development Authority (FDA) signed with Fauna and Flora International to develop the REDD+ Communication Strategy and Information sharing to contribute to the successful implementation of the REDD+ Strategy in Liberia. The objectives of this assignment are to conduct a communication analysis for the REDD+ process in Liberia as envisaged in the R-PP, design a comprehensive and coherent REDD+ Communication strategy that will enable the RIU to accomplish the following:

a. Design a Communication and Information Sharing Strategy targeted at Key Stakeholders Groups and their constituencies
b. Prepare and produce appropriate local language and accessible media for this strategy, including best practice key messages
c. Conduct media campaign to promote REDD+ awareness at National, County and Stakeholder levels through newspaper, radio and TV
d. Raise the public profile of the National REDD+ Programme locally, nationally, regionally and with all identified audiences;
e. Ensure effective lobbying and advocacy with critical stakeholders for buy into the REDD+ dialogue and implementation;
f. Employ an effective communication approach useful for excellent expectation management.

Feedback and Grievance Redress Mechanism

In April 2016, the feedback and grievance redress mechanism contract was awarded to PARLEY Inc. to establish a Grievance Mechanism to address risks of dispute or conflict between stakeholders that may arise as a result of the Readiness preparation challenges. These may include issues relating to commitments made by the project, land, benefit sharing, community rights. The intention of the grievance redress mechanism (GRM), as part of the governance arrangements for the REDD+ Project, is to promote effective channels for citizen feedback and redress so as to improve the credibility and performance of the overall program. The products of this contract are expected to be completed June 2016.

MRV efforts and Norway-Liberia Partnership

In October 2015, the Wageningen University facilitated consultation workshop on the development of capacities for a National Forest Monitoring and Measurement, Reporting and Verification (MRV) System to support REDD+ participation of Liberia. A draft of the MRV roadmap term of references document was reviewed by stakeholders through the REDD+ Implementation Unit and REDD+ Technical Working Group, and the final version was produced on June 7, 2016. The final MRV roadmap recommends key next steps for Liberia to improve its REDD+ NFMS/MRV capacities. It is important to note that some of the recommended steps have already been taken or are currently underway.

Wonegizi REDD+ Pilot Project

The Wonegizi REDD+ Pilot project, developed by Fauna & Flora International (FFI) together with FDA and local NGO Skills & Agricultural Development Services (SADS), aims to lower greenhouse gas emissions from deforestation by reducing agricultural pressures on the Wonegizi forest (and Proposed Protected Area) in Lofa Country, northwest Liberia (approximately 37,968 ha). By introducing community management of the protected area and offering technical support and funding to increase the efficiency of land use and agricultural practices, project proponents intend to lower the use of slash-and-burn agriculture by local populations.

The project was designed for validation through the Plan Vivo Standard, along with biodiversity components compatible for validation under the Climate, Communities, and Biodiversity (CCB) Standard Gold Level certification requirements. Plan Vivo accepted the project idea note (PIN) in January 2014, and in 2015 pre-validation was undertaken by an external auditor. However, due to the size of Wonegizi, and to allow for even greater expansion at the landscape scale, the Wonegizi REDD+ Pilot project will now seek duel certification under the VCS and CCB. The project was initiated in 2012 and is expected to continue for an initial period of over 10 years, with project activities expected to reduce deforestation by an estimated 55% and forest degradation by 60%. This corresponds to total projected emission reductions of around 354,158 t CO_2-e over 10 years and 797,013 t CO_2-e over 50 years (FFI & RSS GmbH, 2014), although compliance with VCS requirements might result in somewhat lower estimates.

1.2 A Note on Available Data

Development of a REDD+ Reference Level and a functioning REDD+ program in general requires significant amounts of data on forest cover, forest use, forest inventory, infrastructure, development plans, and economics. While some data is available for Liberia, there is a lack of complete country-specific information, and in some cases there are multiple sources of data that are inconsistent with no indication of which source provides the most accurate information. This is not unusual as a country begins the process of developing a REDD+ program, however, it is critical that a system for updating, maintaining, and storing data is developed and followed, to allow Liberia to ensure accurate accounting and transparency, and to maximize the efficiency of the REDD+ program.

For this report, data were gathered from numerous sources, including FDA, LISGIS, the University of Maryland, literature searches, global datasets, and partners working on other components of the R-Package. A limited field campaign was also conducted in early 2016. Every effort was made to ensure that the most accurate and current data were used, and data sources are noted throughout the report.

2. DEFINING THE SCOPE OF THE REL/RL

2.1 International Guidance on RL Development

There are two main sources of guidance on the development of a REDD+ Reference Level, the United Nations Framework Convention on Climate Change (UNFCCC) and the World Bank Carbon Fund. The UNFCCC provides general recommendations for the development of an internationally acceptable Reference Level, while the Carbon Fund has a Methodological Framework that includes stricter requirements that must be met in order to receive funding. All of these systems refer to accounting methods described by the Intergovernmental Panel on Climate Change (IPCC).

UNFCCC Conference of Parties (COP) decisions contain modalities that guide the development of forest reference levels, particularly decision 12/CP.17 and its Annex. According to these modalities, Parties must be transparent in establishing RLs, taking into account historical data and, if appropriate, adjusting for national circumstances[17]. While forest RLs can be developed sub-nationally as an interim measure while transitioning to a national scale, Liberia has chosen to develop its RL at a national scale. A step-wise approach may be used, allowing Parties to improve the forest Reference Level (REL) by incorporating better data, improved methodologies and additional pools, if appropriate. Forest RLs are expressed in units of tons of CO_2 equivalent per year and must maintain consistency with a country's greenhouse gas inventory (according to 12/CP.17, Paragraph 8). In response to the guidelines for submissions of information on Reference Levels provided in decision 12/CP.17, a summary of Liberia's decisions on these modalities is given in Table 2. Further descriptions on each of these modalities is described in the remainder of this section.

[17] Decision 4/CP.15, paragraph 7.

Table 2. UNFCCC modalities relevant for Liberia's national Reference Level

Reference to Guideline	Description	Liberia's Proposal
Decision 12/CP.17 Paragraph 10	Allows for a step-wise approach	• REL is at national scale, and includes all drivers of deforestation • Degradation will be added as additional data become available.
Decision 12/CP.17 Annex, paragraph (c)	Pools and gases included	• Pools: (activity specific) - Aboveground and belowground biomass - Dead wood - Litter - Soil carbon • Gases: - Include CO_2
Decision 12/CP.17 Annex, paragraph (c)	Activities included	• Include deforestation caused by agriculture, mining, forestry infrastructure, and other infrastructure • Other activities will be included in step-wise improvements of the RL
Decision 12/CP.17 Annex, paragraph (d)	Definition of forest used is same as that used in national GHG inventory	• Minimum tree cover: 30% • Minimum height: 5 m • Minimum area: 1 ha
Decision 12/CP.17 Annex	The information should be guided by the most recent IPCC guidance and guidelines,	• All data are gathered using best practices and integrated to estimate emissions using IPCC 2003 and 2006 guidelines[18] • Where country specific data are not available, they will be developed
Decision 12/CP.17 II. Paragraph 9	To submit information and rationale on the development of forest RLs/RELs, including details of national circumstances and on how the national circumstances were considered	• Liberia proposes to make adjustments to allow for national circumstances because historical emissions are likely not good indicators of future emissions.

[18] The two IPCC reports used are the IPCC 2003 Good Practice Guidance for the LULUCF sector (IPCC 2003 GPG) and the IPCC 2006 Guidelines for National GHG Inventories, Volume 4 AFOLU (IPCC 2006 AFOLU)

The World Bank Forest Carbon Partnership Facility Carbon Fund was designed to provide incentives for countries to pilot implementation of REDD+ programs. To receive funding under the Carbon Fund, countries must adhere to the guidelines described in the Methodological Framework (FCPF 2013). There are five basic considerations that need to be addressed in the establishment of historical emissions to develop a REDD+ reference level that will be discussed in this section:

- Finalize a forest definition
- Determine the scope of activities
- Establish the reference period
- Determine the scale
- Identify the pools and gases to include

A summary of each of these considerations, and how they are addressed by both the UNFCCC and the Carbon Fund is provided below, along with recommended actions. The potential adjustment of historical emissions based on national circumstances is discussed in Section 5.

2.2 Forest Definition

For the purposes of REDD, forest is defined in terms of minimum thresholds for canopy cover, height and area. According to the FAO and various UNFCCC decisions, including the Marrakech Accords (UNFCCC 2001), forest is defined on a country basis, with a minimum area of land between 0.05 and 1 hectares, with minimum tree canopy cover of 10-30%, and the potential to reach a minimum height of 2-5 m at maturity in situ.

In late January 2016, FDA sponsored a workshop on Liberia's Forest Definition. The workshop was held in Lofa County, and was attended by a broad cross section of stakeholders, from the government, civil society, and international NGOs. During the 5 day workshop, the options for and implications of Liberia's forest definition were discussed. At the completion of the workshop, a final forest definition was chosen, with the following thresholds:

- Minimum area of one hectare
- Minimum canopy cover of 30 %
- Minimum height at maturity of 5 meters

It was further decided that agricultural plantations, including tree crops such as palm, rubber and cacao, would not be considered forest under Liberia's definition.

2.3 Scope

Often, forest reference levels and reference emission levels are considered one and the same. However, some consider reference levels to include both emissions and removals of greenhouse gases, while reference emission levels address only emissions. Different entities have different specifications for what must be included in a reference level.

The **United Nations Framework Convention on Climate Change**[19] encourages undertaking activities, including reducing emissions from forest degradation, as deemed appropriate and in accordance with existing capabilities and national circumstances.

The **Forest Carbon Partnership Facility (FCPF) Methodological Framework**[20] states that Emission Reduction (ER) Programs can choose which REDD+ activities and sources and sinks to include in the ER Program Reference Level. ER Programs are required to account for emissions from deforestation at a minimum, and emissions from forest degradation should be included where they are significant:

> *"Emissions from forest degradation are accounted for where such emissions are more than 10% of total forest-related emissions in the Accounting Area, during the Reference Period and during the Term of the emission reduction purchase agreement (ERPA). These emissions are estimated using the best available data (including proxy activities or data)"*

In general, deforestation must always be addressed in a REDD+ system, and forest degradation activities should be included when at least one of the following conditions exist:

- A specific forest degradation activity results in significant emissions,
- Capacity and resources exist to reliably measure and monitor those emissions cost-effectively,
- There is potential that interventions could reduce such emissions.

While it is possible to obtain a reasonable initial estimate of deforestation from global datasets, it is much more difficult to achieve an accurate picture of degradation. In assessing data currently available for Liberia, it is clear that accurate data relevant to degradation are very limited, at a country, regional, or even global level. This makes it very difficult to estimate emissions from degradation with any certainty; data that are available provide estimates of degradation ranging from 8% to nearly 50% of total emissions

[19] UNFCCC 1/CP.16 Paragraph 70: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf
[20] FCPF Carbon Fund Methodological Framework, December 20, 2013, Criterion 3: https://www.forestcarbonpartnership.org/carbon-fund-methodological-framework

from land use and land use change, depending on the methods used[21]. In order to improve these estimates, it is necessary for Liberia to undertake substantial effort to acquire appropriate data.

Because it is not possible with the current data available to develop reliable estimates of emissions from degradation, it is recommended that Liberia focus at present on assessing emissions from deforestation. As capacity increases over time, emissions from degrading activities, as well as removals from enhancements, can be incorporated in a step-wise approach. **We therefore recommend that Liberia use a Reference Emission Level at present, focusing only on emissions. Moving forward, the country should work towards including removals and developing a Reference Level.** Annex 1 provides additional detail on estimates of emissions from degradation and recommendations for improving these estimates in the future, so that degradation can be included in the Reference Level and the REDD+ program.

2.4 Reference Period

The historical reference period is the period from which data on past changes in forest area are established, analyzed, and projected into the future. It is used to determine the average annual level of emissions against which future years are compared. There are a number of factors that must be considered in determining an appropriate reference period. This period, therefore, is dictated in part by available data. In the case of Liberia, there are reliable data available on forest loss from 2000 through 2014. The Carbon Fund Methodological Framework (Revised Final, June 22, 2016) states that the end year of the reference period should be "the most recent date prior to two years before the TAP starts the independent assessment of the draft ER Program Document and for which forest cover data is available to enable IPCC Approach 3 (Indicator 11.1). Additionally, the start date for the reference period must be about 10 years before the end date, unless an exception is requested and granted, in which case it cannot be more than 15 years before the end date (Indicator 11.2).

Given Liberia's unique circumstances (described in detail in section 1.1), with the second civil war ending in 2003, timber sanctions enacted between 2003 and 2006, and economic decline through 2005, land use and land cover change have increased in recent years, as the country's economy begins to improve. In fact, the average annual rate of forest loss between 2002 and 2006 is 0.19%, while the average annual rate between 2009 and 2013 is 0.61%. The development of annual land cover maps created within this project found a spike of deforestation in 2013. This is likely due to an increase in land use activities, but also may be due to the fact that in 2013, a new Landsat satellite was launched, Landsat 8, which has improved image quality and observation frequency relative to its predecessors. This satellite therefore likely improved detection of deforestation that occurred at some point in the recent past, especially given

[21] Additional information provided in Annex 1.

considerably less Landsat data were collected in 2012 than in previous years following the failure of one of the two satellites collecting data in tandem since 2000, Landsat 5, in November 2011.

Section 3.1 presents the annual deforestation and resulting deforestation rate, and based on this analysis and the recent history of Liberia, **a reference period of 2005-2014 is recommended**. This period is in line with the revised FCPF Methodological Framework.

It should be noted that UNFCCC guidance on reference period is far less prescriptive than the FCPF, and allows for more flexibility.

2.5 Scale

To ensure consistency and a unified approach from the inception of the REDD program, **Liberia's Reference Emission Level has been developed at the national scale**. Such an REL can be applied at the district level as needed. The advantage of a national approach is that the integration of separate subnational RELs and MRV systems is not necessary. Therefore, the process of developing an REL is simplified and can happen more quickly than if common standards and agreements had to be developed for subnational jurisdictions to use. However, there are existing efforts towards REDD, notably the Wonegizi Community REDD+ Pilot, which is currently in its fourth year. To allow for appropriate accounting of emission reductions as well as equitable benefit distribution, it is recommended that Liberia adopt a nested approach for REDD+ implementation, ensuring that the efforts of existing and future projects are encouraged by the national REDD+ program.

There are varied ways that nesting can be undertaken, and a number of issues that must be considered to guarantee that there is alignment between project and national accounting. Primary among these are the activities included and the methods used for establishing reference levels/baseline and monitoring performance. If there are incongruities between project and national systems or accounting, it is necessary to take steps to rectify the incongruities. As the existing project at Wonegizi undergoes final verification, it will be necessary to assess how it relates to the national reference level and REDD+ program and work to align the two. Guidance on implementing nested approaches to REDD and addressing technical considerations of nesting are available through the USAID LEAF Planning Guide – Integrating REDD+ Accounting within a Nested Approach[22] and the VCS Guidance Document: Options for Nesting REDD+ Projects[23].

[22] Available at http://www.leafasia.org/library/planning-guide-integrating-redd-accounting-within-nested-approach.
[23] Available at http://www.v-c-s.org/wp-content/uploads/2016/07/Nesting-Options-1-Jul_Eng_final.pdf.

2.6 Pools and gases

The most significant carbon pool in forests is typically aboveground live tree biomass, and this should be included in all accounting for Liberia's REL and MRV. In addition, belowground live tree biomass can easily be estimated using a root to shoot ratio. Dead wood and litter usually contribute a much less significant percentage of total forest carbon, and often require a significant investment of resources to measure with accuracy. However, it is easy to estimate the extent of these pools using IPCC default values, and this should be done until and unless it is determined that these pools are significant enough that they warrant actual measurements. Change in soil organic carbon can be estimated and included based on IPCC methods. The following are the included pools for Liberia's deforestation REL:

- Aboveground live tree biomass (using available datasets, and inventory data when available)
- Belowground live tree biomass (based on root:shoot ratio)
- Dead Wood (IPCC default ratio)
- Litter (IPCC default ratio)
- Change in Soil Organic Carbon (based on soil carbon from World Harmonized Soil Databased and IPCC default factors for change)

When degradation is added to Liberia's Reference Level, harvested wood products should likely be included, especially in the case of degradation from timber harvesting.

The primary gas that is emitted from land use change is carbon dioxide, and this is the only GHG included in the RL.

3. ACTIVITY DATA

As described in Box 1 above, the estimation of emissions will be based on a combination of activity and emission factors for the various activities. In addition, Section 2.3 describes the recommendation that Liberia focus its reference level development on Deforestation with a Reference Emissions Level. Therefore, historical Activity Data for deforestation have been calculated for the recommended Reference Period. This information is then used to estimates historical average rates of deforestation over the Reference Period. For degradation, at this point the lack of existing information prevents a detailed or accurate estimate of degradation activity data to be completed. Therefore, instead, two approaches for creating an initial estimate of degradation are presented in Annex 1, to better understand the potential magnitude of degradation emissions, especially in comparison to deforestation emissions.

To estimate land use and forest cover change from deforestation, existing spatial data sets were first compiled and evaluated for their applicability, completeness, and accuracy. Based on the assessment, the most applicable spatial data were used to create land cover change products for 2000-2014. These maps were used to create annual estimates of the area of change for different land cover classes over this time period along with the average annual land cover change for the recommended Reference Period 2005-2014. The implications of various stratification options were also examined. The detailed methods to create these products are presented here along with associated Appendices.

3.1 Evaluation of existing spatial datasets

To evaluate deforestation, the existing data sets were examined and assessed for applicability in estimating current and historical land cover (Appendix A). Based on this analysis, it was determined that the recently produced 2014 Land Cover map for Liberia (Metria/GeoVille 2016) would be used as the basis for nonforest and forest stratification. An approach was then developed and applied to estimate historical deforestation rates for each of the forest strata defined by the 2014 land cover map and the 2000-2014 forest loss product developed by Hansen et al (2013). This approach is described in detail below.

2014/15 forest stratification dataset

The high resolution (10m) land cover map for the whole of Liberia for 2014 that has been developed based on RapidEye and Landsat 8 data splits the landscape into 10 different land cover classes (Metria/GeoVille 2016):

- Tree cover >80 %
- Tree cover 30-80 %
- Tree cover <30 %
- Mangrove and swamp
- Settlements (urban and rural)
- Surface water bodies
- Grassland
- Shrub
- Bare soil
- Ecosystem Complex (rock and sand)

According to the recently adopted forest definition, two of these classes are considered forest in Liberia: tree cover >80% and tree cover 30-80%. This map serves as the best and most recent forest classification for Liberia, and will therefore be used as the minimum level of stratification of forest cover in the Reference Level. The Metria/GeoVille product uses a minimum mapping unit of 0.5 hectares; however, the minimum area in the recently adopted forest definition is 1 hectare. Therefore, for the purposes of estimating area of forest loss, all forest areas less than one hectare were excluded from the analysis of deforestation. Pixels in these <1ha forest patches were reclassified in the 'tree cover <30 % canopy cover' class. Removing patches of pixels with >30% canopy cover but covering less than 1 ha reduced the total estimated area of forest in Liberia in by only 0.75 % compared to the original Metria/Geoville map (see Table 3 below). Using these criteria, the total forest area then can be calculated to comprise 68% of Liberia's land cover.

Table 3. Area of each forest class in 2014/15 with a 0.5 ha and 1 ha minimum forest area size. (Note that at the same time as this analysis was performed, the data were transformed from the 10m UTM projection of the M/G map to a 0.00025 degree (~30m resolution) latitude/longitude projection to match the Hansen et al. (2013) layers used later. This results in the slight difference in the total area. All area calculations are however performed in a UTM projection throughout.)

Forest class	Original 2014/15 Metria/Geoville Map with 0.5 ha minimum forest threshold and 10 m pixels size (ha)	Processed Metria/Geoville 2014/15 Map with a 1 ha minimum forest threshold and 30m pixel size (ha)
Forest <80% canopy cover	4,389,270	4,375,862
Forest 30-80 % canopy cover	2,186,495	2,150,657
1-30 % canopy cover	1,529,949	1,579,147
Classes without trees	1,467,152	1,467,424
Total	9,572,866	9,573,090

As stated above, in the recently finalized forest definition, plantations are excluded from the forest definition of Liberia, even if land cover and trees contained would otherwise meet the condition for forest. Thus for this forest definition to be properly reflected in the land cover maps, plantations should be included as a separate non-forest strata, however using current datasets this cannot be accurately performed. Accurate spatial layers showing exactly where oil palm and rubber have been planted (as opposed to the broad concession boundaries) are not currently available. As few large-scale plantations existed in the early 2000's this is not as large an issue for the start of the reference period maps. However, the Metria/Geoville map currently does not distinguish planation areas and thus, some areas in its >30% canopy cover classes are in fact plantations, and are therefore not included in Liberia's definition of forest. An additional effort is required to map all actual plantation areas (as opposed to plantation concession boundaries). Since plantation areas are difficult to map using remote sensing and automated methods, and instead require considerable local experience or data, it is recommended that this effort involve on-the-ground teams and collaboration from plantation companies.

An independent field effort was undertaken in early 2016, to assess the accuracy of the percent forest cover cut-offs of the forest classes of the Metria/Geoville product. The purpose of this exercise was to check that there were no biases that could adversely influence its use in the historical deforestation analysis based on Hansen et al (2013) data. This limited sampling found the Metria/Geoville map to have an accuracy of 92.6%, with no apparent systematic bias between classes and no evidence that the 80% canopy cover cut-off was incorrectly applied. The methods and analysis for this ground-truthing effort are described in Appendix B. This also allowed for the creation of 95% Confidence Intervals around the landcover class areas shown in Table 3, themselves with considerable uncertainty.

2005 forest stratification dataset development

In order to estimate land cover change within each forest stratum over time it is necessary to know the land cover at the start of the reference period. While there are earlier land cover maps for Liberia, they are all at a scale that is not appropriate for estimating land cover change with any accuracy (Appendix A). For instance, a very coarse product was developed in 2004 by Bayol and Chevalier, with a minimum mapping unit of 10 km^2. In addition, no country-wide spatially-explicit estimate of deforestation/degradation has been performed for Liberia post-2000 (See Christie et al. 2007 for an analysis of land cover change from 1986-2000). Details of available land cover and land cover change data and their relevance are provided in Appendix A.

In 2013, Hansen et al published a set of global spatial products that span 2000 to 2013. This includes a global 30-meter resolution '2000 Percent Forest Canopy Cover' map and a 30-meter resolution 'Annual Forest Loss' product produced annually from 2000 onwards. The Hansen et al (2013) '2000 Percent Forest Canopy Cover' precisely matches the 'Annual Forest Loss' product produced from 2000 onwards (Hansen et al 2013), which can be used to create a series of land cover change products and thus create annual deforestation activity data. The Annual Forest Loss product analyzes all available Landsat imagery and combines training data from across the planet to estimate forest loss from (currently) 2000 to 2014 (Hansen et al 2013).

These data have been freely released by the University of Maryland[24] and will be annually updated. The datasets have been widely publicized through Global Forest Watch[25] and the use of such datasets is

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[24] http://www.earthenginepartners.appspot.com/science-2013-global-forest
[25] http://www.globalforestwatch.org/

recommended in the Global Forest Observations Initiative's Methods and Guidance Document "Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests"[26] (referred to as 'MGD'). GFOI MGD explicitly encourages the use of this dataset and now has a module advising on how this dataset can be used in the development of country-level reference levels[27]. However, the MGD and various research indicates that the Hansen et al (2013) can have significant local biases in its canopy cover estimates, and thus need local correction before being used for Liberia.

Based on this evaluation, it was concluded that the Hansen et al dataset provides the highest resolution data available to identify forest loss on an annual basis. This dataset was therefore used to produce annual forest strata maps and annual deforestation estimates for the reference period, 2005-2014. These were based on the Hansen 2000 canopy cover map, corrected for Liberia using the 2014 Metria Geoville classifications, with annual forest loss calculated from that date onwards. As recommended by the GFOI MGD, the data was first processed to create a 'Liberia-Corrected 2000 Percent Canopy Cover' map, stratified by forest class (30-80% Canopy Cover; >80% Canopy Cover), using a combination of information from the Metria/Geoville map and the published Hansen et al (2013). The steps to accomplish these tasks are explained in Appendix C.

3.2 Deforestation Rate Estimation

Using the approach described in Appendix C, Hansen et al's (2013) Annual Forest Loss product was also Liberia-corrected and stratified by forest canopy cover class to produce an annual land cover change product from 2000-2014 (Figure 2). From these datasets, the area of forest in each forest class at the start of the Reference Period, the year 2005, was calculated along with subsequent annual area of forest loss. Table 4 shows the annual forest loss for the two forest strata and Table 5 shows the annual rate of forest loss by forest strata. Over the Reference Period, the annual deforestation rate was 0.46%[28]. For forests >80% canopy cover, the annual deforestation rate was 0.36%, while for forests with 30-80% canopy cover, the annual deforestation rate was 1.07%.

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[26] http://www.gfoi.org/methods-guidance/
[27] http://www.gfoi.org/wp-content/uploads/2015/03/MGDModule2_Use-of-Global-Data-Sets.pdf
[28] For comparison, the annual deforestation rate on the REDD+ pilot project in Wonegizi was estimated at 0.24%, according to the Technical Specification (FFI & RSS GmbH, 2014). This rate was derived from a simple historical analysis of forest cover change within the PPA boundaries between the period of 2001 to 2013.

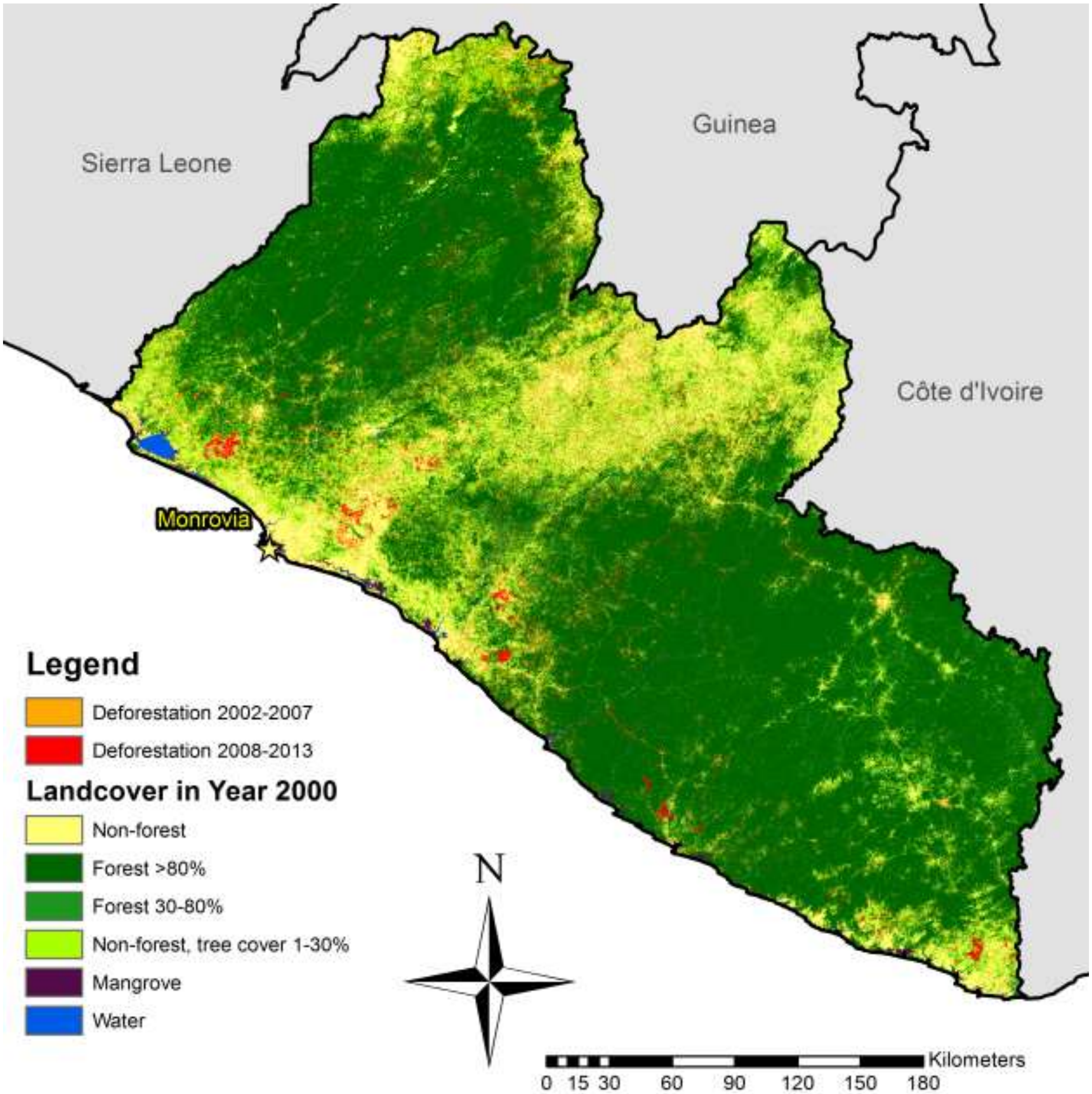

Figure 2. Forest cover and change from 2002-2013. Note that Reference Period is 2005-2014; additional years included for context. (Based on Liberia-corrected 2000 Percent Forest Cover, Forest Cover Change product (Hansen et al 2013) and 2014 Liberia Land Cover Map (Geoville/Metria 2016)

Table 4. Annual forest loss in hectares since 2001 and over reference period 2005-2014, by forest cover class

	Forest >80%	Forest 30-80%	All forest
Total initial area in 2000	Forest area (ha)		
	5,737,119	926,047	6,663,166
	Forest Loss (ha)		
2001	9,635	3,310	12,945
2002	17,848	7,579	25,428
2003	6,675	3,079	9,754
2004	2,407	1,196	3,603
2005	3,559	1,845	5,403
2006	10,735	6,597	17,331
2007	14,742	8,361	23,103
2008	11,100	7,288	18,389
2009	28,528	15,170	43,698
2010	8,764	3,630	12,393
2011	13,428	6,039	19,467
2012	27,093	11,530	38,623
2013	47,692	21,100	68,792
2014	39,496	15,912	55,408
Total forest loss over reference Period	**205,135**	**97,472**	**302,608**
Average annual loss over reference period	**20,513.5**	**9,747**	**30,261**

Table 5. Annual rate of forest loss since 2001 and over reference period 2005-2014, by forest cover class

Year deforested	Forest >80%	Forest 30-80%	Combined forest loss
	percent loss		
2001	0.17%	0.36%	0.19%
2002	0.31%	0.82%	0.38%
2003	0.12%	0.34%	0.15%
2004	0.04%	0.13%	0.05%
2005	0.06%	0.20%	0.08%
2006	0.19%	0.73%	0.26%
2007	0.26%	0.93%	0.35%
2008	0.20%	0.82%	0.28%
2009	0.50%	1.71%	0.67%
2010	0.16%	0.42%	0.19%
2011	0.24%	0.70%	0.30%
2012	0.48%	1.34%	0.60%
2013	0.85%	2.48%	1.07%
2014	0.71%	1.92%	0.87%
Average annual loss over reference period	**0.36%**	**1.07%**	**0.46%**

Figures 3a shows the annual forest loss in hectares from 2000-2014 for both forest strata. Figure 3b shows the cumulative forest loss since 2000 for forests with >80% canopy cover, and Figure 3c shows cumulative forest loss since 2000 for forests with 30-80% canopy cover. Because there is more total forest with >80% canopy cover, there was more total deforestation in this stratum, while the annual rate of deforestation was much lower.

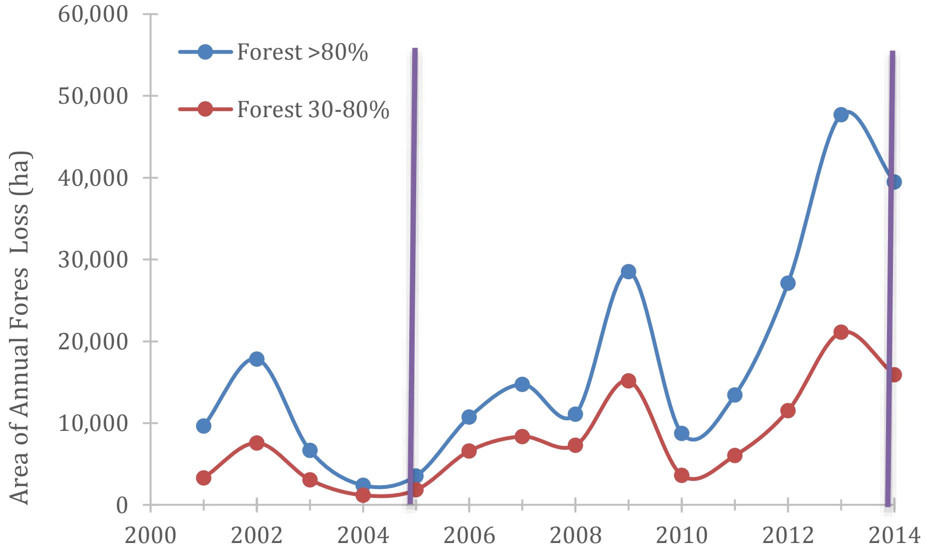

Figure 3a. Annual Forest Loss over time (ha); Purple lines indicate extent of 'Reference Period'

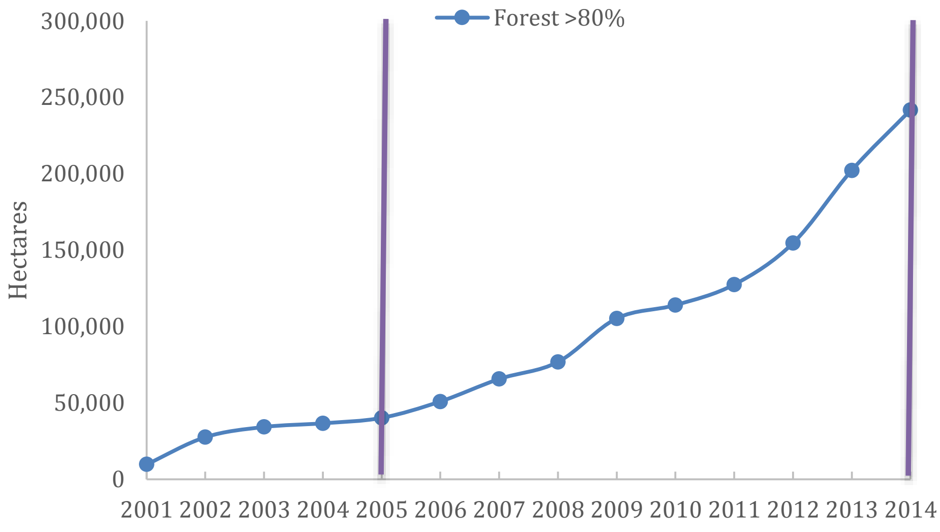

Figure 3b. Cumulative Forest Loss over time for tree cover >80% (ha); Purple lines indicate extent of 'Reference Period'

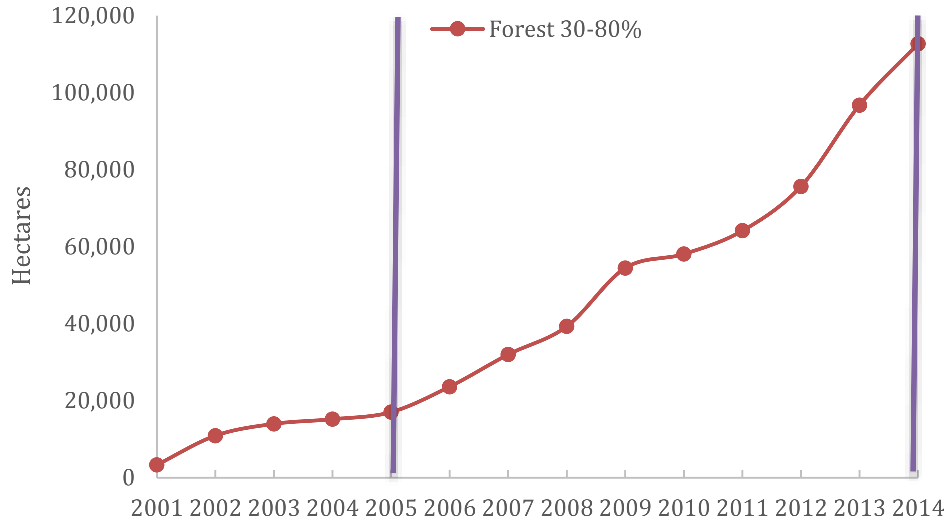

Figure 3c. Cumulative Forest Loss over time for tree cover 30-80% (ha); Purple lines indicate extent of 'Reference Period'

3.3 Characterization of Deforestation Trends

In general deforestation appears to be of two types, with large clearings associated with the creation of plantations, visible as five clusters each 20-50 km from the coast stretching down the whole coastline, and a network of tiny clearings located broadly throughout the country though focused around roads and settlements (Figure 2). The small clearings are likely associated with agriculture and logging, and are relatively evenly spread throughout the time period, whereas the plantation clearings initiate from 2011 onwards.

Additional analyses were conducted to evaluate different types of deforestation trends within the country with respect to roads, county boundaries, and land use designations. If significant trends were identified, this information could be used to further stratify both activity data and emission factors. Although only 35% of total forest is within 1 km of the nearest road, over half the forest loss occurs in this area. While 7% of the forest areas are more than 5 km away from the road, less than 1% of the forest lost occurs more than 5 km from a road (Table 6). The dominance of the two forest types at different distances from access points also does not dramatically change, with 81% of the forest area with >80% tree cover within 1 km of the road and 91% between 2-5 km from the nearest road. It is not surprising that the deforestation rate is lower farther away from access points, but in reality very small areas of Liberia are inaccessible and thus 'accessibility' does not seem to have a very large influence on deforestation rates.

Table 6. Historical mean deforestation rates for various distances from nearest road (historical mean for reference period 2005-2014)

Distance from road (km)	Pre-deforestation cover	Historical mean deforestation rate (2005-2014)	% of Total National Forest Area
<1	Forest >80%	0.46%	28%
	Forest 30-80%	0.96%	7%
	Total forest		35%
1 - 2	Forest >80%	0.33%	24%
	Forest 30-80%	0.89%	4%
	Total forest		28%
2 - 5	Forest >80%	0.16%	27%
	Forest 30-80%	0.68%	3%
	Total forest		30%
>5	Forest >80%	0.02%	7%
	Forest 30-80%	0.37%	0.3%
	Total forest		7.3%
All Forest	Forest >80%	0.37%	86%
	Forest 30-80%	1.12%	14%

There are some geographic differences in deforestation rates, with the southern counties having the highest rates and the northwest and southeast having the lowest rates. These regions also have the most protected or proposed protected land. Four counties account for a total of 56% of all forest loss: Bong, Grand Bassa, Lofa, and Nimba, with the remaining counties each accounting for less than 6% of forest loss (Table 7).

Table 7. Historical deforestation rates (2005-2014) by county and forest cover, grouped by region.

County	Pre-deforestation cover	Historical mean deforestation rate
NORTHWEST		
Gbarpolu	Forest >80%	0.22%
Gbarpolu	Forest 30-80%	0.89%
Lofa	Forest >80%	0.43%
Lofa	Forest 30-80%	1.06%
SOUTHWEST		
Bomi	Forest >80%	0.78%

Bomi	Forest 30-80%	1.35%
Grand Cape Mount	Forest >80%	0.24%
Grand Cape Mount	Forest 30-80%	0.86%
CENTRAL		
Bong	Forest >80%	0.83%
Bong	Forest 30-80%	1.05%
Nimba	Forest >80%	0.45%
Nimba	Forest 30-80%	1.11%
SOUTH		
Grand Bassa	Forest >80%	0.71%
Grand Bassa	Forest 30-80%	1.09%
Margibi	Forest >80%	0.94%
Margibi	Forest 30-80%	0.96%
Montserrado	Forest >80%	1.00%
Montserrado	Forest 30-80%	1.14%
Rivercess	Forest >80%	0.39%
Rivercess	Forest 30-80%	1.18%
SOUTHEAST		
Grand Gedeh	Forest >80%	0.12%
Grand Gedeh	Forest 30-80%	0.37%
Grand Kru	Forest >80%	0.21%
Grand Kru	Forest 30-80%	0.92%
Maryland	Forest >80%	0.34%
Maryland	Forest 30-80%	0.98%
River Gee	Forest >80%	0.10%
River Gee	Forest 30-80%	0.31%
Sinoe	Forest >80%	0.19%
Sinoe	Forest 30-80%	0.65%

Based on data evaluated, there are over 700,000 hectares of land within oil palm concessions. In 2000, using the calculation methods described, over 520,000 ha of this area is classified as forest. However, it is not known what portion of this area was already oil palm. Between 2005-2014, over 47,000 ha of forest were lost within the concessions (Table 8). This accounts for 16% of the national forest loss over this time period. These areas have slightly higher rates of deforestation than forest areas outside of concessions if the entire reference period is examined. However, since 2012 forest loss rates have risen sharply (Table

8, Figure 4) but still do not exceed 3% per year. It is not known if this trend will increase further, however Oil Palm concession owners may have existing plantation establishment plans that could be consulted. However, this information could not be accessed for this report. Without this information, it may be difficult to justify using a deforestation rate from 2011-2014 only for oil palm. In addition, the two forest classes are found in roughly the same proportions as in the rest of Liberia.

Table 8. Historical mean deforestation rates in Oil Palm concessions in comparison to forest areas outside of Oil Palm concessions during the Reference Period (2005-2015)

	Pre-deforestation cover	Historical mean deforestation rate (2005-2014)	Total Loss (ha)	2011-2014 mean deforestation rate
Not oil palm concession areas	Forest >80%	0.32%	160,723	
	Forest 30-80%	1.01%	78,208	
Oil palm concessions	Forest >80%	0.75%	31,848	1.6%
	Forest 30-80%	1.49%	15,207	2.55%
All Forest	Forest >80%	0.37%	192,571	
	Forest 30-80%	1.12%	93,415	

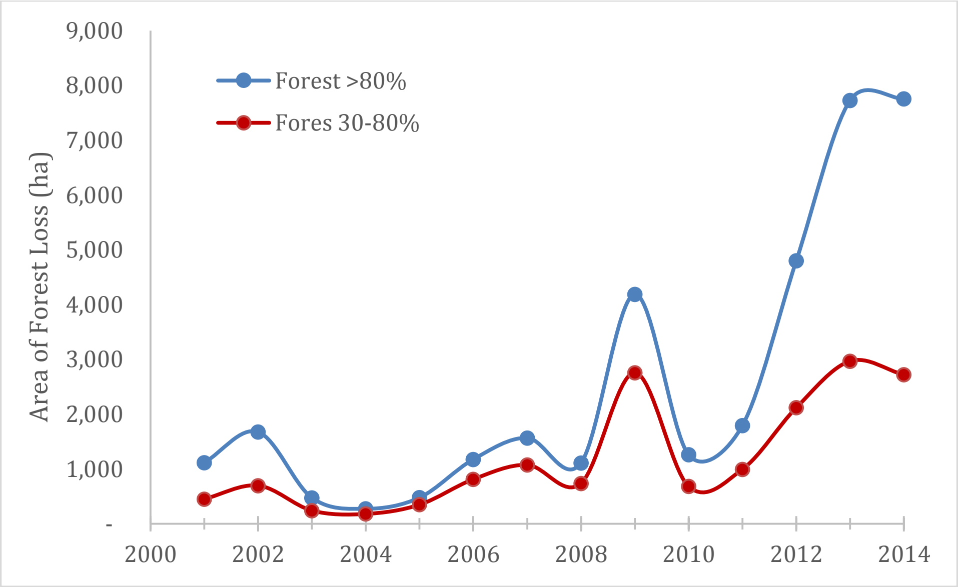

Figure 4. Forest loss within Oil Palm concessions over time

3.4 Deforestation Activity Data development

To estimate net emissions most accurately, it is necessary to identify the land cover/land use following deforestation, and develop activity data accordingly. This is because although deforestation will result in the emissions of greenhouse gases, the vegetation in the land use class following deforestation will sequester and store greenhouse gases over time. Although accurately knowing what land use the forest land was converted to historically following forest loss is difficult given the available mapping products, the Metria/GeoVille map can be used to identify the land cover class in 2015 of all areas not in a forest class within this map. In addition, concession boundaries for oil palm, rubber, and mining plantations are available, and it was assumed in this analysis that deforestation in those areas resulted in development of plantations or mines respectively. Therefore, the following post-deforestation land uses were identified:

- Shifting cultivation
- Oil palm plantation
- Rubber plantation
- Non-forest mixed vegetation
- Mining
- Settlements

Land cover classes from the Metria/GeoVille map were assigned to these post-deforestation land uses for all deforested lands. Any deforested land not within concession boundaries that had tree cover in 2015 (Metria/GeoVille classes Forest >80% cover, Forest 30-80% cover, and <30% cover) was considered shifting agriculture. Deforested land outside of concession boundaries that was classified as grassland, shrub, or bare soil in 2015 was considered non-forest mixed vegetation. Lands classified as settlement in 2015 remained as such. Finally, any deforestation occurring within active concessions was classified as the respective post-deforestation land use: oil palm, rubber, or mining.

It should be noted that these classifications are based on estimates of land use according to land cover, and therefore there likely will be some misclassifications. For example, those areas classified as non-forest mixed vegetation are likely a mix of cropland, the cropping cycle of shifting cultivation, grassland, and other non-forest mixed vegetation land uses. Additionally, there is currently no way to identify areas where deforestation results in smallholder plantations, so that land use is not included here. Section 6 provides recommendations on improving future estimates of land use. For this reason, Liberia should prioritize improving the land use classifications; recommendations are provided in Section 6.

The proportion of each land use in 2015 was identified, based on these classifications, and it was assumed that these proportions remained constant over time. They were therefore applied to the forest loss for each year for each forest cover class. These numbers provide activity data for deforestation (Table 9), and reflect an IPCC Approach 3, with land cover classes of forest and non-forest.

Table 9. Historical activity data by forest class, showing estimated post-deforestation land use

Forest >80% cover							
Post-deforestation	Shifting Cultivation	Oil palm Plantation	Rubber Plantation	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Area change (ha)						
2005	1,691	519	50	1,036	260	4	3,559
2006	5,099	1,565	150	3,125	784	11	10,735
2007	7,003	2,150	206	4,291	1,077	15	14,742
2008	5,273	1,619	155	3,231	811	12	11,100
2009	13,552	4,160	398	8,304	2,084	30	28,528
2010	4,163	1,278	122	2,551	640	9	8,764
2011	6,379	1,958	187	3,909	981	14	13,428
2012	12,871	3,951	378	7,886	1,979	28	27,093
2013	22,656	6,955	665	13,882	3,484	50	47,692
2014	18,762	5,760	551	11,496	2,885	42	39,496

Forest 30-80% cover							
Post-deforestation	Shifting Cultivation	Oil palm Plantation	Rubber Plantation	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Area change (ha)						
2005	826	274	36	569	139	1	1,845
2006	2,954	981	129	2,033	495	5	6,597
2007	3,744	1,243	163	2,577	628	7	8,361
2008	3,263	1,083	142	2,246	547	6	7,288
2009	6,792	2,255	296	4,676	1,139	12	15,170
2010	1,625	540	71	1,119	273	3	3,630
2011	2,704	898	118	1,861	454	5	6,039
2012	5,163	1,714	225	3,554	866	9	11,530
2013	9,448	3,136	411	6,503	1,585	17	21,100
2014	7,125	2,365	310	4,904	1,195	13	15,912

It is important to note that these broad land use classes do not address drivers of degradation. Notably, while Table 9 above indicates that shifting cultivation and non-forest mixed vegetation are the main post-deforestation land cover, it does not include pitsawing and charcoal production, which have been identified by both the R-PP and the REDD+ Strategy (LTS 2016) as common. However, the MRV roadmap describes chainsaw logging and charcoal production as drivers of degradation. Indeed, these forest uses generally do not necessarily in conversion to a non-forest cover. These forest activities are therefore difficult to quantify without additional data, for instance, on volume of timber and charcoal produced.

4. EMISSION FACTORS

Emission factors are measures of the emissions and removals of greenhouse gases per unit of activity data, usually expressed in units of t CO_2e ha^{-1}. Emission factors for land use change are generally developed using estimates of biomass and carbon stocks of the relevant pools and land cover types and calculating the difference between pre-deforestation forest carbon stocks and post-deforestation carbon stocks to determine the change in carbon stocks due to deforestation.

4.1 Forest biomass carbon stocks

Various sources of data may be used to estimate forest biomass and develop emission factors. Potential sources for generating emission/removal factors include:

- Carbon measurement inventories including ground measurement, **allometric equations** and remote sensing techniques. These rely on allometric models that relate the biomass of trees with certain measureable morphological features (e.g. diameter and height) to indirectly quantify aboveground and belowground tree biomass estimates.
- Forest or timber inventories that provide data on the number or trees per hectare or the volume of timber. These rely on **biomass expansion factors** to estimate aboveground biomass.
- Academic and other research studies that have previously produced biomass and/or carbon estimates.

Appendix D describes Liberia-relevant allometric equations, biomass expansion factors, and available biomass data. Currently there are no existing data in Liberia that can be used to develop reliable Tier 3, country-specific emission factors. To develop these, therefore, it would be necessary for Liberia to develop a forest sampling scheme and undertake a forest inventory (an example sample design is described in the companion document “Guidance for developing an NFI for Forest Carbon Sampling[29]). It is recommended that such an inventory be conducted when time and resources allow, in order to develop an estimate of carbon stocks and emission factors with an acceptable uncertainty level.

At present, however, we must rely on existing global datasets to develop provisional emission factors. There are three available pantropical maps of aboveground biomass that can be used to produce carbon stocks for each of the forest cover classes identified in the Metria/GeoVille map: Saatchi et al. (2011), Baccini et al. (2012), and Avitabile et al. (2015). (See Appendix D for further description.) These datasets can be used to develop Tier 2 emissions factors, because while they are global datasets, they are derived using country-specific biomass estimates, as required for Tier 2 emission factors. The carbon stocks for aboveground biomass from Avitabile are based on actual, though limited, field data from Liberia, used to weight and average the Baccini and Saatchi maps. They also match most closely with existing data from Liberia and neighboring countries, and they provide the most realistic differences between forest classes. They are therefore likely to be the most accurate of the available global datasets. However, we are using carbon stocks from Baccini et al (2012) to develop provisional emission factors, because they provide lower estimates and result in a more conservative reference level. This report will describe historical emissions and a reference level developed using Bacini carbon stocks. However, when country specific carbon stock data are developed this should be used in place of the provisional emission factors and the reference emission level should be recalculated. (See Table 10 for carbon stocks from each.)

Table 10. Above ground carbon stocks in Liberia by forest class, based on global datasets, shown in CO_2e ha^{-1}

Forest Class	Baccini et al.	Saatchi et al.	Avitabile et al.
	t CO_2 ha^{-1}		
Forest >80%	364	436	566
Forest 30-80%	317	333	365
Forest <30%	291	311	302

[29] Walker SM, Goslee, KM, Eickhoff, G, and Morikawa, Y. 2015. Guidance for developing a National Forest Inventory for Forest Carbon Sampling. Winrock International.

Appendix D describes existing data that provides a comparison to the global datasets used here. These include data from Sierra Leone, Guinea Bissau, and from the Wonegizi REDD+ pilot project in Liberia. These data are similar to, or larger than the Baccini data in Table 10. This indicates that while country specific data for Liberia will be different from Baccini, they are unlikely to be substantially lower. Regardless, such data are required to develop Tier 1 emission factors.

Belowground biomass is estimated based on root to shoot ratios developed by Mokany et al (2006), with belowground biomass equal to aboveground biomass multiplied by 0.235.

Leaf litter and deadwood are estimated as the fraction of live tree biomass following factors used by CDM[30] (Table 11). All deadwood and leaf litter carbon is assumed to be emitted as CO_2e in the year of forest loss.

Table 11. Default factors for leaf litter and deadwood, taken from CDM A/R Methodological Tool[23]

Carbon Pools	Fraction of live tree biomass
Litter	0.01
Deadwood	0.01

Total biomass carbon stocks are provided in Table 12.

Table 12. Estimated forest carbon stocks for all pools, based on two global datasets.

	AGB	Mokany BGB	Litter and deadwood (CDM)	Total carbon stocks
	tCO2e/ha, based on Baccini AGB			
Forest >80% cover	364	85.5	9.0	**458.5**
Forest 30-80% cover	317	74.5	7.8	**399.3**
	tCO2e/ha, based on Avitabile AGB			
Forest >80% cover	566	133.0	14.0	**713.0**

[30] See: A/R Methodological tool: Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities Version 03.0. Data/Parameter tables 5 & 6.

Forest 30-80% cover	365	85.8	9.0	**459.8**

4.2 Post deforestation biomass carbon stocks

As described in section 3.4, post-deforestation land use(s) were identified as shifting cultivation, oil palm plantations, rubber plantations, non-forest mixed vegetation, mining, and settlements. Carbon stocks were estimated for each land use/cover, and are shown in Table 13.

Carbon stocks for shifting cultivation are based on a field study for croplands in Ghana's High Forest Zone[24], which reflects all biomass carbon pools in all cropland (currently cropped or in fallow), rice fields, and agro-forestry systems. These stocks may be an underestimate of carbon stocks for this land use in Liberia. Numbers for shifting cultivation exclusively would be expected to be higher than an average across all types of cropland, and shifting cultivation cycles in Ghana typically involve shorter fallow periods (3-5 years) than what might be expected in Liberia which has a lower population density. However, no appropriate data were found for Liberia.

Oil palm and rubber plantation carbon stocks are derived from studies conducted on tropical tree crop systems in Ghana (Kongsager et al 2013)[31], as no relevant data were found for Liberia. The values represent time-averaged carbon stocks for a 30-year rotation, based on the results of the Kongsager study, as cited in a presentation by the same author.

Lands classified as non-forest mixed vegetation are likely a mix of cropland, the cropping cycle of shifting cultivation, grassland, shrubland and other non-forest mixed vegetation land cover. These carbon stocks are based on IPCC default values for cropland. This is likely an overestimate of some land cover, such as grassland, and an underestimate of other cover, such as shrubland.

It is assumed that there is no biomass carbon on areas converted to mines or infrastructure (roads and settlements).

[31] Konsager et al. The carbon sequestration potential of tree crop plantations. Mitigation Adaptation Strategies for Global Change (2013) 18:1197–1213. Time-averaged results from http://orbit.dtu.dk/files/55883745/Carbon_Sequestration.pdf

Table 13. Post deforestation biomass carbon stocks by land use

Land Use	Carbon Stocks	Source
Shifting Cultivation	135.7 t CO_2e ha^{-1}	PASCO CORPORATION (2013) Report on Mapping of Forest Cover and Carbon Stock in Ghana. Forest Preservation Project.[32]
Oil Palm Plantations	110.0 t CO_2e ha^{-1}	Kongsager et al. 2013.
Rubber Plantations	275 t CO_2e ha^{-1}	Kongsager et al. 2013.
Non-forest mixed vegetation	18.3 t CO_2e ha^{-1}	Based on Ch. 3 LUCF TABLE 3.3.8, value for annual cropland
Mining and Infrastructure	0	Assumed based on removal of all vegetation

4.3 Soil carbon stocks

Soil carbon stocks were sourced from the Harmonized World Soil Database[33]. Soil organic carbon calculations are based on the carbon that is contained in the top 50 cm of the soil. Average values of SOC were established by comparing forested areas of Liberia to the Harmonized World Soil Database[34]. The values are 46.5 t C ha^{-1} (170.34 t CO_2e ha^{-1}) for forest > 80% canopy cover and 44.6 t C ha^{-1} (163.48 t CO_2e ha^{-1}) for forest with 30-80% canopy cover. The amount of soil carbon emitted as CO_2e is a function of land-use practices that follow forest loss. The IPCC provides guidelines for calculating soil emissions based on default factors related to the post-deforestation land-use type, management regime, and application of

[32] Data were derived from the Forest Preservation Program (FPP), which conducted the Mapping of Forest Cover and Carbon Stock in Ghana project.
[33] http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
[34] FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria

organic materials such as manure[35]. This IPCC method estimates changes in soil carbon stocks based on soil factors that account for how the soil is tilled, management practices, and inputs for post deforestation land use, based on the equation:

$$\Delta SOC = C_{soil} - (C_{soil} \times F_{LU} \times F_{MG} \times F_I)$$

Where:

ΔSOC	= Soil carbon emitted, t C ha^{-1}
C_{soil}	= Carbon stock in soil organic matter pool (to 30 cm depth), t C ha^{-1}
F_{LU}	= Stock change factor for land-use systems for a particular land-use, dimensionless (IPCC AFOU GL)
F_{MG}	= Stock change factor for management regime, dimensionless (IPCC AFOLU GL)
F_I	= Stock change factor for input of organic matter, dimensionless (IPCC AFOLU GL)

This study assumes that all areas converted to agriculture will be cultivated for at least 20 years with moderate organic inputs. A summary of SOC stock change factors is given in Table 14. These emissions from soil respiration are assumed to occur over a 20 year period. However, for the purposes of the accounting in this study, all soil emissions are considered to occur in the year of forest loss.

Table 14. Change in Soil Organic Carbon calculations, based on IPCC default factors by post-conversion land use

Stratum	SOC stock ($t CO_2e/ha$)	IPCC Factors			SOC stock at 20 yr ($t CO_2e/ha$)	Change in Soil C ($t CO_2e/ha$)
		F_{LU}	F_{MG}	F_I		
Forest > 80% Canopy Cover	170.34					
Shifting Cultivation		0.80	1.00	1.00	136.27	**34.07**
Plantations		0.82	1.00	0.92	128.51	**41.84**
Non-forest mixed vegetation*		0.48	1.00	1.00	81.76	**88.58**
Mining		0.48	1.00	0.92	75.22	**95.12**
Infrastructure		0.82	1.00	0.92	128.51	**41.84**
Forest 30-80% Canopy Cover	163.48					

[35] Intergovernmental Panel on Climate Change: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use - Table 5.5

Shifting Cultivation		0.80	1.00	1.00	130.79	**39.56**
Plantations		0.82	1.00	0.92	123.33	**47.01**
Non-forest mixed vegetation*		0.48	1.00	1.00	78.47	**91.87**
Mining		0.48	1.00	0.92	72.19	**98.15**
Infrastructure		0.82	1.00	0.92	123.33	**47.01**

*Used values for conversion to cropland for non-forest mixed vegetation

4.4 Emission factors

Emission factors for deforestation were calculated separately for each forest class, based on the estimated land use following deforestation (Table 15), using the following equation:

$$EF_{deforestation,x} = C_{forest} - C_{deforestation} + C_{soil}$$

Where:

$EF_{deforestation,x}$ = Emission factor for deforestation in forest class x; t CO_2 ha^{-1}

$C_{forest,x}$ = Carbon stock in forest class x; t CO_2 ha^{-1}

$C_{deforestation,y}$ = Carbon stock in post-deforestation land use y; t CO_2 ha^{-1}

$C_{soil,x,y}$ = Change in soil organic carbon, forest class x converted to land use y; t CO_2 ha^{-1}

These reflect provisional emission factors for deforestation, and priority should be placed on improving them using country-specific data.

Table 15. Deforestation emission factors by forest class and post-deforestation land use, using forest carbon stock data from Baccini et al (2012)

Stratum	**EF (t CO_2e ha^{-1})**					
	Shifting cultivation	Oil palm plantation	Rubber plantation	Non-forest mixed vegetation	Mining	Settlement
Forest > 80% Canopy Cover	356.9	390.4	225.4	528.8	553.7	500.4
Forest 30-80% Canopy Cover	303.2	446.3	171.3	472.9	497.5	446.3

5. REFERENCE LEVEL DEVELOPMENT

5.1 Historical Emissions

Historical emissions were estimated as the product of activity data and emission factors (Table 16 and Figure 5).

Table 16. Historical emission estimates for Reference Period, by forest class and post-deforestation land use, based on emission factors from Avitabile et al dataset.

Forest >80% cover							
	Shifting Cultivation	Oil palm Plantations	Rubber Plantations	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Emissions (t CO_2e)						
2005	603,365	202,589	11,187	547,780	143,925	1,871	1,510,717
2006	1,819,976	611,084	33,746	1,652,311	434,132	5,645	4,556,892
2007	2,499,395	839,209	46,343	2,269,138	596,198	7,752	6,258,035
2008	1,881,996	631,908	34,896	1,708,618	448,926	5,837	4,712,180
2009	4,836,709	1,623,997	89,681	4,391,128	1,153,734	15,001	12,110,249
2010	1,485,816	498,885	27,550	1,348,936	354,422	4,608	3,720,217
2011	2,276,653	764,420	42,213	2,066,916	543,066	7,061	5,700,329
2012	4,593,477	1,542,328	85,171	4,170,304	1,095,714	14,247	11,501,241
2013	8,085,815	2,714,932	149,925	7,340,910	1,928,766	25,078	20,245,427
2014	6,696,246	2,248,364	124,160	6,079,355	1,597,302	20,768	16,766,195

Forest 30-80% cover							
	Shifting Cultivation	Oil palm Plantations	Rubber Plantations	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Emissions (t CO_2e)						
2005	250,411	122,380	6,157	268,864	68,930	664	717,406
2006	895,481	437,638	22,017	961,471	246,497	2,375	2,565,480
2007	1,135,055	554,722	27,907	1,218,700	312,444	3,010	3,251,839
2008	989,389	483,533	24,326	1,062,300	272,347	2,624	2,834,519
2009	2,059,278	1,006,407	50,631	2,211,032	566,854	5,461	5,899,663
2010	492,738	240,810	12,115	529,049	135,635	1,307	1,411,654
2011	819,784	400,644	20,156	880,197	225,661	2,174	2,348,615

2012	1,565,213	764,948	38,484	1,680,557	430,853	4,151	4,484,206
2013	2,864,344	1,399,858	70,425	3,075,425	788,463	7,596	8,206,110
2014	2,160,081	1,055,671	53,109	2,319,263	594,601	5,728	6,188,454

Sum of All Forests							
	Shifting Cultivation	Oil palm Plantations	Rubber Plantations	Non-forest mixed vegetation	Mines	Settlement	Total
Year	Emissions (t CO_2e)						
2005	853,775	324,969	17,344	816,644	212,855	2,535	2,228,122
2006	2,715,457	1,048,722	55,763	2,613,782	680,629	8,019	7,122,372
2007	3,634,450	1,393,931	74,250	3,487,838	908,643	10,762	9,509,874
2008	2,871,385	1,115,441	59,221	2,770,917	721,273	8,461	7,546,699
2009	6,895,987	2,630,404	140,312	6,602,159	1,720,588	20,462	18,009,913
2010	1,978,554	739,695	39,664	1,877,985	490,057	5,915	5,131,871
2011	3,096,437	1,165,064	62,369	2,947,113	768,726	9,235	8,048,944
2012	6,158,690	2,307,277	123,655	5,850,861	1,526,567	18,397	15,985,448
2013	10,950,159	4,114,790	220,350	10,416,335	2,717,229	32,674	28,451,538
2014	8,856,326	3,304,035	177,270	8,398,617	2,191,904	26,497	22,954,649

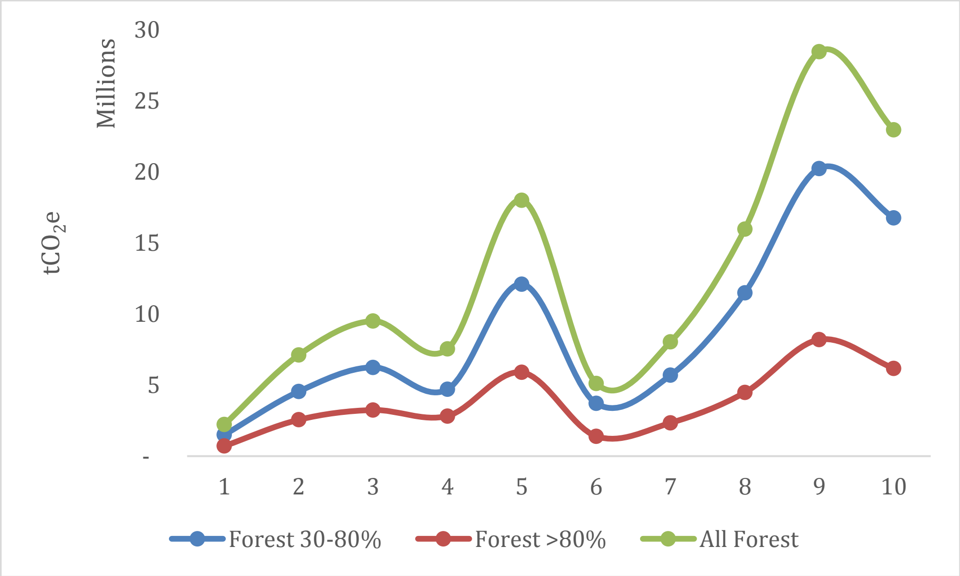

Figure 5. Historical emission estimates based on emission factors from Baccini et al dataset.

5.2 Projecting Future Emissions without REDD

While Liberia's historical emissions show a general upward trend over time, the FCPF requires use of the historical average. According to the Carbon Fund Methodological Framework, Indicator 13.2:

> *The Reference Level does not exceed the average annual historical emissions over the Reference Period, unless the ER Program meets the eligibility requirements in Indicator 13.2. If the available data from the National Forest Monitoring System used in the construction of the Reference Level shows a clear downward trend, this should be taken into account in the construction of the Reference Level.*

Liberia's average historical emissions over the reference period 2005-2014 are **12,498,943t CO_2e/yr** based on Baccini et al data and the average annual historical deforestation rates for each forest class. The cumulative greenhouse gas emissions over ten years would then be over 125 million t CO_2e (Figure 6). This represents the Reference Emission Level, without adjustments for national circumstances.

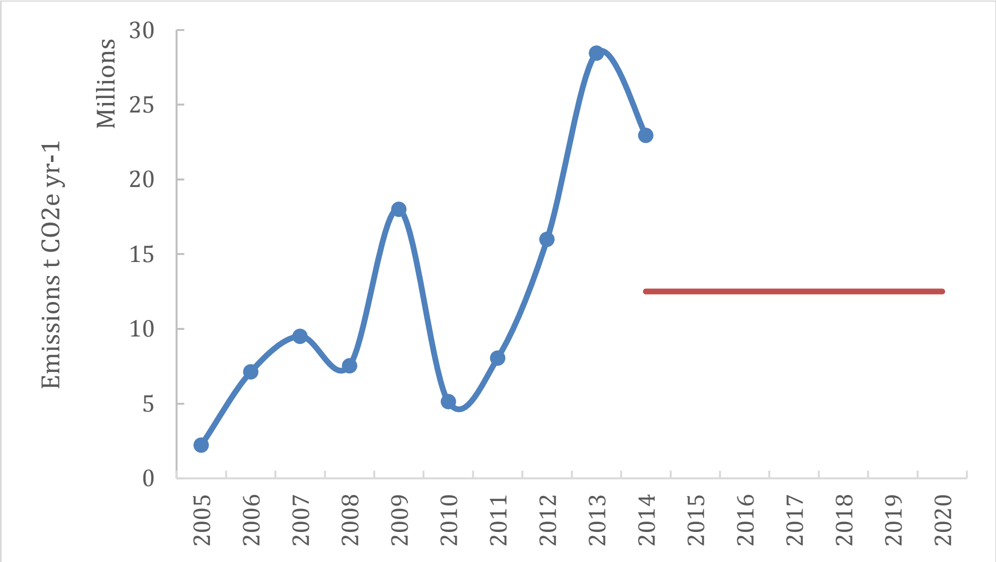

Figure 6. Total historical emission estimates over 2005-2014 reference period and historical average projected into future.

5.3 Adjusting for national circumstances

According to the Carbon Fund Methodological Framework, Indicator 13.2:

> *The Reference Level may be adjusted upward above average annual historical emissions if the ER Program can demonstrate to the satisfaction of the Carbon Fund that the following eligibility requirements are met:*
> *i.) Long-term historical deforestation has been minimal across the entirety of the country, and the country has high forest cover;*
> *ii.) National circumstances have changed such that rates of deforestation and forest degradation during the historical Reference Period likely underestimate future rates of deforestation and forest degradation during the Term of the ERPA.*

If a country meets these criteria, the Carbon Fund allows the Reference Level to be based on an adjustment of the average annual historical emissions over the Reference Period, not to exceed 0.1% of carbon stocks (Indicator 13.4). Using the carbon stocks from Baccini, 0.1% is equal to 2,844,633 t CO_2e, which serves as a cap on upward adjustment of the reference level.

Liberia arguably meets these criteria, with relatively low historical levels of deforestation[36], remaining forests over a large percent of the country, and substantially changed national circumstances. Since the end of the civil war, the economy has grown steadily, especially during the Historical Reference Period (2005-2014). The Ebola outbreak paused this growth, yet now that this crisis has ended, the economy is expected to rebound quickly (Figure 7).

[36] It is important to note, however, that Liberia does not fit the definition of a "High Forest, Low Deforestation" country, which must have >50% forest cover and a deforestation rate of <0.22% per year. While Liberia has more than 50% forest cover based on Metria Geoville's mapping analysis, the deforestation rate is higher than 0.22% annually.

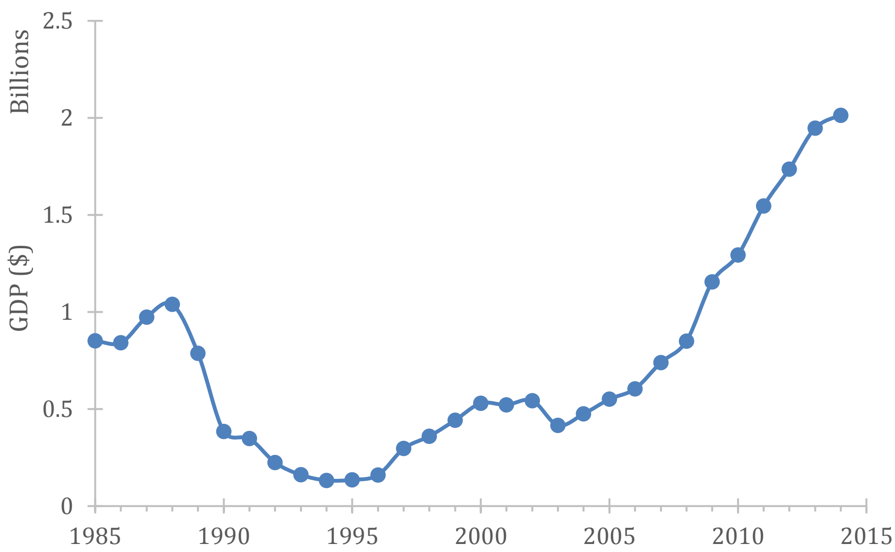

Figure 7. Liberia's GDP over time (World Bank[37])

As described in the economic analysis of the drivers of forest change in Liberia, provided in Annex 1, prior to the civil wars in Liberia there was substantial production in the country, particularly in timber, iron ore, and diamonds. In all cases, production dropped off significantly during and after the wars, and has begun to increase again in recent years in the case of timber and iron ore. This likely indicates additional land use change as a result of conversion of areas for mining, removal of forest cover for timber production, and impacts of associated activities such as road building.

Based on existing information, it is extremely likely that the economy of Liberia will continue to recover at its pre-Ebola growth rate of around 7% (Figure 8).

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[37] http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries

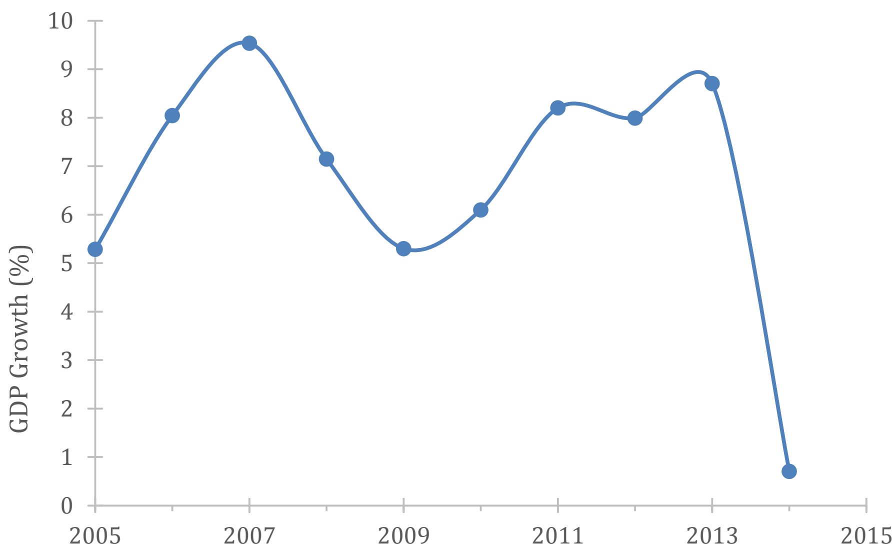

Figure 8. GDP Annual Growth Rate (%) (World Bank)

Additionally, the economic analysis shows a steady increase in production of palm oil, starting in 1966 and continuing into the future. This sector of the economy is likely to have an even larger impact than indicated by this analysis, as evidenced by the extent of land currently allocated for oil palm concessions, but as yet undeveloped. According to the land use analysis conducted under Liberia's REDD Readiness efforts (LTS International 2016) concessions have been granted to four international palm oil companies since 2009, covering over 620,000 hectares. As discussed in Section 3.3, across the Reference Period, over 47,000 hectares of forest have been lost within existing palm oil concession boundaries, accounting for approximately 7% of concession areas. Over the next 15 years, however, it is anticipated that between 160,000 and 352,000 hectares of forest area will be cleared for oil palm plantations. Additional efforts could be made to work with the palm oil companies to determine their expected conversion plans in the future. If sufficient evidence is made available, it may be possible for this to be used to justify adjusting the Reference Emission Level.

While existing evidence indicates that there is justification for an upward adjustment of the historical average emissions, there must also be justification for the numerical adjustment applied, and such justification requires additional data and analysis. While the economic analysis indicates increasing development relative to recent past trends, there was not a correlation found between mining, forestry, and palm prices and deforestation rates in the country, making it difficult to quantify the impact of anticipated future price increases and related expanded development. One possible reason for the difficulty in making the link between prices and deforestation has to do with the lack of information on the specific activities that lead to instances of deforestation, e.g., mining, oil palm development, agriculture. If improved data on the drivers of deforestation were available over time, we could attempt to develop land use change models. Population was correlated with deforestation rates, and it is likely that there is a correlation between GDP growth and deforestation. Additional analysis could be conducted to quantify expected increase in deforestation based on this correlation.

The LTS International draft Land Use Analysis (2016) does provide some indication of anticipated land use change in the near future. This report assessed spatial data on land use from the Government of Liberia, which is focused on concessions for forestry, agriculture, and mining. Based on their assessment, a significant proportion of land is under threat for development in the near future. Table 17 provides the estimates of forest area the land use analysis projects will be impacted, by activity.

Table 17. Area of development by activity, based on land use analysis by LTS International (2016); only those activities likely to result in deforestation are included

Activity	Area (ha)		
	>80% cover	30-80% cover	total
Projected oil palm expansion*		180,810	180,810
Timber sale expansion	94,981	52,432	147,413
Mining – Mineral Development Agreements	134,042	66,508	200,550
Mining – class A	81,596	55,649	137,245
TOTAL DEFORESTATION	310,619	355,399	666,018

*Oil palm expansion was not divided by land cover, so it was conservatively assumed all the land falls under the 30-80% cover

Projected activities that would result in deforestation include oil palm expansion, forest management contracts, and mining. Combined, these three activities account for 1.167 million hectares, as projected in the land use analysis. Using the emission factors based on Baccini carbon stocks, and averaging over 20 years, this represents annual emissions of 16,794,096 t CO_2e. Therefore, such forest loss would result in greater emissions than the historical average emissions (12,498,943 t CO_2e) plus the 0.1% cap (2,844,633 t CO_2e) specified by FCPF for an upward adjustment of the reference level, totalling emissions of 15,343,576 t CO_2e.

While these estimates provide a general sense of potential future emissions, and may be justification for Liberia arguing that it should be allowed to adjust its REL to the extent of the FCPF cap, it is recommended that additional documentation of expansion plans be developed through consultation with the existing concession companies and other stakeholders. Based on the information compiled, discussions should be held with FCPF on options for adjusting the Reference Emission Level based on National Circumstances.

5.4 Reference Emission Level

The Reference Emission Level described here for Liberia is based on Reference Period of 2005-2014. It currently accounts for only emissions from deforestation, based on data available for the country. Activity data were developed using deforestation data developed by Hansen et al (2013) and adjusted for Liberia based on the 2015 landcover map produced by Metria/Geoville. Post deforestation land uses were extrapolated based on land cover in the Metria/Geoville map; improved land use classification is strongly recommended to improve the REL. Emission factors were developed using Baccini et al (2012) global biomass data, and should be considered provisional; it is recommended that Liberia collect country-specific biomass data in order to develop Tier 2/3 emission factors.

Liberia must decide whether to propose a reference level based strictly on average historical emissions or based on an adjustment for national circumstances. However, FCPF must permit Liberia to adjust for national circumstances, and it is not clear that such an adjustment would be allow. An initial suggested adjustment is based on justification using the draft LTS Land Use Analysis report (2016). The two options for Liberia's Reference Emission Level, given the assumptions described here, are provided in Table 18.

Table 18. Potential Reference Emission Levels with average historical emissions and adjusted for national circumstances

Reference Emission Level	tCO_2e
Based on average historical emissions	12,498,943
Adjusted for national circumstances	15,343,576

6. NEXT STEPS AND RECOMMENDATIONS

6.1 Submitting the proposed REL

Sections 1-5 of this report are intended to provide the background, methods, rationale, and findings for a proposed Reference Emission Level that can be submitted to the UNFCCC and/or the World Bank Carbon Fund. It is also intended that this REL can meet requirements established under a multilateral agreement between Norway and Liberia, although such requirements have not yet been fully specified. The REDD+ Implementation Unit of Liberia's Forestry Development Authority, along with the REDD+ Technical Working Group must decide the appropriate venue for submission of this proposed REL.

Submitting a RL/REL to such bodies inevitably entails some level of back and forth regarding methods used, decisions that have been made, and the appropriateness of the recommended REL.

Guidelines and procedures regarding the UNFCCC's technical assessment of submitted proposed RL/RELs, with regard to use for results based payments, can be found in Decision 13/CP.19[38]. The objectives of the technical assessment, as described in the annex of Decision 13/CP.19, are:

> *"(a) To assess the degree to which information provided by Parties is in accordance with the guidelines for submissions of information on forest reference emission levels and/or forest reference levels contained in the annex to decision 12/CP.17 for the construction of the forest reference emission levels and/or forest reference levels;*
>
> *(b) To offer a facilitative, non-intrusive, technical exchange of information on the construction of forest reference emission levels and/or forest reference levels with a view to supporting the capacity of developing country Parties for the construction and future improvements, as appropriate, of their forest reference emission levels and/or forest reference levels, subject to national capabilities and policy."*

6.2 Future improvements

Given that a step-wise approach has been recommended, there are a number of improvements that Liberia can make to the proposed REL, as resources allow. These have been mentioned throughout this report, and are summarized here. Additional capacity building activities are described in further detail in Annex 2.

A. Develop a Forest Carbon Monitoring System

Because Liberia does not have a National Forest Inventory or similar system, global datasets have been used here to estimate forest biomass and develop emission factors. These are, at best, IPCC Tier 2 emission factors, and should be improved by developing country-specific data on Liberia's forest and forest carbon stocks. This can be done by implementing a National Forest Inventory or a smaller scale Forest Carbon Monitoring System. Guidance on developing such an inventory, conducting measurements, and analysing the resulting data are provided in the following documents, presented as companions to this report:

- Walker SM, Goslee, KM, Murray, L, Eickhoff, G, and Morikawa, Y. 2016. Guidance on Developing a National Forest Inventory for Forest Carbon Sampling. Adapted by Winrock International.

[38] http://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=34

- Walker, SM, TRH Pearson, FM Casarim, N Harris, S Petrova, A Grais, E Swails, M Netzer, KM Goslee and S Brown. 2016. Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2016. Winrock International.
- Goslee, K, SM Walker, A Grais, L Murray, F Casarim, and S Brown. 2015. LEAF Technical Guidance Series for the Development of a Forest Carbon Monitoring System for REDD+, Module C-CS: Calculations for Estimating Carbon Stocks. Winrock International.

B. Develop accurate data on land use

The RL and any developed MRV system would benefit greatly from better data on Liberia's land area under different land use types, for example, plantations, active logging concessions, active fuelwood extraction/charcoal, swidden agriculture, cocoa, and others. Some such data exists in Liberia; for example there are shapefiles of logging concession boundaries and plantations in Liberia, but it is unclear how accurate these data are and the areas in active concession are much smaller than the total concession boundaries. With land uses such as smallholder agriculture and plantations, fuelwood, and charcoal extraction, the government is not involved and typically activities are performed by individual farmers and families, not by companies, making any reporting of areas very difficult. However, accurate identification of land uses and land use change improves total emission estimates. It is important for Liberia to maintain data on active plantation areas, including both commercial and smallholder. It is also important to identify areas of permanent agriculture and areas of shifting cultivation, regardless of whether the current landcover is cropped or fallow. Liberia can undertake improved land use classification by identifying post-deforestation land uses, rather than just land cover. Land use classification can also be done using remote sensing methods, described in brief in Appendix F.

C. Develop data required for justification for adjusting REL

The options for adjusting the REL for national circumstances described in section 5.3 are likely to require additional justification to be accepted by FCPF. This will require additional data and information. Specific planned or expected development activities should be identified and documented, especially from oil palm plantations. This information can be used to estimate emissions that would result from such activities and develop a defensible quantitative adjustment of average historical emissions, for a reference emission level based on national circumstances.

D. Improving Activity Data estimates for deforestation

While the methods that have been used to develop estimates of deforestation activity data described in this report are appropriate for developing a Reference Emission Level, they could be improved if time and resources allow. An initial improvement would entail conducting a complete ground truthing exercise for the Metria/Geoville 2014/15 Landcover Map. This would require sampling across the country, in areas representing all major land cover types and land cover changes. The methods applied during the limited ground truthing exercise (described in Appendix B) would be appropriate for such an exercise. If biomass data are collected, either in a forest carbon monitoring system, or in conjunction with ground-truthing efforts, L-band radar data would be used to validate deforestation estimates going forward. Biomass plot data could enable calibration of maps, by assisting in determination of whether a change in radar backscatter is sufficient to be deforestation or degradation, and establishments of thresholds for forest/non-forest.

Additionally, improved methods could be implemented that would increase the accuracy of activity data estimates over the historical reference period (Appendix E). This could potentially increase the accuracy of the deforestation area estimates for each forest stratum. However, it is not possible to estimate the expected accuracy increase. The costs for undertaking such improvements for historical activity data are significantly high and thus likely cost prohibitive. However, in the future under an MRV system, improved methods to monitor deforestation events overtime are recommended. Potential improvements for both historical AD and the future MRV, including cost estimates, are described in Appendix E.

E. Estimate emissions from Degradation and Enhancement

In order to move from the current Reference Emission Level to a full Reference Level, accounting for all significant sources of emissions from land use, as well as removals, Liberia will need to include degradation and enhancement in its accounting. This will require increased data collection capacity and activities. Options for including degradation are described in Annex 1. This should be pursued in the medium term, following implementation of a National Forest Inventory. Incorporating removals from enhancement into the Reference Level and a future MRV should be a longer term objective, if Liberia decides it is appropriate. It would be reasonable and beneficial to include enhancement if the country intends to undertake activities to substantially increase the extent of forest land and/or canopy cover of existing forests. At present, there is no indication that such activities will be undertaken in the near future, nor does Liberia have the capacity to gather the necessary data to allow appropriate accounting of enhancement.

F. Progressing from REL to MRV

As described in Box 1, the Reference Emission Level (REL) provides estimates of historical emissions and a projection of those emissions into the future, in the absence of a REDD+ program, while a system for Monitoring, Reporting, and Verification (MRV) is needed to compare actual emissions with the REL, and estimate emission reductions. The MRV should follow the same methods as the REL, although it is usually possible to improve the methods used for data collection under the MRV. The MRV roadmap provides an initial description of what steps Liberia can undertake to implement a full MRV system. As described in Annex 2, many of these steps are currently underway.

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APPENDIX A: AVAILABLE LAND COVER, LAND COVER CHANGE, AND RAW SATELLITE DATA

Developed by Ed Mitchard

This table provides all data identified as potentially relevant to assessing land cover change in Liberia, as well as a description of how they could be used and whether they were used for analysis.

Name & description	Year(s)	Resolution	Utility	Source	Use in analysis
Land Cover					
Globcover 2.2 and 2.3. Global land cover maps.	2009 & 2005-6	300 m	Differentiates between some land use and land cover classes that could be useful in baseline production, including agriculture-forest mosaic. Resolution probably too coarse though. Not suitable for land cover change.	ESA http://due.esrin.esa.int/page_globcover.php	Not used, as 300 m pixel size too coarse for requirements.
CCI Land Cover Products. Global land cover maps.	98-02; 03-07; 08-12	300 m	Differentiates between some land use and land cover classes that could be useful in baseline production, including agriculture-forest mosaic. Resolution probably too coarse though. Reasonably suitable for land cover change. In theory better than Globcover, but less well known.	ESA http://www.esa-landcover-cci.org/?q=node/156	Not used, as 300 m pixel size too coarse for requirements.

Name & description	Year(s)	Resolution	Utility	Source	Use in analysis
Liberia land cover and land use map	?	? - vector	Could assist with baseline map	LISGIS via Tera Tech ARD	Not used; full dataset never received and definitions of forest and dates never clear
GeoVille/Metria Land Cover map	2014	? 5m/30m	Essential for baseline, and first time point for monitoring.	GeoVille/Metria	Extensively used. Final product was 10 m resolution and dated 2015.
FRM Forest cover map	2004	30 m	Potentially useful for baseline. Forest cover map based on Landsat. Not clear what forest definition used, nor what classes	Bayol & Chevalier 2004	Not used due to lack of clarity on classes, and actual spatial data never made available.
Canopy Cover					
Hansen *et al.* (2013) "Tree Cover" product. Percentage tree cover for every pixel. Global.	2000	30 m	Could be used to make a forest/non-forest map for 2000 – useful for baseline. Unlike straight landcover maps, can make a forest cover map based on different forest definitions.	Original paper in Science: http://www.sciencemag.org/content/342/6160/850 Raw data can be downloaded from http://earthenginepartners.appspot.com/science-	Used; converted to <30, >30 and >80 % canopy cover classes using the GeoVille/Metria map and the Hansen deforestation product to ascertain which areas should not have changed.

Name & description	Year(s)	Resolution	Utility	Source	Use in analysis
				2013-global-forest	
Forest Loss					
Hansen *et al.* (2013) "Forest Loss" product. Global.	Annual data from 2000-2013	30 m	Could provide baseline deforestation data.	Original paper in Science: http://www.sciencemag.org/content/342/6160/850 Raw data can be downloaded from http://earthenginepartners.appspot.com/science-2013-global-forest	Used extensively
Forest Gain					
Hansen *et al.* (2013) "Forest Gain" product. Global.	Gives gain information between 2001-2013.	30 m	Could help with baseline production, but NB no annual information, states gain occurred sometime between 2001 and 2013.	Original paper in Science: http://www.sciencemag.org/content/342/6160/850 Raw data can be downloaded from http://earthengi	Not useful due to lack of date information for gain

Name & description	Year(s)	Resolution	Utility	Source	Use in analysis
				nepartners.appspot.com/science-2013-global-forest	
Satellite data					
Landsat. Optical satellite data.	1972-present	30 m (from mid-80's)	Data available throughout 2000-2015 from Landsats 5, 7 & 8, though with some 2-3 year gaps due to cloud cover. Dry season data can be used to make reasonably reliable land cover maps.	Data free to download from http://earthexplorer.usgs.gov/	Used by G/M extensively to create their 2014 map, in combination with small areas of 5 m resolution RapidEye data.
ALOS PALSAR. L-band radar satellite data.	2007-2010	20 m	Free mosaics available at 25 m resolution annually from 2007-2010. These data have been shown before to be very useful at differentiating different stages of forest regeneration, particularly in farmland-regrowth mosaics. Was used successfully with Landsat in neighbouring area of Sierra Leone. Additional advantage of seeing through clouds	http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm	Downloaded and processed, but without ground data creating maps of deforestation/degradation and regrowth was not possible.

Name & description	Year(s)	Resolution	Utility	Source	Use in analysis
JERS-1. L-band radar satellite data	1996	100 m	Free mosaic available for 1996. Could be used to help with early baseline. Data similar to PALSAR, but lower quality.	JAXA. Not available online, but EM has data.	Not used as 1996 was seen as too early to be helpful for baseline development, plus same lack of ground data problems as for ALOS.
Sentinel 1. C-band radar satellite data.	2014-	~10 m	Data free from 2014 and will continue into 2030's. Cloud-free, but shorter wavelength than L-band so less useful for differentiating forest types. Could be useful for degradation mapping, though tricky to analyse.	ESA. https://sentinel.esa.int/web/sentinel/missions/sentinel-1	Not used. Only available from 2015 in the end, so too late for baseline development and good map already existed for 2015 from G/M.
Sentinel 2. Optical satellite data.	2015-	10 m	Data will be available every 10 days from late in 2015, increasing to every 5 days later this decade. Could be used for monitoring in the future.	ESA. Portal not set up as yet, but in theory data will be free and open	Not available until early 2016

APPENDIX B: FIELD ASSESSMENT OF SPATIAL DATASET ACCURACY

As historical ground data in Liberia are especially sparse, an attempt was made to assess the accuracy of the spatial datasets applied in this study and identify potential shortcomings in accuracy. A field assessment was undertaken in early 2016 whereby crews visited a number of pre-determined sites and were tasked with collecting a set of measurements and photos to help corroborate land cover classifications as determined by the datasets actual observed land cover.

This effort was not designed to be a formal accuracy assessment or ground truthing exercise of the Geoville/Metria land cover map as it did not include a comprehensive selection of evenly distributed sites. Rather, instead it was designed to collect independent field data to evaluate the accuracy of the forest stratification in the G/M land cover map. Due to resource limitations, measurement sites were selected with a bias toward accessibility.

The three datasets whose accuracy was being assessed have been extensively used in the creation of land cover and land cover change maps for Liberia in the development of its Reference Levels include:

- The Geoville/Metria landcover map for 2014/15
- The Hansen *et al.* (2013) Forest Loss product (2000-2014)
- The Hansen *et al.* (2013) Percent Canopy Cover Map for the year 2000

These datasets invariably contain errors, such as mis-classifications in the G/M landcover map, false detections of deforestation or missed deforestation events in the Forest Loss product, and incorrect estimates of canopy cover in the Hansen *et al. (2013)* Percent Forest Cover map for the year 2000. Nevertheless, it is generally accepted that global or regional datasets, even with errors, are suitable for use in producing Reference Levels (or Reference Emission Levels)[39,40]. However, existing guidance clearly indicates that they should only be used if verified against ground data, to correct for biases and allow and estimation of confidence intervals.

[39] GFOI Methods & Guidance Document, http://www.gfoi.org/methods-guidance/
[40] GOFC-GOLD Sourcebook of methods and procedures for monitoring, measuring & reporting http://www.gofcgold.wur.nl/redd/index.php

Methods

The field team visited 70 plots located across three distinct areas of Liberia (see Figure B1). Plots were random locations chosen in advance, stratified by original G/M landcover type. The field team were given discretion as to which sites could be skipped based on accessibility. The field team used GPS devices to locate each of the predetermined sites, and once located, established a 50m circular plot. Information on the following characteristics were then recorded to describe the area within the circular plot:

- Land cover type
- Crop type if grown
- Canopy cover (estimated using a spherical densitometer)
- Maximum tree height (estimated using a vertex hypsometer)
- 4 photographs, one in each compass direction.

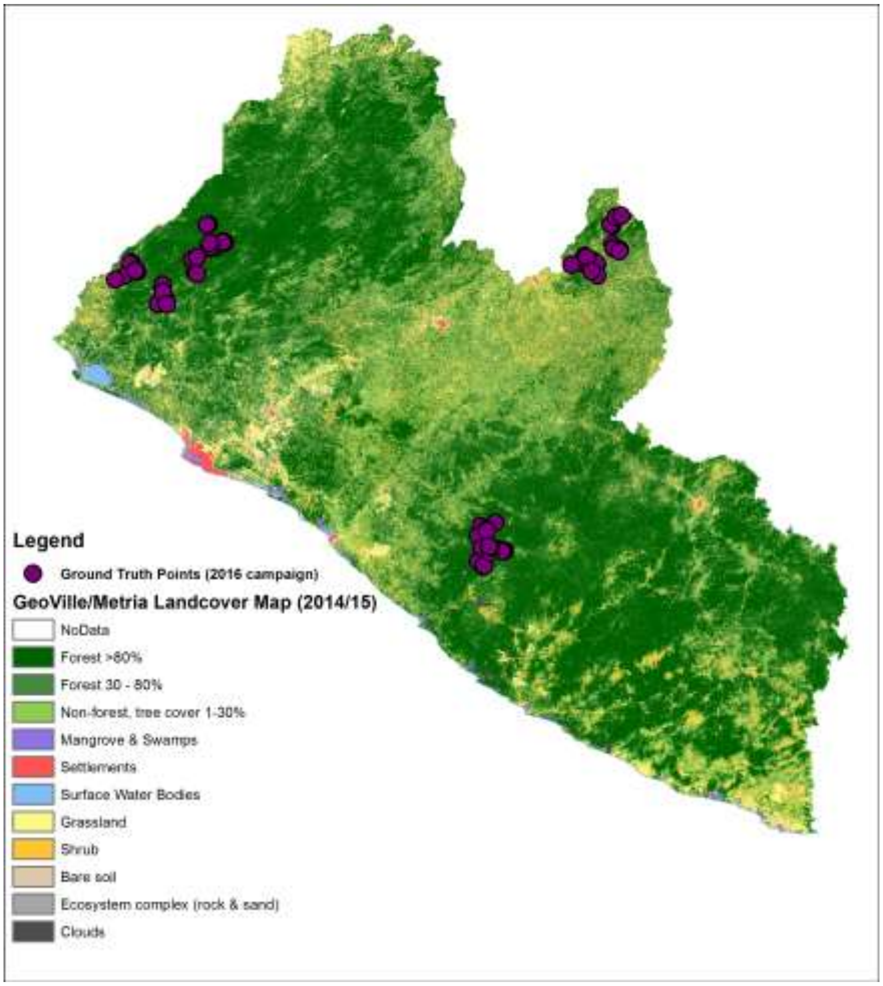

Figure B1. Location of ground truth plots

Results

An initial examination of the landcover types suggested the team had over-sampled agriculture and under-sampled forest types, which was not expected given the equal weighting of the input points (Table B1).

Table B1. Ground truth points by field-reported landcover/landuse type

Landcover class	Number of points
Forest (>80% canopy cover)	2
Forest (30-80% canopy cover)	18
Non-forest with trees (1-30%)	4

Farmed	42
Swamp	4
Total	**70**

Land cover versus land use

Liberia's landscapes are largely comprised of a mosaic of agricultural land at various stages of production and fallow. Even under somewhat shortened fallow periods, Liberia's tropical moist climate allows for trees to grow quickly in the absence of cultivation, and thus many areas that are under agricultural fallow are classified as forest by the remote sensing technology used to produce the spatial datasets in this study.

As such, plots whose canopy cover met the official forest definition of meeting 30% canopy cover threshold and height at maturity threshold of 5 meters were erroneously considered by field crews to be agriculture due to evidence of previous agricultural activity. This critical distinction between land cover and land use may not have been fully understood by the field crews, and thus results reflected a bias toward classifying land cover type according to land use, rather than the correct land cover classification. This bias may have been further compounded by the fact that sites visited were closer to more accessible areas (along roads and other infrastructure), which are more likely to be subject to land cultivation.

For perhaps these same reasons, the number of points given as Forest >80% seemed very low compared to the G/M map that had been used to determine plot locations. Upon examination of the photographs taken, for 9 plots classified as 'forest 30-80% canopy cover', it appeared that they may instead be very dense, intact forest, with >80% canopy cover. The under-sampling of this forest class could also be partly explained by the fact that denser forests are found far from roads, and thus were less accessible by field crew.

Reclassification

There were further difficulties related to the 4 plots that were listed as 'swamp' as the land use. Swamp is not a class in the G/M classification, and conversations with the field team and further examination of the photographs resulted in the reallocation of these plots to other classes where appropriate.

In an attempt to correct for the errors in field sampling, Ed Mitchard performed a secondary classification largely based on the photographs collected at each plot. Plots were re-allocated to one of four classes (Table A2):

Table B2. Ground truth points by re-analysed landcover type

Landcover class	**Number of points**
Forest (>80% canopy cover)	10
Forest (30-80% canopy cover)	26
Non-forest with trees (1-30%)	23
Non-forest without trees	11
Total	**70**

The distribution of points between these three classes was reasonably balanced, with an under-sampling of >80% forest expected due to the access difficulties with reaching these areas from the road (as mentioned above).

For the purpose of the RL/REL development, the distinction between the two non-forest classes is not especially important. Given how fast land changes between these two classes in this area, with the fast encroachment of trees in abandoned agricultural (fallow) areas, and the generally irregular cycles of land clearing for agriculture, errors between these two land use classifications were expected given the ~18-month gap between the average date of the map and the field data. Therefore, the latter two classes were combined for the accuracy analysis, leaving just three classes to be assessed: forest >80%, forest 30-80%, and non-forest.

This fast rate of land use change was exemplified in two plots visited, which were ultimately excluded from further analysis, as from the photos it was obvious they had been recently cleared (see photos below for burned stumps). While the G/M map had recorded the areas as >80% canopy cover, it was clear these areas had been recently cleared. These two plots are not considered in further analysis, so the sample size falls to just 68 plots.

Plot 558, photo 7871 **Plot 68, photo 94**

Confusion matrix

The basic comparison between the field assessment data and the G/M map[41] are reported in a Confusion Matrix below. Confusion matrices present the full results, with the rows showing many points started as each class in the field assessment plots and how many were classified as each class in the G/M map. The columns show how many plots were classified as each class in the G/M map, and where they were classified in the field assessment dataset. It can be seen that in general the map put the points in the correct class, but with a few exceptions.

Confusion matrix

		G/M map			
		non-forest	forest <80% canopy	forest >80% canopy	**SUM**
Field assessment	non-forest	30	2	0	**32**
	forest <80%	2	21	3	**26**
	forest >80%	0	0	10	**10**
	SUM	**32**	**23**	**13**	**68**

[41] The version of the G/M map used here is a derivative product at 30 m resolution, with forest areas <1 ha removed, but in the set of points chosen only 2 plots have a different value between the two maps.

Confusion matrices do not offer percentage accuracies, but simple calculations can provide estimates of *Producer*'s and *User'*s accuracies. *Producer's Accuracy* refers to the probability that a ground truth point given a particular class on the ground is that class in the map, whereas *User's Accuracy* is the probability that a given pixel of that class chosen on the map is really that class in the ground.

The simplest way to explain the difference is to look at an extreme case: if our map predicted the whole area was 'Forest >80%', then the Producer's Accuracy for that class would be 100%, but for the other two classes 0%; by contrast the User's Accuracy for the 'Forest >80%' class would be the landcover proportion of that class in the dataset. It is important to note, however, that these estimates likely do not reflect true accuracy values as the sample size was small and not distributed across the map.

For the purposes of mapping assessments both are important, but for the purpose of this study (estimating the extent of one class) the User's Accuracy is the most useful. Nevertheless, the values for Producer's and User's accuracy were not found to be vastly different, but it is clear the G/M map predicts too much Forest >80%, resulting in a 100% Producer's Accuracy for this class but a lower User's Accuracy.

Both are given in the tables below:

Producer's Accuracy

		Correctly classed	Out of total	Prop correct
Field assessment	**non-forest**	**30**	**32**	**93.75%**
	Forest <80%	**21**	**26**	**80.77%**
	Forest >80%	**10**	**10**	**100.00%**

User's Accuracy

		GM correct	Out of total	Prop correct
Field assessment	**non-forest**	**30**	**32**	**93.75%**
	Forest <80%	**21**	**23**	**91.30%**
	Forest >80%	**10**	**13**	**76.92%**

We can also calculate an Overall Accuracy, which is the proportion of pixels calculated correctly: 92.6 %.

Area-weighted calculations

While the confusion matrix offers useful results, they are not area weighted. For example, the >80% forest class represents a far smaller proportion of the area sampled than it represents within all of Liberia (15% of the field plot observations, 45% of the country). Nevertheless, methods exist to estimate confidence intervals from such unbalanced ground truth datasets[3].

While technically there were not enough field assessment plots to allow for the development of formal confidence intervals on the areas of classes in the G/M map (ideally we would need 75-100 plots per class, randomly placed within them over the whole country[42]), these methods were nevertheless applied, as recommended by GFOI, to estimate the 95% confidence intervals. The results are summarised in the table below:

Class	Area in G/M map	Unbiased area estimate, based on field assessment (ha)	95% C.I. (ha)	Minimum (ha)	Maximum (ha)
non-forest	3,046,571	3,043,174	362,656	2,680,518	3,405,830
forest <80%	2,150,657	3,163,868	1,104,391	2,059,478	4,268,259
forest >80%	4,375,862	3,366,048	1,043,149	2,322,899	4,409,197
Total	**9,573,090**	**9,573,090**			

The calculated confidence intervals are very wide, especially for the forest class, and are likely overestimates. Yet, due to the small sample size, it is not possible to make that claim conclusively. What is clear is that the unbiased estimator made possible through these methods predicts that in reality there is more forest <80% and less forest >80% than predicted in the G/M map.

It should be emphasized that these estimates would change markedly (by hundreds of thousands of hectares) were a single point to be misplaced or misclassified, and thus these estimates should be considered with care. Nevertheless, they do represent the logical conclusion of this analysis based on the field assessment data, which did show a tendency to incorrectly classify <80% cover forest as >80%.

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[42] Olofsson, P et al. 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment,* 148, 42-57.

APPENDIX C: CREATION OF LAND COVER CHANGE PRODUCTS

This appendix provides more detailed information on the development of estimates of land cover change, also addressed in Section 3 of the main report. In order to estimate activity data and emission factors it is necessary to know the starting state of a forested area prior to it being deforested or degraded. The 2014 Metria/GeoVille has limitations for estimating RL/REL values due to these timing considerations. Thus we need to be able to back-date the Metria/GeoVille map to a point in time before the start of the reference period (i.e. for 2004 or earlier).

A global 30-meter resolution map of Percent Forest Canopy Cover for the year 2000 has been produced by Hansen et al. (2013) and can be used to produce the necessary historical forest stratification. The Hansen Percent Canopy Cover Map precisely matches an Annual Forest Loss product produced from 2000 onwards at a 30 m resolution (Hansen et al 2013), which can be used to estimate activity data. This product analyses all available Landsat imagery and combines training data from across the planet to estimate forest loss from 2000 to 2014. This provides the highest available resolution of data available to identify forest loss on an annual basis. These data are freely available and annually updated, and increasingly trusted by the forest monitoring community. The use of such datasets is recommended in the Global Forest Observations Initiative's Methods and Guidance Document "Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests"[43] (referred to as 'MGD'), and specifically encouraged in the recently published 'Module 2' of the MGD.

The only other systematically produced products giving deforestation are reliant on MODIS data, with a best resolution of 250 m. This was coarser than required in this landscape, where small patches of deforestation dominate, and thus would be likely to underestimate total change. It would separately have been possible to manually classify Landsat scenes as part of the project, producing our own landcover and landcover change products from 2000 onwards. However, a lack of ground data and extensive cloud cover meant that there was no reason that maps produced through the project would be any more accurate than the ready produced Hansen et al. (2013) global deforestation maps, and certainly there would be no means to assess their relative accuracy. In fact, it would have been likely that any maps we produced would have had lower accuracy as we would have considered fewer Landsat scenes: the Hansen et al. products use all Landsat data collecting, involving thousands of scenes over Liberia, whereas we would have been limited to using at most tens of scenes. Using fewer scenes increases the proportion of the

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[43] http://www.gfoi.org/methods-guidance/

country that would not be considered due to cloud cover at any one point, and increases errors by not fully considering time series data.

The Hansen et al canopy cover map was used to create estimates of activity data, however, prior to its use a local correction was made, as also recommended by the MGD. This Appendix explains the correction made for this data series to best reflect the land cover realities in Liberia.

Prior to this correction, the global Hansen et al. canopy cover map did not match up with the GeoVille/Metria map – it underestimates the area of >80% cover forest, and over-estimates the area of 30-80% canopy forest, with almost no areas of the country given an area <30% cover. This is not surprising as the Hansen *et al.* canopy cover product relies on a global algorithm, and Liberia, with its dense grass and crop cover and quick-growing fallow, is considerably greener for a given canopy cover percentage than most of the rest of the world. However, this discrepancy requires that an adjustment needs to be applied to use it to produce reliable classes in the past.

As there are no independent reference data available for 2000, nor any independent high resolution datasets, a visual comparison with the Metria/GeoVille classification for areas without deforestation was performed. This relied on the theory that areas without deforestation should have the same distribution of classes in both 2000 and 2014. Thresholds were found that appeared to replicate the Metria/GeoVille classes to a good extent in areas where deforestation had not occurred. The thresholds are shown in Table C1, displayed in C1, and the resulting forest areas given in Table C2. Figure C1 includes a map of deforestation density within 1 km pixels. This is included as the differences between canopy cover in 2000 and 2014 should, if the correction has been performed appropriately, be explained by this change map.

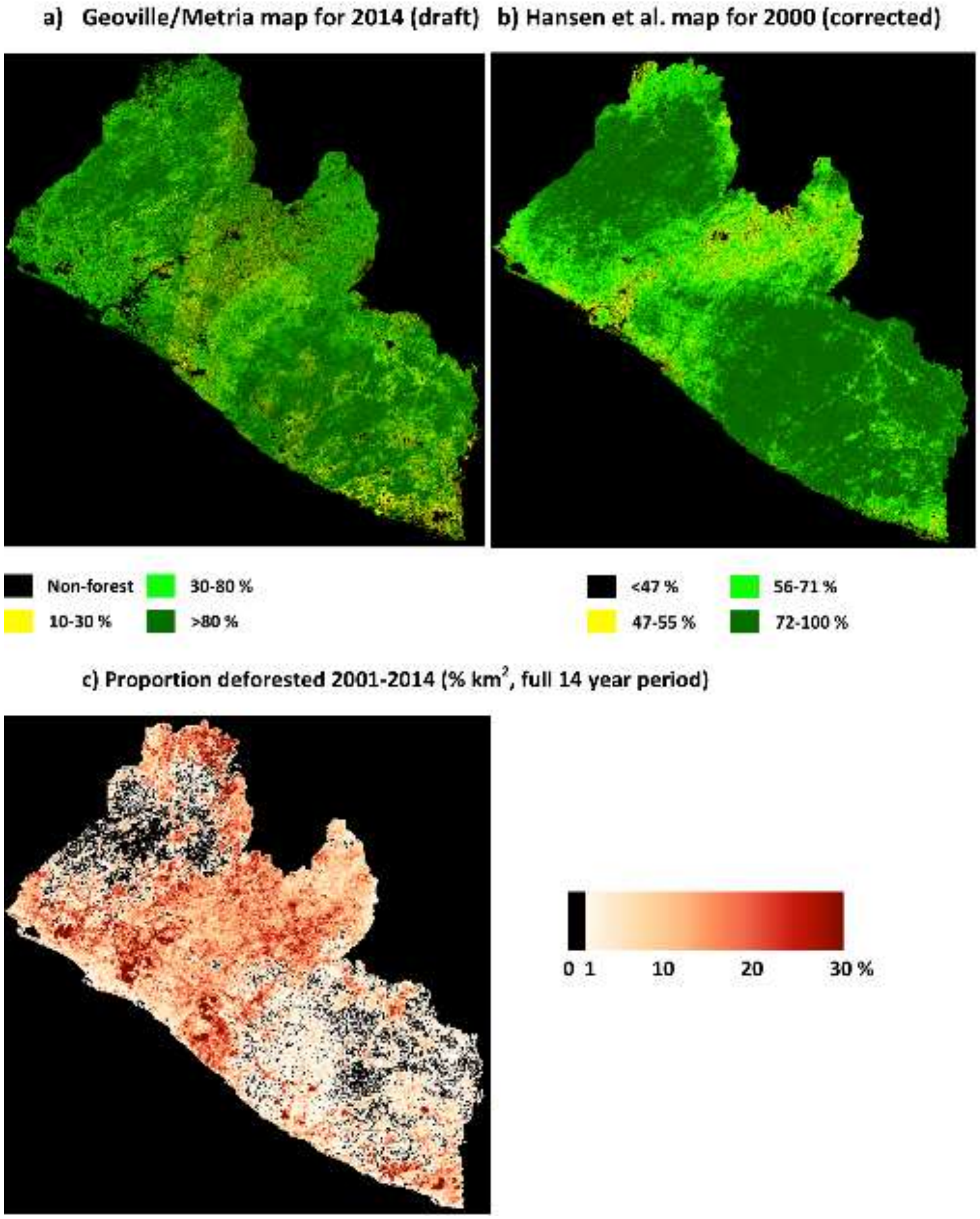

Figure C1. Maps of three forest classes with 'corrected' Hansen et al. thresholds

Table C1. Canopy cover thresholds for three forest classes, Metria/GeoVille (2014) & Hansen (2000)

Forest Class	GeoVille range	Hansen range
Dense forest (> 80 %)	>80	>72
Secondary forest (30-80 %)	30-80	56-71
Trees in agricultural mosaic (10-30 %)	10-30	47-55

Table C2. Areas of three forest classes, Metria/GeoVille (2014) & Hansen (2000 – corrected)

Forest Class	GeoVille	Hansen (corrected)	Difference in area
canopy cover	*ha, 2014*	*ha, 2000*	*ha, 2000-2014, integrating deforestation, degradation and regrowth*
>80 %	4,583,778	5,778,415	-1,194,637
30 - 80 %	2,188,842	2,485,622	-296,780
1-30 %	1,462,931	953,070	509,861
Total	**8,235,551**	**9,217,107**	**-981,557**
Total >30%	***6,772,620***	**8,264,037**	**-1,491,417**

Accuracy of Hansen *et al.* product

The Hansen *et al.* (2013) deforestation product was published in the respected journal *Science*, with an accompanying website distributing the raw data[44] receiving hundreds of thousands of download requests over the subsequent months. Further, a website run by the World Resources Institute funded by governments, NGO's and the UN called Global Forest Watch allowed the querying and display of the data[45], receiving millions of views as well as widespread media coverage. The attention and widespread use of the data led to many attempts to validate its accuracy.

The original paper contained a rigorous validation exercise. Different biomes were treated separately; for the tropics, the focus here, 628 x 120m x 120m sample blocks were chosen, distributed between no change, gain and loss pixels. Local experts used time series of very high resolution independent remote sensing data to assess the proportion of forest loss or gain through the time series, and then these were compared

[44] https://earthenginepartners.appspot.com/science-2013-global-forest
[45] http://www.globalforestwatch.org/

to the original results. The test data were not used in generating the product, and so were independent. For the tropics the results suggested the product was unbiased (mean difference in loss per block is 0, with a Standard Error of ±0.5 %), and reasonably accurate, with a User's Accuracy of 87% for 'Loss' and 99.8% for 'No change'.

Uncertainty of forest loss data

A lack of historical field data made a Liberia-specific assessment of the accuracy of the Hansen et al. forest loss data impossible. Only the 2014 landcover map was validated by the field data collection in 2016, and no suitable historical data was found. This is contrary to guidance in the MDG, which suggests that global deforestation datasets should be compared to a large number of points, stratified randomly across the country, derived from either field data or high resolution remote sensing data.

An attempt was made to use L-band radar data available from 2007-10 to perform validation, but a lack of local biomass plot data made calibration of the data layers impossible. Without biomass plot data for calibration, it was not possible to ascertain whether a change in radar backscatter was sufficient to be deforestation or degradation, nor to set thresholds for forest/non-forest. Ultimately validation can only proceed if there is greater confidence in the test dataset (the L-band radar data) than the dataset to be validated: this was not possible in this case. Such validation could be performed going forward, if biomass data are acquired.

Similarly, an initial examination of available archives of high resolution optical data suggested no suitable time series of sufficiently high resolution imagery (<1.5 m) was available over the study period. At least 3 cloud-free images, each separated by at least 12 months, would have been necessary, and no suitable areas were detected after examining GeoEye, Worldview and SPOT archives. This situation has improved markedly since 2014 with many new satellites launched and an increased interest in collecting data over forests, but more recent high resolution data cannot assist with assessing the accuracy of historical change data.

Therefore we must rely on extensive independent ground truthing exercise performed by Hansen et al. (2013). In the Tropical climate domain they used local experts examining very high resolution imagery to assess 628 reference areas. These had an overall accuracy of 99.5 %, with a 95% confidence around that accuracy percentage of 0.2. However, the accuracy was much higher for the 'no loss' class (99.7 ±0.1 %) than the Loss class (87.0 ±4.7 %). The full error matrix is given in Table C3 below.

Table C3. Loss Error Matrix expressed as a percent of area. Data taken from Hansen et al. (2013), based on 628 observations over the tropical climate domain.

		Reference (%)		
		Loss	No Loss	Total
Map (%)	Loss	1.50	0.22	**1.72**
	No Loss	0.30	97.98	**98.28**
	Total	**1.80**	**98.2**	

Applying the Olofsson et al. (2013)[46] method this allowed an unbiased area estimate for the Reference Level, based on pantropical accuracy assessment data, divided by strata assuming an equal chance of error between the 30-80 and >80 % strata. This is shown in Table C4 for the whole reference period, but can also be applied evenly to every year.

Table C4. 95% confidence ranges and unbiased area estimates based on Hansen et al. (2013) ground truth data for entire reference period (2005-2014).

Class	Original area estimate (ha)	Unbiased area estimate (ha)	95 % Confidence interval (ha)	Minimum (ha)	Maximum (ha)
Unchanged forest	6,568,973	6,549,932	128,499	6,421,433	6,678,431
Deforested, forest 30-80%	97,472	103,605	46,692	56,914	150,297
Deforested, forest >80%	205,135	218,043	64,248	153,795	282,291
Total	6,871,580	6,871,580			

These can also be used to give adjusted means and confidence ranges for the deforestation rate over the period, as summarised in Table C5 below.

[46] Olofsson, P., Foody, G.M., Stehman, S.V., & Woodcock, C.E. (2013). Making better use of accuracy data in land change studies: estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment* 129:122-131

Table C5. Annual mean deforestation rates with 95% confidence intervals.

Class	Mean estimate of deforestation rate	95% Confidence interval on deforestation rate	Confidence interval proportion of total
Deforestation rate, forest 30-80%	1.137%	0.513%	45.1%
Deforested, forest >80%	0.382%	0.113%	29.5%

These give broad ranges for estimated deforestation rates. However, as these are based on a pantropical accuracy assessment, itself not stratified by forest type, these uncertainty ranges are themselves highly uncertain.

Hansen *et al.* did not report on percentage errors of Omission and Commission in their results, which are ideal for estimating the impact of errors on result statistics. Omission errors are where the map has missed deforestation that occurred in reality, and commission where the map predicts deforestation occurred in an area where in fact no change occurred. A number of studies in this area are ongoing, and are yet to be published as the typical research and publication cycle takes a minimum of 2-3 years. However two independent assessment are available:

1. Mitchard et al. (2015)[47] used 5m resolution RapidEye data and field knowledge to test the Hansen et al. data in the Brazilian Cerrado and Ghana's tall forest. Two different methods of interpreting the RapidEye data were used, giving slightly different results – manual interpretation of changes, and semi-automated classification. The overall findings were that the Hansen et al. data performed very well in the Brazilian Cerrado, with Commission and Omission rates both less than 15% overall. This example is probably most comparable to the Liberia case, with a mixture of tall forest, scrub and agriculture. In Ghana the Hansen et al. product was found to have performed poorly, missing extensive degradation occurring in tall forest blocks: but this is probably irrelevant to the Liberia example where the Hansen et al. data is not being used to assess degradation.
2. Muller et al. (2016)[48] assessed long term deforestation trends throughout the Brazilian Amazon, using their own deforestation assessment as well as the Hansen *et al.* dataset. They could not

[47] Mitchard, E., Viergever, K., Morel, V., & Tipper, R. Assessment of the accuracy of University of Maryland (Hansen et al.) Forest Loss Data in 2 ICF project areas. http://ecometrica.com/wp-content/uploads/2015/08/UMD_accuracy_assessment_website_report_Final.pdf

[48] Muller, H., Griffiths, P., & Hostert, P. 2016. Long-term deforestation dynamics in the Brazilian Amazon – Uncovering historic frontier development along the Cuiba-Santarem highway. *International Journal of Applied Earth Observation and Geoinformation.* 44, 61-69.

> conduct a formal accuracy assessment as their own classification only had an accuracy of 85%, but found that their results closely matched the Hansen *et al.* product in annual trends and absolute values, though with a slight tendency to underestimate total area through missing small clearings.

These results, while not specific to Liberia, suggest that the Hansen et al. data is sufficiently accurate to create unbiased estimates of forest change suitable for the further analyses done to estimate Reference Levels. If such data were to be used for MRV purposes we would recommend a combined ground and high-resolution remote sensing campaign, as will be detailed in Version 2.0 of the GFOI Methods and Guidance Document due out this summer, to further assess the specific accuracy of the Hansen et al. method by landcover type and size of disturbance in Liberia.

APPENDIX D: EXISTING BIOMASS DATA, ALLOMETRIC EQUATIONS AND BIOMASS EXPANSION FACTORS

Existing Biomass Data, Allometric Equations and Biomass Expansion Factors

Emission factors are measures of the emissions and removals of greenhouse gases per unit of activity data, usually expressed in units of t CO_2e ha^{-1}. Emission factors for land use change are generally developed by estimating biomass and carbon stocks of the relevant pools and land cover types.

Various sources of data may be used to estimate forest biomass and develop emission factors. Potential sources for generating emission/removal factors include:

- Carbon measurement inventories including ground measurement, **allometric equations** and remote sensing techniques. These rely on allometric models that relate the biomass of trees with certain measureable morphological features (e.g. diameter and height) to indirectly quantify aboveground and belowground tree biomass estimates.
- Forest or timber inventories that provide data on the number or trees per hectare or the volume of timber. These rely on **biomass expansion factors** to estimate aboveground biomass.
- Academic and other research studies that have previously produced biomass and/or carbon estimates.

Existing relevant Allometric Equations

The underlying data to estimate carbon stocks are collected during field inventories. These data are then converted to biomass estimates using allometric equations. However, before biomass data is collected a field team must determine which allometric equation(s) it will use, so that it knows what must be measured in the field. Live trees contain the majority of biomass in most forests, and the informed selection and verification of allometric models to estimate biomass is a crucial step in developing accurate estimates of forest carbon stocks[49].

[49] Biomass stocks are converted to carbon stocks using the IPCC default carbon fraction of 0.47.

There are a number of variables that are commonly used to estimate tree biomass. Most allometric equations are developed to estimate total aboveground biomass, however, some equations are created to estimate different components of the tree such as stem, branches, leaves etc. Variables commonly within equations include:

- Stem/trunk diameter at breast height (at 1.3 m aboveground; DBH)
- Stem diameter at stump height (DSH) (common for multi-stemmed trees)
- Basal area
- Total height
- Botanical identification
- Wood density
- Site quality
- Tree age (common for trees grown in plantations)
- Crown width (common for shrubs)
- Climate (environmental stress factor)

Of these variables, DBH and wood density are easiest to attain and provide the most reliable inputs (Brown 1997; Chave et al. 2005).

Developing allometric equations is a labour intensive and costly process. If an existing equation is found to be appropriate, it is much more cost effective to use that equation, rather than developing a country-specific equation. If possible, it is generally recommended to verify existing allometric equations by destructively sampling a small number of trees to directly measure biomass.

Equations have been developed across Africa and globally across the tropics. Tables D1 & D2 provide existing biomass allometric equations, including Africa specific equations (Table D1) and pan-tropical equations (Table D2). The following variables are used in these equations:

AGB = aboveground biomass (kg)
D = diameter at breast height, at 1.3 m aboveground (cm)
BA = basal area (cm^2)
H = height (m)
ρ = wood density (g/cm^3)
E = environmental stress factor (unitless)

Table D1: Select Region/Country specific allometric biomass equations for Africa

Area/ Country	Equation	Forest Type	n	R^2	Tree Size	Source
Central Africa, Congo Basin, Cameroon	$AGB = \rho * exp(-1.183 + 1.940 \times \ln(D) + 0.239 \times (\ln(D))^2 - 0.0285 \times (\ln(D))^3)$	Lowland tropical forest (moist forests)	138	0.988 RSE= 0.188	NA	Fayolle et al. 2013
Cameroon	$\ln(AGB) = -2.1801 + 2.5634 \times \ln(D)$	Moist tropical forest	443	0.9671 RSE=0.444	1-148cm DBH	Djomo et al. 2010
	$\ln(AGB) = -3.2249 + 0.9885 \times \ln(D^2 \times H)$		274	0.971 RSE=0.437	1-138cm DBH	
	$\ln(AGB) = -2.4733 + 0.2893 \times (\ln(D))^2 - 0.0372 \times (\ln(D))^3 + 0.7415 \times \ln(D^2 \times H) + 0.2843 \times \ln(\rho)$		274	0.9717 RSE=0.437	1-138cm DBH	
Cameroon	$AGB = -3.37 + (0.02483 \times D^2H)$	Regenerating tropical forest species	14	0.99	5-120cm DBH	Deans et al. 1996
	$AGB = -30.87 + 0.7684 * BA$					
Ghana	$AGB = 0.30 * D^{2.31}$	Tropical Rainforest, Wet evergreen forests	42	0.93	2-180cm DBH	Henry et al. 2010
Central Africa	$ABG=\exp(-4.0596+4.0624\times\ln(D)-.0228 \times (\ln(D))^2 + 1.4307 \times \ln(\rho))$	Evergreen rainforest mixed semi-deciduous species	101	0.944	11.8-109.4cm DBH	Ngomanda et al. 2014
	$ABG=\exp(-2.5680 + 0.9517 \times \ln(D^2\times H) + 1.1891 \times \ln(\rho))$					
	$AGB = 0.1083 \times (D^2 \times H)^{0.0138}$		30	0.99		
	$AGB = 0.0558 \times H^{0.0113}$		30	0.97		

Table D2. Pan-tropical allometric biomass equations

Life Zone	Equation	n	R^2 (adj)	*RSE*[50]	Tree size	Source
Dry	$AGB = 34.4703 - 8.0671 * D + 0.6589 * D^2$	32	0.67	*0.02208*	58-39 cm DBH	Brown et al. 1989
Moist	$AGB = 38.4908 - 11.7883 * D + 1.1926 * D^2$	168	0.78	*0.06181*	5-130 cm DBH	
	$AGB = \exp(-3.1141 + 0.9719 * \ln(D^2 * H))$	168	0.97	*0.1161*		
	$AGB = \exp(-2.4090 + 0.9522 * \ln(D^2 * H * \rho))$	94	0.99	*0.06079*		
	$H = \exp(1.0710 + 0.5677 * \ln(D))$	3824	0.61	*0.07495*		
Wet	$AGB = 13.2579 - 4.8945 * D + 0.6713 * D^2$	69	0.90	*0.02247*	5-110 cm DBH	
	$AGB = \exp(-3.3012 + 0.9439 * \ln(D^2 * H))$	69	0.90	*0.2110*		
	$H = \exp(1.2017 + 0.5627 * \ln(D))$	69	0.74	*0.4299*		
Dry	$AGB = \exp(-1.996 + 2.32 \times \ln(D))$	28	0.89		5-40cm DBH	Brown 1997
	$AGB = 10^{(-0.535 + \log_{10}(BA))}$	191	0.94		5-30cm DBH	
Moist[51]	$AGB = \exp(-2.289 + 2.649 \times \ln(D) - 0.021 \times \ln(D)^2)$	226	0.98		5-148cm DBH	
Wet	$AGB = 21.297 - 6.953 \times D + 0.740 \times D^2$	169	0.92		4-112cm DBH	
Dry	$AGB = \exp(-2.187 + 0.916 * \ln(\rho * D^2 * H))$	316	0.99	0.311	5-63.4cm DBH	Chave et al. 2005
	$AGB = \rho * \exp(-0.667 + 1.784 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	316	0.99	0.356		
Moist	$AGB = \exp(-2.977 + \ln(\rho * D^2 * H))$	1349	0.99	0.311	5-138cm DBH	

[50] All Brown et al. (1989) values listed in this column for are MSE, not RSE

[51] The moist equation is updated from Brown 1997 with additional destructive sampling data and a new form of the equation

Life Zone	Equation	n	R^2 (adj)	*RSE*[50]	Tree size	Source
	$AGB = \rho * \exp(-1.499 + 2.148 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	1349	0.99	0.356		
Wet	$AGB = \exp(-2.557 + 0.940 * \ln(\rho * D^2 * H))$	143	0.99	0.311	5-133cm DBH	
	$AGB = \rho * \exp(-1.239 + 1.980 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	143	0.99	0.356		
Pantropical	$\ln(AGB) = -1.8222 + 2.3370 \times \ln(D) + 0.1632 \times (\ln(D))^2 - 0.0248 \times (\ln(D))^3 + 0.9792 \times \ln(\rho)$	1816	0.973	0.3595	>10cm DBH	Feldpausch et al. 2012
	$\ln(AGB) = -2.9205 + 0.9894 \times \ln(D^2 \times \rho \times H)$	1816	0.978	0.3222	>10cm DB	
Pantropical	$AGB = 0.0673 * (\rho * D^2 * H)^{0.976}$	4004		0.357	5-180cm DBH	Chave et al. 2014
	$AGB = \exp(-1.803 - 0.976 * E + 0.976 * \ln(\rho) + 2.673 * \ln(D) - 0.0299 * (\ln(D))^2)$	4004		0.431		

With a multitude of varying options for calculating AGB, a pan-tropical allometric equation, such as Chave et al. (2005, 2014), is extremely useful. The validity of the Chave et al (2005) equation has been confirmed in studies across Africa, areas where uncertainty in the 2005 models was thought to be due to climatic variations. Chave et al. (2014) published an improved allometric equation inclusive of a variable representative of climatic effects on tree growth. In many cases, these pan-tropical equations have been shown to be more reliable than country-specific equations, primarily due to increase sample size (Goslee et al, 2015). Therefore, the Chave el at 2014 equation is recommended for use in Liberia, in association with relevant inventory data.

Use of biomass expansion factors

Allometric equations are one way to use measurement to estimate above ground tree biomass and therefore carbon, but tree biomass can also be estimated from volume over bark of merchantable growing stock wood (VOB) by "expanding" this value to take into account the biomass of the other aboveground components – this is referred to as the biomass expansion factor (BEF) (Walker et al. 2013).

When data on tree volumes exist the BEF can be used to estimate a trees biomass and therefore carbon (Goslee et al. 2015). Above ground biomass can be estimated base on existing volume per ha data. The primary data needed for this approach is VOB/ha and a volume-weighted average wood density (oven dry mass per unit of green volume in t/m^3).

Biomass density can be calculated from VOB/ha by first estimating the biomass of the inventoried volume and then "expanding" this value to take into account the biomass of the other aboveground components as follows:

$$\text{Aboveground biomass density (t/ha)} = \text{VOB} * \text{WD} * \text{BEF}$$

Where:

VOB = volume over bark of free bole from stump or buttress to the crown point or first main branch (m^3/ha)
WD = volume-weighted average wood density (t/m^3)
BEF = biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume, unitless)

The IPCC (2006) report provides a method for using VOB to estimate the AGB of forests—in this report it refers to the Biomass Conversion and Expansion Factor (BCEF) that is the product of the BEF and wood density and values of BCEF are given for a range of VOB classes. The values for tropical humid natural forests range from 9.0 (range 4-12) for a VOB of <10 m^3/ha to 0.95 (range 0.7-1.1) at VOB >200 m^3/ha (Table 4.5 in Vol. 4, Ch. 4 of IPCC 2006).

Existing relevant Biomass Data

Once an allometric equation is selected field measurements can commence. Traditional ground-based forest inventories are based on statistical sampling, where field data of easily measurable tree parameters, such as diameter at breast height (DBH measured at 1.3 m from the ground) are collected. Collecting carbon stock information for several samples (plots) across the population of interest generates summary statistics about the population, such as the mean (average) carbon stock, and the measured variation among samples. Tables D3 and D4 below show carbon stock data for two specific regions in Sierra Leone and Guinea Bissau that could relate to carbon stock in Liberia.

Table D3. Above and below ground tree carbon stocks ($C_{AB\_Tree,I}$ and $C_{BB\_Tree,i}$, respectively) and soil carbon stocks ($C_{SOC,i}$) for the Gola Rainforest National Park in Sierra Leone in t CO_2e ha^{-1} (Netzer and Walker, 2013).

Carbon Pool	Strata 1 (GRNP Central/North)				Strata 2 (GRNP South)			
	Number of Plots	Mean Stock	95% CI	95% CI as % of mean	Number of Plots	Mean Stock	95% CI	95% CI as % of mean
		t CO_2 ha^{-1}				t CO_2 ha^{-1}		
$C_{AB\_Tree,i}$	353	654.7	48.4	7%	49	582.5	76.6	13%
$C_{BB\_Tree,i}$		157.1	11.6	7%		139.8	18.4	13%
$C_{SOC,i}$	18	253.9	30.6	12%	29	192.3	24.4	13%

Both strata in the Gola Rainforest National Park (GRNP) in Sierra Leone can be classified as moist evergreen forest. The results of this extensive survey work showed that the forests across the GRNP were relatively homogenous in species composition (same forest type), however there were significant differences in carbon stocks between Gola South, and Central/North. It was hypothesized that the difference between the stocks in the 2 areas was due to past management histories, the southern block having been more extensively logged than the central or northern blocks, thus resulting in a forest with lower carbon stocks but with potential for significant re-growth.

Table D4. Above ($C_{AB\_Tree,i}$) and below ($C_{BB\_Tree,i}$) ground tree carbon stock) for closed forest in Canthanhez Park in Guinea Bissau in t CO_2e ha^{-1} (Amaro et al., 2012).

Carbon Pool	Number of Plots	Mean Stock	95% CI	95% CI as % of mean
		t CO_2 ha^{-1}		
$C_{AB\_Tree,i}$	45	320.3	15.26	17%
$C_{BB\_Tree,i}$	45	85.9	4.53	19%

The Cantanhez National Park in Guinea Bissau, with an area of 106,500 hectares is located in the administrative region of Tombali, covering the Bedanda sector in Guinea Bissau. Cantanhez forests represent the latest patches of sub-humid forest which form part of a larger area that extends to the south, into Guinea Conakry. Terrestrial vegetation in the Cantanhez Park consists of patches of dense mature forest in a mosaic of patches of secondary forests from cultivation and fallow by shifting agricultural practices. Mangroves cover a large proportion of the area of the park, particularly to the south and western regions, in the margins of the Cumbijã River (Amaro et al., 2012).

In addition to these data from nearby regions, there have been some studies estimating carbon stocks within Liberia. In 2005 and 2006, a forest inventory was conducted, with 405 sampling clusters located across the country, covering five different land cover classes, including three forest classes: agriculture degraded forest, open dense forest, and closed dense forest. However, due to accessibility and time constraints, data were collected on only 167 clusters, 127 of which were on forest classes (Hess and Trainer, 2006). The carbon values estimated based on this inventory data are provided in Table D5, however, the inventory did not meet its minimum criteria for a standard error ±10% (Ebeling and Asare, 2011). Liberia's R-PP states that error estimates from this inventory were too high to allow its use to develop a database of biomass stocks.

Table D5. Carbon estimates based on Liberia's National Inventory (adapted from Ebeling and Asare, 2011).

Forest type	Number of clusters	AGB	BGB	Total
		t CO_2 ha^{-1}		
Agriculture degraded forest	18	400	81	480
Open Dense Forest	42	598	114	711
Closed Dense Forest	67	631	121	752

Additionally, in 2011, an initial carbon stock assessment and capacity building exercise was conducted on the Wonegizi REDD+ project in Lofa County. During this exercise, three one hectare plots were established, one in each of three land cover types: forest, coffee, and cocoa. From the forest plot, aboveground carbon stocks were estimated at 108 t C/ha (Asante and Jengre, 2010). A more complete inventory was conducted on the Wonegizi project in 2013. In this effort, carbon stocks were established for primary forests (718.7 t CO_2e) and secondary forests (392.3 t CO_2e), based on a total of 37 plots (FFI and RSS GmbH, 2014).

Gaps in Existing Data

Although some carbon stock data exist in the region as described above, there are no existing data in Liberia that can be used to develop reliable country-specific emission factors or to assess whether existing data correlate closely enough to Liberia forest carbon stocks. To develop these, therefore, it would be necessary for Liberia to develop a forest sampling scheme and undertake a forest inventory (an annex providing further guidance on this will be provided in the final report). It is recommended that such an inventory be conducted when time and resources allow, in order to develop an estimate of carbon stocks and emission factors with an acceptable uncertainty level.

However, because this is outside the scope of this current effort, we must rely on existing datasets from outside Liberia to develop emission factors. These datasets can be used to develop Tier 1 emissions factors, because while they are not based on IPCC defaults, they are also not derived from country-specific data, as required to Tier 2 emission factors. Recommendations for the capacity and resources needed to develop Tier 2 emission factors will be provided in the final capacity building strategy and the final report.

Global Biomass Datasets

There have been two widely publicised maps of pantropical aboveground biomass: Saatchi et al. (2011) which is at a 1 km resolution, and Baccini et al. (2012) at a 500 m resolution. Both are produced using broadly similar methods, extrapolating rare forest height measurements from a LiDAR satellite that operated in the mid-2000's (ICESat GLAS) using other remote sensing data (mostly MODIS). The height estimates from GLAS are in both cases converted to aboveground forest biomass using a few hundred field plots – the actual plots and allometric equations used do differ between the studies. Similarly they differ by date – the Saatchi et al. map is for the early 2000's, Baccini et al for 2007.

The two maps have been compared to each other, finding significant differences (Mitchard et al. 2013), and compared to field data finding some potentially large regional biases (Mitchard et al. 2014), but are thought useful as a first estimate of aboveground biomass distribution in a region. It was thought interesting to compare these two for Liberia, and use them to find an approximate biomass value stored within the different forest classes identified.

Recently, a 'consensus' map has been produced using inputs from these two pantropical maps and a dataset of field plots and local high resolution maps covering almost 15,000 1 km pixels (Avitabile et al. 2015). This map is expected to have lower regional biases, and contains plots from within Liberia itself as well as various other countries in West Africa. This dataset is also included in the comparison.

Maps

The maps (Figure D1) produce strikingly different distributions of biomass across the country: the figure below shows the three maps displayed with an identical scale.

Baccini et al. **Saatchi et al.** **Avitabile et al**

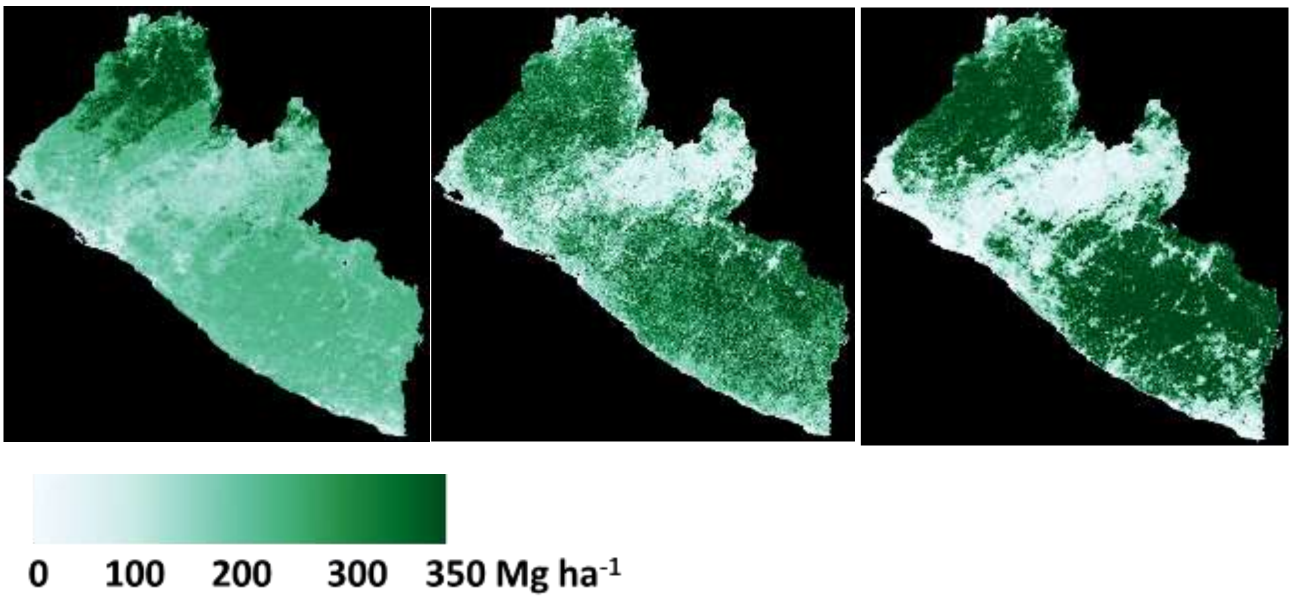

Figure D1. Maps showing distribution of forest biomass in Liberia, based on available global datasets.

In particular the Baccini et al map predicts high AGB only in the north of the country, whereas the Saatchi et al. and Avitabile et al. maps predict far higher biomass in the north and south of the country, and to the west. There is also more contrast between high and low biomass areas in the Saatchi et al. than Baccini et al. map, and more still in the Avitabile et al. map.

Total Carbon Stocks

The mean biomass and total carbon stock predicted by the Saatchi et al. and Baccini et al. maps differ, but not by as much as might have been thought looking at the maps (Table D6). The lower AGB values in agricultural areas in the Saatchi map cancel out its higher values in the forested areas to some extent. The Avitabile et al map on the other hand predicts considerably higher AGB – it has a larger area of high biomass forest than the other two, but also has far higher values, going up to 567 Mg ha^{-1} for its highest pixel, compared to 423 Mg ha^{-1} in Saatchi et al. and 435 Mg ha^{-1} in Baccini et al.

Table D6. Biomass values across Liberia based on three global datasets. ***(Carbon is calculated by multiplying biomass by 0.47. It should be noted that both forest and non-forest land is included in the 'per ha' figures, which is appropriate as these are 1 km maps, but means that these numbers will be an underestimate compared to forest area alone.)***

Product	Mean biomass per ha
Baccini et al. (2012)	188.7 Mg ha^{-1}
Saatchi et al. (2011)	209.7 Mg ha^{-1}
Avitabile et al. (2015)	244.9 Mg ha^{-1}

Mean aboveground biomass density by vegetation type

The three maps were queried to calculate the mean carbon stock in the three forest classes identified by Metria/GeoVille in their 2014 landcover map of Liberia at a 5 m resolution.

Table D7. Carbon stocks in Liberia by forest class, based on global datasets, shown in CO_2e ha^{-1}

Forest Class	Baccini et al.	Saatchi et al.	Avitabile et al.
	t CO_2 ha^{-1}		
Forest >80%	364	436	566
Forest 30-80%	317	333	365
Forest <30%	291	311	302

The biomass values increase in step between the three maps, as would be expected given their overall biomass numbers. However, of particular interest is the increased contrast between vegetation types from Baccini to Saatchi, then Saatchi to Avitabile. The highest canopy cover forest class is only 25 % bigger than the lowest cover in the Baccini map, but 87 % bigger in the Avitabile map. We would expect a big difference in stocks between these classes, so this suggests the Avitabile map could be the most reliable. In addition, the Avitabile carbon stocks are based on actual field data collected in Liberia (albeit limited) and used to locally weight and average the Baccini and Saatchi maps. Further, the overall carbon stocks are more in line with the values that have been collected in Liberia (see Table D7). For this reason, it is expected that the Avitabile data provide a more accurate estimate of carbon stocks in Liberia. Nonetheless, we have used the Baccini estimates to develop provisional emission factors, as they are more conservative, and therefore less likely to overestimate historical emissions. Regardless, this constitutes only Tier 1 emissions factors, which may not be accepted by FCPF or UNFCCC. It is therefore highly advisable for Liberia to develop country-specific emissions factors.

APPENDIX E: RECOMMENDATIONS FOR IMPROVING DEFORESTATION ACTIVITY DATA FOR LIBERIA

Assessing deforestation rates in the past for Liberia is limited by two factors: the availability of satellite data and the availability of field data. These factors are far less limiting in the future, with satellite data provision (for both unrestricted and commercial data) far more plentiful from 2014-15 onwards. There is therefore more scope to improve mapping of deforestation for MRV purposes than for improving past Activity Data, but both can be improved from current estimates.

Here are provided 1) options for developing activity data under the future MRV, and 2) potential methods for improving estimates of historical emissions.

Recommendations for historical Activity Data mapping

Improving the current maps of past activity data is limited by data availability, in terms of both satellite data and field data. While the methods described in this report are appropriate for developing Approach 3 activity data, they could be improved if time and resources allow. The methods described here could improve the accuracy of forest change and activity data estimates, but would require significant investment to undertake. Therefore, Liberia must decide if such improvement are required and/or desired.

The recommended method below (Box 4) relies on a combination of the purchase of high resolution optical data and analysis of mosaics of free Landsat data. The accuracy would likely be higher than using the Hansen et al. dataset, not because the input data quality would be higher, but because the forest/non-forest definition and forest classifications would be tuned to Liberia.

If high resolution and Landsat data approach is considered unfeasible due to a lack of cloud free data, an alternative method could be considered, still using high resolution optical data for training/testing, but using radar data rather than Landsat data for the classification. However, radar data is only available from 2007 onwards, which would not span the range of the Reference Period, and thus would not be an ideal choice.

Box 3. **Overview of Historical Land Cover Map Creation Option**

Below is an overview of the steps required to develop a series of land cover maps as an alternative to using the Hansen et al database. This is not required and involves significant financial and human resources.

1. Mapping past deforestation

1.1. High resolution reference data order and download

1.1.1. Reference data is needed to calibrate and validate the past forest/non-forest maps. As no suitable historical field data exists, we recommend the use of hyperspatial remote sensing data with a resolution smaller than 2.5 m per panchromatic pixel, so individual trees can be seen.

1.1.2. Such data is available from three satellites earlier in the time period: the IKONOS (launched 2000, 1 m resolution) QuickBird satellite (launched 2001, 80 cm resolution) and SPOT 5 (launched 2002, 2.5 m resolution). The range of satellites increases from 2007 with the launch of WorldView satellites and further SPOT satellites.

1.1.3. Data availability over Liberia is not very high, due to cloud cover and few commercial clients ordering data for forest monitoring in the mid-2000's. We therefore recommend an opportunistic approach to finding data stacks, involving archive searches on all commercial satellite archives with sufficient resolution throughout the period.

1.1.4. Ideally a set of high resolution training areas (at least 3), each at least 500 km^2 in size, would be found, with high resolution data stacks at least 3 deep available. For example, ideally three contrasting areas could be found with high resolution observations c. 2003, 2007, 2010 and 2015.

1.2. Landsat data preparation

1.2.1. Landsat 5, 7 and 8 data should be downloaded covering all of Liberia, with years matching those in the training data series. At least four dates should be used, for example 2005, 2008, 2011 and 2014.

1.2.2. For each year, cloud-free scenes from as close as possible at date to each other should be mosaicked. Any remnant clouds should be filled in by other scenes from the same year, or where necessary, pixels from the year before or after. Colour balancing should be performed to match the spectral characteristics of the mosaics, using for example the features in the Semi-

Automated Classification Plugin in QGIS (open source), or the in built mosaicking tool in ENVI (commercial software).

1.2.3. For 2015, the Landsat 8 mosaic already prepared by Geoville/Metria could potentially be used.

1.3. **Creating training data from high resolution optical data**

1.3.1. Classifying hyperspectral remote sensing data can produce low accuracy products, as shadows, texture, different look angles and phenology can all lead to confusion in automated classifiers. By contrast, a trained human interpreter can normally assess whether a given pixel is over a tree or bare ground with high accuracy. Therefore the data will be analysed by creating virtual plots on the high resolution data and giving % canopy cover values to 1 ha square regions of data.

1.3.2. Using QGIS (or other GIS software) 1000 random points should be generated in each of the three areas where hyperspectral image stacks are available. Around each point, a 100 x 100 m square plot with a 1m grid of points should be created.

1.3.3. A team of interpreters should classify each point within a plot as either 'tree' or 'not-tree'. It is recommended that each plot is classified at least twice, blind, by different interpreters, in order to confirm that results are accurate. If the different classifications agree on a total canopy cover for the plot within 10%, the result should be averaged; if they differ by more than 10 % a third interpretation should be performed, or the plot removed.

1.3.4. The grid of points is converted to a canopy cover % for that hectare, resulting in 3000 training points spread across the country.

1.4. **Classification**

1.4.1. The training data in 3.3 would be used to classify the Landsat data prepared in 3.2. The most accurate results would come from the use of just two classes, non-forest (canopy cover <30% as one class) and forest (canopy cover >30 % as the other class). However, the forest class could, if desired, be split into more classes to produce more useful, if less accurate, results. A cut off for high canopy cover forest of >80%, as used by the Metria/Geoville classification, worked reasonably well for the 2014 map.

1.4.2. The best classification result would probably come from the use of proprietary software, for example the use of the Support Vector Machine or Neural Network algorithms in ENVI[52], or an object-based approach using Ecognition[53]. However very good results could probably be achieved from using open source software such as R (where RandomForest[54] or other tools could be used to perform a robust machine learning classification), or using the Semi-Automated Classification plugin[55] in QGIS.

1.4.3. The map accuracy should be tested by withholding 50 % of the training data for testing purposes. A forest/non-forest accuracy of >90 % should be achievable, ideally >95%. If the forest class is split into more classes, the accuracy between these classes would be good if >85%.

1.5. **Validation**

1.5.1. As stated above, the classifier would be tested by holding back 50 % of points. This will provide an accuracy assessment for the classifications only. It does not validate the change map performed by differencing the classifications produced in 2003 with 2007, and so on, as most of the ground truth points will not have changed class in that period.

1.5.2. Instead therefore the change map should be validated after creation by targeting 'change' pixels in the Landsat maps within the boundaries of the three high resolution areas. 300 random change pixels and 300 random unchanged pixels within each of three areas, for each change period, should be assessed by eye against the high resolution data and marked as 'changed or unchanged'. The operator performing this validation should not be informed whether the pixels being checked as changed or unchanged, nor whether the change direction is positive or negative.

1.5.3. This will allow a calculation of the error and bias of the deforestation product

1.6. **Estimated costs**

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[52] http://www.exelisvis.co.uk/ProductsServices/ENVIProducts/ENVI.aspx
[53] http://www.ecognition.com/
[54] https://cran.r-project.org/web/packages/randomForest/index.html
[55] https://plugins.qgis.org/plugins/SemiAutomaticClassificationPlugin/

1.6.1. Data costs for archive SPOT data is approximately $3/km^2$ (for 2.5 m Pansharpened colour), or for Quickbird/IKONOS around $15/km^2$. In both cases discounts may be available. For the 1500 km^2 x 4 periods requested that suggests a total cost of about $18,000 for SPOT 5 imagery (2.5 m resolution) and $90,000 for IKONOS/Quickbird (<1 m resolution). [*accuracy is likely to be higher for IKONOS/Quickbird, but it is not clear if that would be worth the price premium. In reality, due to data availability, it may be necessary to use a combination of the two, and maybe other sensors too*].

1.6.2. Data interpretation and processing is high with hyperspatial data, and with mosaicking large volumes of Landsat data for colour balancing and cloud removal. This task could probably be done in Liberia with a team of 3-4 GIS specialists working for a year, with appropriate training and support, and access to commercial software licenses such as ENVI (c. $6000/license, discounts may be available). Alternatively an external consultant could commit to this for about 200-300 skilled days work.

Recommendations for activity data mapping from 2016 onwards

While it would be possible to rely on the Global Forest Watch (Hansen et al. 2013) product, used for calculating the Activity Data for Liberia's Reference Level, for MRV, this has various disadvantages.

a) The data are released about a year in arrears – for example the site[56] that allows a user to download the raw data (rather than just visualise it as with Global Forest Watch) is still giving 2014 as the final year of deforestation available, and it is now 8 months after 2015 finished.
b) There is no guarantee that these data will be produced in a similar manner in perpetuity, so relying on them would be a substantial risk.
c) The 30 m resolution is quite coarse, especially compared to the 10 m resolution Metria/Geoville map for 2014 – this may reduce the accuracy of the results.
d) The deforestation data is binary, reporting forest loss only regardless of starting class. No classification by canopy cover has been performed in this dataset since 2000. Liberia will need to perform a process of stratification, updated frequently, in order to assign

[56] http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html

losses to different strata: the Hansen et al. data will not provide this stratification, so further mapping will be necessary.

e) No annual gain data layer is given by Hansen et al. There is a gain product, but it is not given a year, unlike for deforestation. Thus it is not possible to produce a net deforestation figure from these data, which would not allow for complete reporting under IPCC and MGD guidance.

f) Forest loss can only occur in a pixel once, so a pixel that was deforested in 2001 is never again reported as deforested. As the length of the dataset increases this is becoming ever more of a problem, especially in an area with rapid tree growth such as Liberia. This will over time lead to an under-reporting of deforestation rate if these data are used, as deforestation in pixels that have regrown into forest, and then are deforested again, will not be reported.

As a consequence we would not recommend continuing to use the Hansen et al. dataset for monitoring forest loss in Liberia in the future. Here we present two possible alternative methods that are recommended (Box 5).

Box 4. **Two approaches for monitoring forest cover change over time into the future**

Option 1:

1 Optical data at 10 m resolution

Geoville & Metria successfully produced a landcover map for Liberia in 2014 using a combination of 5 m resolution RapidEye and 30 m resolution Landsat 8 data. The most obvious way to monitor deforestation, and more general land use change, in Liberia, would therefore be to continue the methods they have used successfully.

RapidEye is a commercial satellite and charges for data; Landsat 8 is free but its 30 m resolution is relatively coarse, and no successor satellite has yet been fully funded by the US Government. Landsat 7 is still operational but it has a significant problem in terms of stripes in the data caused by its Scan Line Corrector failing in 2003, therefore if Landsat 8 was to fail there would be a significant data gap. Landsat 9, if funded, is currently expected to launch in 2023, 5 years after the 5-year design lifetime of Landsat 8. A potential solution to the cost problem with RapidEye, and resolution/data supply risk of Landsat, has emerged with the launch of Sentinel 2. This is an EU-funded set of operational satellites, part of the Copernicus program, which commits to having two of each operational satellites in orbit continuously well into the 2030's, with continuity of design and data supply. Like Landsat, the data are to be distributed in an unrestricted format.

Sentinel 2 is a 10 m resolution satellite with bands similar to those on Landsat (more extensive than those on RapidEye), and a frequent revisit time (10 days currently, every 5 days once two satellites are operational in 2017, compared to every 16 days for Landsat 8). This combination of high resolution, zero data cost, frequent revisits, and a commitment to data provision over a long period, makes Sentinel 2 our recommended sensor for monitoring Liberia's forests.

A recommended method follows below

1.7. Sentinel 2 data collection and pre-processing

1.7.1. The frequent observations of Sentinel 2 allows for data to be collected during a single season. We recommend downloading all scenes with a cloud cover <20 % during January and February of each year, starting with 2016. This 2-month window is chosen partly as it is during the height of the dry season in Liberia, when the difference between forest and non-forest pixels should be at their greatest, and partly for reporting ease: reporting change January-January will allow for the fastest possible reporting of a previous year's deforestation.

1.7.2. Scenes should be downloaded at Level 2A. There are various data hubs available for data download, it may be to Liberia's advantage to set up an International Data Hub agreement with the European Union, but it could otherwise use one of the other data hubs for example the general Scientific/Other Use Data Hub[57]

1.7.3. The scenes should be mosaicked, choosing for each pixel the earliest possible cloud free observation. Clouds and cloud-shadow should be identified using the standard Quality Indicators which flag clouds and cloud shadows. Simple software could be developed to automatically download the data and perform the step of choosing the most recent cloud free pixel, for example using open source software such as the Sentinel Toolbox and GDAL, held together using python code.

1.7.4. It may be that, for a small subset of pixels, no cloud free observations were made in February. In that case targeted download of scenes from March, and the previous December might be necessary to fill in the gaps.

1.8. Collecting training data

[57] https://scihub.copernicus.eu/

1.8.1. At its most basic all that is needed for training data is a set of points collected in the January of each year stating whether they are 'forest' or 'non-forest'. There are options for collecting these data:

a) These could be physical assessments in the field, involving teams of two people with a GPS, a camera and a means of assessing canopy cover (for example a curved mirror or hemispherical lens for the camera). Ideally they would collect points randomly across the country, but a series of say 200 points within a set of 10 'super-sites' (10km x 10 km areas containing a range of forest types) spread across the country would be sufficient

b) Alternatively these could be marked on an image through the use of <1.5 m resolution satellite data, where individual tree canopies are visible. This might be cheaper than option a) and could be as, if not more, accurate. As with a), potentially 10 x 10km x 10km areas could be spread across the country, with data collected from the Pleides or Worldview constellations

1.8.2. Alternatively, more ambitiously, this task could involve a full landcover mapping exercise. In this case a set of about 8 classes, including 2-3 forest classes, could be attempted, duplicating more closely the Geoville/Metria classification with the benefit of being able to track the land use post deforestation. This would only be possible with a large scale field campaign, involving many more teams and points than for 1.2.1. It is not likely that a remote-sensing only campaign would be possible here (as in b. above), because land use is hard to assess without ground knowledge.

1.9. Classification

1.9.1. Classification would be performed using the annual Sentinel 2 mosaic and the ground truth data. Further 'truth' data points could be added to the process from obvious classes, for example from water bodies (lakes, rivers), and obvious non-vegetated areas.

1.9.2. While the classification should be performed using the 10 m resolution data, we would recommend a Minimum Mapping Unit (minimum possible object size) of 1 ha, to match with Liberia's forest definition. Experimentation may show that this should be reduced to say half a hectare for non-forest classes for best results.

1.9.3. The best classification result would probably come from the use of proprietary software, for example the use of the Support Vector Machine or Neural Network algorithms in ENVI[58], or an object-based approach using Ecognition[59]. However very good results could probably be achieved from using open source software such as R (where RandomForest[60] or other tools could be used to perform a robust machine learning classification), or using the Semi-Automated Classification plugin[61] in QGIS.

1.9.4. The map accuracy should be tested by withholding 50 % of the training data for testing purposes. A forest/non-forest accuracy of >95 % should easily be achievable, ideally >99%. If a wider landcover classification is attempted (e.g Option 1.2.2.), the forest/non-forest classification should still exceed 95%, with accuracy for classes below that >90%.

1.10. **Validation**

1.10.1. As stated above at the same time as the test dataset is collected, enough points would be collected for an independent test dataset for the classification. Typical best practice is to hold back 50 % of points for training and 50 % for testing. This will provide an accuracy assessment for the classification. However, it does not validate the change map performed by differencing the classifications produced in 2016 to 2015, and so on, as most of the ground truth points will not have changed class in that period.

1.10.2. Instead therefore the change map should be validated after creation by targeted field visits to a random set of pixels highlighted by the dataset

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[58] http://www.exelisvis.co.uk/ProductsServices/ENVIProducts/ENVI.aspx
[59] http://www.ecognition.com/
[60] https://cran.r-project.org/web/packages/randomForest/index.html
[61] https://plugins.qgis.org/plugins/SemiAutomaticClassificationPlugin/

as 'changed', and a nearby random set of pixels that are 'unchanged'. The number of changed and unchanged pixels visited should be equal, and we would recommend at least 500 points of each type are visited, spread across ideally 10 areas of the country.

1.10.3. In each case the visited point would be located using a GPS, and photographs and a canopy cover assessment made to decide if the point was forest or non-forest. Signs of obvious recent human activity, for example tree stumps or burn scars, would be recorded.

1.10.4. This will allow a calculation of the error and bias of the deforestation product

1.11. **Estimated costs**

1.11.1. Provided sufficient investment in the physical and network infrastructure, and training, the above protocol could be performed entirely within Liberia. This would have the biggest long-term benefits by developing data processing expertise and ensuring data ownership within Liberia. However, the costs for this option are likely to be high.

1.11.2. Alternatively, an external consultant could provide the mapping services following this protocol, and oversee and provide training for the fieldwork component.

1.11.3. Either way, the initial set-up costs in terms of setting up a software pathway and physical infrastructure could be high and hard to estimate. Once set up though, the fieldwork component could be conducted using existing staff in the FDA or other Liberians at relatively low cost (perhaps 150-200 person days, plus transport and subsistence costs), and the data processing task would involve perhaps 120 days of two GIS Technicians plus 20 days of Management.

Option 2:

2. **L-band radar data at 20 m resolution**

L-band radar from the ALOS PALSAR (2007-2011) and ALOS-2 PALSAR-2 (2014-) satellites has been successfully used for mapping aboveground biomass, degradation and deforestation in landscapes similar to those found in Liberia (e.g. in neighbouring Sierra Leone[62], in forest-agriculture mosaics in Peru[63],). However, this more sophisticated use does not prevent it being used solely to reliably map simple change from forest to non-forest classes. Indeed, JAXA produced a well-regarded forest/non-forest product from ALOS PALSAR for 2007-2011 at an impressive 10m resolution[64]: it is not well calibrated for Liberia's forests, but suggests that such a product could be easily produced.

ALOS-2 PALSAR-2 data is not freely available, and thus data would have to be purchased. However, it does have various advantages over optical data: it does not suffer from cloud cover as the sensor can see through clouds, and it is only sensitive to trees, with grasses and crops having little effect. Therefore, if well calibrated, it can produce very high quality maps of forest and non-forest suitable for detecting deforestation at high accuracy.

A recommended method follows below

2.1. ALOS-2 PALSAR-2 Data download and pre-processing

2.1.1. We recommend that the first scenes collected across Liberia each year are ordered and downloaded. It is expected that a complete mosaic will be possible using scenes collected in January and early February.

2.1.2. Scenes should be ordered in the 'Fine', 9.1 x 5.3 m resolution mode, as 70 x 70 km tiles. Level 1.1. data should be ordered for best results, though if capacity (physical and digital) is not high enough level 2.1 data, which is terrain corrected and geocoded already, would reduce download size and processing without greatly reducing accuracy.

2.1.3. At the time of writing, the cost per scene is YEN300,000 from http://en.alos-pasco.com/offer/price.html, approximately $3,000. However we would expect a discount of at least 30 % would be available given the high volume and use of the data, and it is possible data would be provided free of charge through Japanese aid programs or their Kyoto and Carbon program, given the use case here.

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[62] http://database.v-c-s.org/sites/v-c-s.org/files/VCS+CCB+MonitoringImplementationReport%20SUBMITTED%2025Aug2015.pdf

[63] http://iopscience.iop.org/article/10.1088/1748-9326/10/3/034014/meta

[64] http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm
http://www.sciencedirect.com/science/article/pii/S0034425714001527

2.1.4. 34 scenes are required to cover Liberia, and all should be downloaded for January 2015, January 2016, etc.

2.1.5. Data pre-processing would involve terrain correcting, multilooking and geocoding the data using open source software such as the Sentinel-1-toolbox[65], or commercial software such as SARscape within ENVI[66] or GAMMA[67]. The 30 m SRTM DEM should be used, unless another is available. As stated in 2.1.2, if the capacity is not available to use these software, then data download at level 2.1 would skip this step, and the processed scenes could be directly mosaicked using software such as QGIS or ArcMap. However the terrain correction and data quality would be lower.

2.2. **Collecting training data**

2.2.1. At its most basic all that is needed for training data is a set of points collected in the January of each year stating whether they are 'forest' or 'non-forest'. There are options for collecting these data:

c) These could be physical assessments in the field, involving teams of two people with a GPS, a camera and a means of assessing canopy cover (for example a curved mirror or hemispherical lens for the camera). Ideally they would collect points randomly across the country, but a series of say 200 points within a set of 10 'super-sites' (10km x 10 km areas containing a range of forest types) spread across the country would be sufficient

d) Alternatively these could be marked on an image through the use of <1.5 m resolution satellite data, where individual tree canopies are visible. This might be cheaper than option a) and could be as, if not more, accurate. As with a), potentially 10 x 10km x 10km areas could be spread across the country, with data collected from the Pleides or Worldview constellations

[65] http://step.esa.int/main/toolboxes/sentinel-1-toolbox/
[66] http://www.sarmap.ch/page.php?page=sarscape
[67] http://www.gamma-rs.ch/no_cache/software.html

2.3. **Classification**

2.3.1. Classification would be performed through a simple threshold on the HV polarisation data: the ground truth data would be used to assign a threshold HV value where a pixel is forest, and all pixels below that point would be classified as ‘non-forest’ and those above would be ‘forest’.

2.3.2. Half the ground data should be used to develop this threshold, the other half to test it. If the accuracy is not sufficiently high (<95%), then the landscape should be split using the stratification, performed elsewhere, and the classification process performed separately for the different strata. We would then expect an accuracy in excess of 95% compared to the ground data.

2.3.3. The classification should be performed at 20 m resolution, but post-processing after the classification should remove any remaining ‘forest’ patches with a size smaller than 1 ha, as these are not, in fact, forest, by Liberia’s definitions.

2.3.4. A comparison of the annual maps will give areas of deforestation and regrowth.

2.4. **Validation**

2.4.1. As stated above at the same time as the test dataset is collected, enough points would be collected for an independent test dataset for the classification. Typical best practice is to hold back 50 % of points for training and 50 % for testing. This will provide an accuracy assessment for the classification. However, it does not validate the change map performed by differencing the classifications produced in 2016 to 2015, and so on, as most of the ground truth points will not have changed class in that period.

2.4.2. Instead therefore the change map should be validated after creation by targeted field visits to a random set of pixels highlighted by the dataset as ‘changed’, and a nearby random set of pixels that are ‘unchanged’. The number of changed and unchanged pixels visited should be equal, and we would recommend at least 500 points of each type are visited, spread across ideally 10 areas of the country.

2.4.3. In each case the visited point would be located using a GPS, and photographs and a canopy cover assessment made to decide if the point was forest or non-forest. Signs of obvious recent human activity, for example tree stumps or burn scars, would be recorded.

2.4.4. This will allow a calculation of the error and bias of the deforestation product

2.5. **Estimated costs**

2.5.1. Assuming a 30% volume discount, the data cost would be $68,000 per year. It might be possible to reduce this cost significantly, and possibly completely, through negotiations with JAXA.

2.5.2. Licences for commercial software such as GAMMA or SARscape are likely to be on the order of $10K, though again discounts could be available. Free software could be used, though results are likely to be less good.

2.5.3. Implementing the processing, if software and trained staff existed, would not be difficult, either internally or through an external consultant. It would perhaps be 60 days' work for a trained technician, involving 30-50% as much time as the optical method in 1.

2.5.4. Fieldwork costs are hard to estimate, but would be identical to method 1. Future fieldwork costs for calibration are likely to be lower than Method 1, as there are not expected to be calibration differences from year to year.

APPENDIX F: MAPPING LAND USE WITH REMOTE SENSING

Satellites detect properties of the vegetation, soil, topography and buildings on a piece of land. These may relate to land use, but the features measured by remote sensing are rarely unique to a particular landuse type. As a typical example, a grassland area grazed by cattle, and one grazed only by wild animals, could look identical to a satellite. Therefore land use mapping typically relies on a combination of satellite data (which mainly gives landcover) and ancillary data, such as vector layers giving the boundaries of plantations, or the distance from roads. Often the eventual landuse map is as much a model as a set of observations.

One other technique that is often used is the use of historical data to assist with current land use mapping. For example an area of bright green trees might be either a rubber plantation or a forest; but if it was known to be non-forest 5 years ago, it might become certain that it was a forest. Similarly, a small patch might look like secondary forest, but if it has been cleared 3 times in the past 15 years, then it is likely to be under swidden agriculture cycles.

Finally, improved maps of land use can be developed through combining different types of remote sensing data. For example, optical data gives information on vegetation greenness and could provide historical data, and long-wavelength radar could provide a biomass map: a fusion of the two could produce more accurate land use mapping. Fusion further with vector data might provide a highly accurate map.

Proposed methodology

A proposed methodology for land use mapping in Liberia could follow these steps:

1. **Collate input raster layers**
   1.1. Optical layers of landcover (ideally those produced from a different analysis, for example that connected with Liberia's Activity Data). These should cover at least a decade, ideally with four points, e.g. 2003, 2007, 2010, 2013, 2016 would be ideal. The maps produced during the Activity Data task using the Metria/Geoville map and the Hansen et al. deforestation data would provide a reasonable starting point.
   1.2. Collate currently optical satellite data. This could for example be a mosaic of Landsat 8 data, or Sentinel-2, from the same season.
   1.3. [Collate current radar satellite data, for example by creating a mosaic of PALSAR-2 data (see AD proposed methods) – this is optional, and could maybe be added if initial accuracy not sufficiently good]
   1.4. All layers should be warped to the same projection and to match each other, using the highest available resolution and most recent data as the reference image (e.g. 10 m Sentinel-2).

2. **Collate input vector layers**
    2.1. Collate all vector layers that could potentially be useful, including at least
        2.1.1. Settlements and their populations
        2.1.2. Roads (including quality)
        2.1.3. Rivers
        2.1.4. The concession boundaries for all land use types that are available
    2.2. Reproject to the same projection/datum as the optical data (typically UTM), and compare to high resolution optical data to ensure e.g. roads and rivers line up with the data. If not, adjust.
    2.3. Create raster layers from the road and settlement layers, giving layers such as 'distance from road', 'travel time to the nearest village', 'travel time to the nearest town', 'travel time to the nearest city', 'travel time to the nearest sea port' or similar. Consult local experts as to what would be the most relevant cut-off points for community size here for different economic activities (e.g. selling charcoal vs timber), and to mean travel time on different qualities of roads (and rivers if appropriate.)
3. **Collect ground data on actual land use**
    3.1. At least 200 examples of each land use type should be visited and recorded with a GPS (outline of areas of at least 0.5 ha). Ideally these should be spread through the country.
    3.2. Again expert guidance may be needed as to what constitutes the most important land use type and how they can be found.
4. **Classification and validation**
    4.1. Half the input points should be used to train a neural network algorithm, involving all input data layers (including radar if available, historical classifications, vector-derived rasters, as well as current optical data). This could be performed using QGIS, but commercial software such as ENVI or object-based software such as Ecognition would probably produce the best results.
    4.2. The map should be validated against 50 % of data held back for testing.

ANNEX 1: FOREST DEGRADATION

Degradation Emission Estimates

Forest degradation involves greenhouse gas emissions taking place within forest areas as a result of anthropogenic actions, but with the area remaining with the national forest definition throughout. Degradation can include things such as commercial selective logging for timber, small-scale legal and illegal logging for village use and timber, fuelwood collection, and fire. Drivers of forest degradation impact forests in a variety of ways, and result in different magnitudes of emissions. The primary activities leading to deforestation and forest degradation in Liberia, as identified by Liberia's R-PP and discussed in the Land Use Analysis (LTS 2016), are forestry, agriculture, mining, and charcoal production, all at both the commercial and community scale. The MRV Roadmap distinguishes between the drivers of deforestation and degradation, and lists commercial logging, chainsaw logging, conversion of natural forests to forest plantations, fuel wood collection and charcoal production as drivers of degradation.

There are two fundamentally different general approaches to measuring and monitoring emissions from forest degradation, both of which are briefly discussed below.

The **activity-based approach** focuses on specific forest degradation activities, such as timber harvesting or woodfuel collection and allows accounting to focus on the forest degradation activities assumed to have the largest impact on degradation emissions. Under this approach, specific emission factors and activity data are generated for each forest degradation activity included in the REDD+ program.

The **land-based approach** can be taken using remote sensing products to detect where forest cover decreases, and therefore is assumed to be forest degradation. Under this approach, the specific source or driver of forest degradation is not a particular consideration, and rather emissions are estimated based on the difference between carbon stocks in the before forest degradation and after forest degradation scenarios.

Regardless of the method used, identifying forest degradation is a considerably more difficult technical challenge than identifying deforestation. Degradation estimates can be developed using a variety of spatial and non-spatial datasets.

Currently, there are no reliable country-specific data on the extent of degradation that can be used to estimate historical emissions from degradation for use in the REL. The descriptions below merely provide an indication of the potential magnitude of degradation emissions, and the general methods that were used to derive these estimates.

Approximating degradation magnitude by 'activity'

Estimating emissions from forest degradation based on activities requires knowledge of the prevalent degrading activities, and data on both the extent of these activities and the resulting emissions. Unfortunately, there is currently no available data suitable for assessing rates or the extent of degradation or that can be used to estimate either the emissions per unit of degrading activity.

First order estimates of Liberia's emissions have been assessed by activity using the methods developed by Winrock for the World Bank REDD+ Decision Support Toolbox[68] (Table A1-1). These estimates reflect Liberia's forest definition[69] and can largely be considered IPCC Tier-2 due to their use of global spatial datasets and country-specific data. A full description of the methods and data sources to produce estimates of emissions per activity are included in below.

Table A1-1. First order estimate of Liberia's emissions for deforestation and forest degradation using data from WB Decision Support Tool. Forest degradation is comprised here of logging, woodfuel and fire. (Note that deforestation estimates are based on the DST, not the methods described elsewhere in this report, and are only shown here for comparison to degradation.)

Activity	tCO_2 emissions per year	Percent of total emissions
Deforestation	18,946,559	91.3%
Degradation by activity		
Logging	1,320,835	6.4%
Woodfuel	217,835	1.0%
Fire	272,436	1.3%
Total Emissions	**20,757,665**	**100%**
Enhancements	-378,136	--

These estimates indicate that deforestation is the source of the vast majority of Liberia's emissions from the forest sector. While this is likely true, the estimates provided in Table A1-1 are based on global datasets, which have limitations.

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[68] Sidman, G., L. Murray, T.R.H. Pearson, N.L. Harris, M. Netzer. 2014. World Bank REDD+ Decision Support Toolbox Methods. Online DST available at http://redd-dst.ags.io.
[69] Canopy closure exceeding 30%

If an activity based approach is utilized to estimate Liberia's emissions from forest degradation, relevant activity data includes volume and type of timber harvested, mill efficiency, and amount of woodfuel harvested for heating or cooking. These data may be impossible to acquire if they do not already exist, and while they may be more accurate than remotely sensed activity data, they are contingent upon complete accounting and record-keeping[70].

Methods and data sources applied for generating first order estimates of deforestation and degradation emissions

A set of methods were developed to create estimates of emissions from deforestation and the main degradation activities. The methods follow the approach developed for the World Bank funded REDD+ Decision Support Toolbox (REDD+ DST)[71], available online. The information below has been adapted from the full description of methods applied in this Toolbox[72].

Deforestation

Activity Data

Hansen et al. (2013)[73] raster layers, which were derived from Landsat 7 ETM+ satellite images, were used for all activity data for deforestation in the REDD+ DST. The tree cover raster, which shows "canopy closure for all vegetation taller than 5 m in height" as a percentage from 0-100, was used to establish area of forest. The REDD+ DST allows users to select either 10%, 20%, or 30% canopy cover as the definition of forest, but estimates offered in this report reflect the 30% canopy cover threshold, to match with Liberia's national forest definition. Cells with values of equal to or greater than each canopy cover threshold were extracted from the original tree cover raster to create forest mask for each canopy cover definition.

The Hansen et al. (2013) loss year raster was then used to determine areas of deforestation. The loss year raster shows all areas that were deforested, on an annual basis, between 2001-2012. Areas of deforestation for each year between 2001-2012 were clipped to each forest definition threshold (10%,

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[70] Goslee, K.M., S. Walker, S. Brown, T.R.H. Pearson, P. Stephen, R. Turner, and A.M. Grais. 2015. Technical Guidance Series for the Development of a National or Subnational Forest Monitoring System for REDD+: Forest Degradation Guidance and Decision Support Tool. Developed by Winrock International and the United States Forest Service under the USAID LEAF Program

[71] http://www.forestcarbonpartnership.org/dst

[72] https://redd-dst.ags.io/static/docs/REDD%2B%20DST%20Methods%20and%20Data%20Sources.pdf

[73] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

20%, and 30%) canopy cover) and summed for each subnational administrative unit.

Subnational units used in the WB DST were derived from the Database of Global Administrative Areas (GADM)[74] which provides a data layer of national and subnational political boundaries. Both Level 1 and Level 2 subnational units are available in the WB DST, which represent subnational boundaries at different levels of scale. GADM Level 1 units are typically states, departments, or prefectures whereas Level 2 GADM units subdivide Level 1 units into municipalities or counties. The first order estimates of emissions from deforestation produced by the REDD+ DST are the average deforestation emissions for each year Hansen et al. (2013) activity data are available (2001-2012).

Carbon Stocks/Emission Factors

Estimates of emissions from deforestation in the DST are inclusive of all relevant carbon pools: aboveground biomass, belowground biomass, deadwood and litter, and soil carbon. All emissions from deforestation except for those from the soil/peat pool are assumed to be committed the year that the deforestation activity occurs. The contribution of emissions from the soil pool are calculated differently as post-deforestation land use and soil type must also be considered, according to Intergovernmental Panel on Climate Change (IPCC) Guidelines. Biomass values were converted to carbon values by dividing biomass in half, and carbon dioxide values were then estimated by applying the molecular weight ratio of carbon dioxide to carbon (i.e., carbon estimates were multiplied by 44/12).

Aboveground Biomass values were obtained from a spatial layer of carbon stocks in tropical areas developed by Saatchi et al. (2011)[75] which maps aboveground biomass carbon stocks per hectare over Latin America, Africa, and Asia for the early 2000s, providing a useful pre-deforestation benchmark for the REDD+ DST. The biomass map was clipped to three forest mask layers matching the three forest definitions used in the DST (10%, 20%, and 30% canopy cover). Since the forest canopy layer (Hansen et al. 2013) and the biomass layer (Saatchi et al. 2011) use different remote sensing sources and have different spatial resolutions, there were some inevitable mismatches between the two data sources. To prevent counting non-forest biomass pixels that were retained after clipping to the forest masks, all pixels that had less than 40 tons of aboveground carbon per hectare were removed. This biomass threshold has been used to exclude pixels represented as forest in the Hansen dataset but effectively not considered as such in the Saatchi dataset from biasing carbon stocks for a broader deforested area (40 t C/ha derived from

[74] Available on-line from: www.gadm.org

[75] Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M., Morel, A. 2011. "Benchmark map of forest carbon stocks in tropical regions across three continents." Proceedings of the National Academy of Sciences, USA, 108, 9899.

Dinerstein et al. 2014)[76]. Although this threshold may not be accurate in other forest biomes that exist in countries shown in the REDD+ DST, it provided a conservative estimate of aboveground biomass that could be applied universally across forested areas. The resulting biomass was averaged across subnational units using a zonal statistics function, and then converted from biomass to tons of carbon by dividing in half, as specified in Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF)[77].

Belowground Biomass estimates were developed through the application of an allometric equation developed by Mokany et al. (2006)[78]:

$$BGB = 0.489AGB^{0.89}$$

Deadwood and Litter estimates were calculated based on a fraction of aboveground biomass as specified by methods under the United Nations Framework on Climate Change's (UNFCCC) Afforestation/Reforestation Clean Development Mechanism (A/R CDM)[79]. This methodology assumes deadwood and litter to be a fraction of aboveground biomass based on an area's elevation and annual precipitation regime (Table A1-1). Only fractions for tropical biomes were used in the REDD+ DST.

Elevation was obtained from the Global 30 Arc-Second Elevation (GTOPO30)[80] digital elevation model and the annual precipitation from the WorldClim database[81].

[76] Dinerstein, E., Baccini, A., Anderson, M., Fiske, G., Wikramanayake E., McLauglin, D., Powell, G., Olson, D., Joshi, A. 2014. "Guiding Agricultural Expansion to Spare Tropical Forests." Conservation Letters, in press.
[77] IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Druger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Wagner, F. (eds). Published: IGES, Japan. Available online at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html.
[78] Mokany, K., Raison, J.R., Prokushkin, A.S. 2006. Critical analysis of root : shoot ratios in terrestrial biomes. Global Change Biology, 12, 84-84, doi: 10.1111/j.1365-2486.2005.001043.x.
[79] UNFCCC. 2012. "Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities Version 2.0.0." EB 67 Report Annex 23.
[80] United States Geological Survey. "Global 30 Arc-Second Elevation (GTOPO30). Available online at https://lta.cr.usgs.gov/GTOPO30.
[81] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. "Very high resolution interpolated climate surfaces for global land areas." International Journal of Climatology 25, 1965-1978.

Table A1-1: UNFCCC A/R CDM methodology for determining deadwood and litter biomass stocks from aboveground biomass. Numbers shown are for the tropical biome only.

ELEVATION (m)	ANNUAL PRECIPITATION (mm yr^{-1})	DEADWOOD FRACTION OF AGB	LITTER FRACTION OF AGB
< 2000	< 1000	0.02	0.04
< 2000	1000 – 1600	0.01	0.01
< 2000	> 1600	0.06	0.01
> 2000	All	0.07	0.01

Soil Carbon[82] emissions were estimated leveraging data from the Harmonized World Soil Database which offers data on carbon content (in the top 30 cm of soil, which is the assumed depth affected by deforestation) and bulk density. To estimate tons of carbon per hectare in forested areas, the bulk density was multiplied by the volume of topsoil in one hectare, and then multiplied by the fraction of carbon content. This was done for all pixels within the forest mask, and the weighted average was found for each subnational unit.

To calculate soil emissions from deforestation, land use change factors (F_{LU}) were used. F_{LU}s were obtained from the IPCC Guidelines for National Greenhouse Gas Inventories[83]. Only F_{LU}s for conversion to long-term cultivated crops were used, which varied based on the temperature regime of the subnational unit (tropical or temperate). Although not all land will become long-term cultivated crops, this assumption was made in the absence of a good method of predicting post-deforestation land use on the local level across all FCPF countries. The following formula was used to find deforestation emissions Ems_{SOIL} from soil carbon based on pre-deforestation soil carbon stocks (C_{PRE}):

$$Ems_{SOIL} = C_{PRE} - (C_{PRE} * F_{LU})$$

[82] The REDD+ DST estimated soil carbon emissions from deforestation on mineral soils differently from those on peat, but as no emissions from peat soils were included in estimates for Liberia, methods are not described here.
[83] IPCC. 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories." Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Volume 4 Agriculture, Forestry and Other Land Use. Paustian, K, Ravindranath, N.H. and Van Amstel, A (coordinating lead authors). Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html.

Forest Degradation

Due to the increased complexity associated with detecting and measuring the impacts of activities that do not result in deforestation, but degrade forest carbon stocks, methods and data sources applied in the REDD+ DST to calculate deforestation emissions differ considerably from those applied to calculate emissions resulting from degradation activities.

Timber Harvesting

Activity Data: In the context of the REDD+ DST, timber harvesting refers to commercial selective logging. The methodology described in Pearson et al. (2014)[84] was used to calculate national-level logging emissions. This methodology used extraction volumes from the 2010 FAO Global Forest Resources Assessment, and then calculates emissions from extracted logs, damage to the surrounding trees at the logging location, and logging infrastructure.

As emissions were calculated on a national scale, it was necessary to divide emissions among the subnational units represented in the REDD+ DST. The Global Forest Watch database[85] provides logging concessions data for Liberia, and thus national-level logging emissions were divided according to the proportion of national concessions area within Liberia's subnational units.

Emission Factors: Some of the volume in extracted logs is stored as harvested wood products (HWP) in the form of lumber, wood panels, or other products that have an in-use lifetime and then may remain sequestered even after disposal especially when in landfills. As such, harvested wood that is manufactured into these products does not immediately contribute to emissions, so the portion of extracted wood that is effectively permanently sequestered in HWP must be subtracted from total logging emissions. Storage at 100 years is used as a simplification for permanent storage reflecting estimations of atmospheric residence of carbon dioxide. Earles et al. (2012)[86] calculated the percentage of aboveground carbon in harvested timber that remains stored in HWP after 100 years by estimating the proportion of national-level extraction volume data that became long lasting end products.

To calculate the amount of aboveground carbon stored in HWP for each subnational unit (AGB_{HWP}), the following equation was used where L_{NAT} is national-level logging extraction volume, Pct_{HWP} is the percent

[84]Pearson, T.R.H., Brown, S., Casarim, F.M. 2014. "Carbon emissions from tropical forest degradation caused by logging." Environmental Research Letters, 9, 034017. doi:10.1088/1748-9326/9/3/034017

[85]"Logging." World Resources Institute. Accessed through Global Forest Watch on Oct 7 2014. Available online at www.globalforestwatch.org.

[86]Earles, J.M., Yeh, S., Skog, K.E. 2012. "Timing of carbon emissions from global forest clearance." Nature Climate Change, 2, 682-685. doi:10.1038/nclimate1535

of aboveground biomass stored in HWP after 100 years, BCEF is the biomass conversion and expansion factor, and FArea is the proportion of national forested area within the subnational unit:

$$AGB_{HWP} = L_{NAT} * Pct_{HWP} * BCEF * FArea$$

Biomass conversion and expansion factors (BCEF) allow for the conversion of merchantable growing stock volume to aboveground biomass. BCEFs for temperate conifer forests and humid tropical natural forests were used from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the seven countries that have concessions data available through Global Forest Watch, the proportion of national concessions area within the subnational unit was substituted for the proportion of national forested area within the subnational unit in the above equation.

Woodfuel

To estimate emissions from woodfuel harvesting, an analysis conducted by Drigo et al. (2014)[87] was leveraged to derive estimates that reflect emissions from the fraction of non-renewable woodfuel harvest. Drigo et al. (2014)'s analysis offered estimates of NRB from land cover change (LCC) by-products was as well, since some wood that is burned as woodfuel comes from deforestation rather than degradation. In an effort to avoid double-counting emissions, in the REDD+ DST, only the woodfuel demand that was satisfied by non-LCC by-products was considered.

Forest Fire

Emissions from forest fires are the third source of degradation emissions included in the REDD+ DST. Forest fires refer to fires that degrade the forest through low to high severity burning, but are not the source of fires that cause a land cover change, such as human-induced deforestation. The Global Fire Emissions Database (GFED)[88] provides monthly dry matter emissions that are classified into different sources and land cover types. Within the humid tropical forest biome, deforestation fire emissions are decoupled from other emissions based on fire persistence (the length of time for which a fire burns in the

[87]Drigo, R. 2014. "Elaboration of the pan-tropical analysis of NRB harvesting (Tier 1 data, version 01 April 2014)." Produced by the Yale-UNAM GACC Project: Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and Beyond for Global Alliance for Clean Cookstoves.

[88]van der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Mu, M., Kasibhatla, P.S., Morton, D.C., DeFries, R.S., Jin, Y., van Leewen, T.T. 2010. "Global fire emissions and the contribution of deforestation, savannah, forest, agriculture, and peat fires (1997-2009)." Atmospheric Chemistry and Physics, 10, 11707-11735. doi:10.5194/acp-10-11707-2010

same location). Deforestation fires are assumed to have a longer fire persistence in order to achieve complete combustion of fuels, clearing the land completely for a different land cover use.

To only count emissions from forest fires that contribute to emissions from degradation (since deforestation fires are already included in the deforestation emissions), only emissions from the forest land cover class were tabulated in the REDD+ DST. Furthermore, emissions from three main gases were included: carbon dioxide, methane, and nitrous oxide. Methane and nitrous oxide were converted to carbon dioxide equivalent, and total emissions per hectare were averaged over each subnational unit.

Carbon stock Enhancements through Afforestation and Reforestation

Afforestation is the establishment of forest on non-forest land that had not previously been forest for a long period of time while reforestation is the establishment of forest on recently deforested land. Zomer et al. (2008)[89] created a global layer of land suitable for A/R based on several biophysical suitability variables. These variables excluded lands with high aridity, elevation above tree line, urban areas, water bodies, areas of high agricultural production, and current/recently deforested areas. Forests were defined as above 30% canopy cover according to a Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Continuous Fields (VCF) layer of canopy cover. The MODIS VCF canopy cover used in Zomer et al. (2008) was different than the Hansen et al. (2013) layer used in the REDD+ DST for canopy cover, resulting in a mismatch of forest definitions. Due to this mismatch, the Hansen et al. (2013) forest masks for each forest definition were used to clip the Zomer et al. (2008) A/R layer so that only A/R land on non-forest land was included in enhancements calculations in the REDD+ DST.

Default values for annual average aboveground biomass increments in plantations from the IPCC Good Practice Guidance for LULUCF were used for annual increases in tons of carbon. Subnational units were given a biomass increment based on their precipitation regime (from the WorldClim dataset) and location (Africa, Asia, or the Americas). Biomass increments for tree categories (pine, eucalyptus, etc.) for each location were averaged to create one biomass increment per continent. The tabulated area of eligible land for A/R was multiplied by the biomass increment and converted into emissions in tons of carbon dioxide equivalent, giving each subnational area an annual rate of emissions removals. Since it is not feasible to convert all land eligible for A/R into forest, the values reported for enhancements in the DST assume a conversion of 20% of eligible A/R land when considering the removals potential of an area.

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[89]Zomer, R.J., Trabucco, A., Bossio, D.A., Verchot, L.V. 2008. "Climate Change Mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation." International Agricultural Research and Climate Change, 126, 1-2, 67-80.

Evaluating potential historical degradation through the use of spatially derived land cover data

As stated, currently the data required to estimate degradation using remote sensing is insufficient for Liberia. Identifying degradation is challenging, and requires generally requires high resolution spatial data along a time series together with significant amount of field data (Box 3).

Box 5. **Challenges to identifying degradation using Remote Sensing**

Identifying degradation using remote sensing products is more complex than estimating deforestation, significantly less accurate, and may not thoroughly detect degradation. This is true for three different reasons:

1. Degradation is more difficult to accurately detect using remote sensing, as by definition a significant proportion of canopy cover remains after the loss event. If trees are removed below the canopy, degradation may be entirely invisible to normal, optical remote sensing, that only sees the top of the canopy. Even if canopy trees are removed, there may only be a short window (perhaps a few months) where it is visible to optical remote sensing before regrowth in the gap masks the change.
   In general the smaller the magnitude of change (e.g. the fewer canopy trees removed), the harder it is to detect: i.e. a change from 100% to 35% canopy cover will be more likely to be detected than a change from 80% to 65%, but both are degradation. Also the size of the patch of degradation is critical: the larger it is the more likely it will be detected.
   For most degradation levels, the pixel resolution and temporal frequency of medium resolution sensors such as Landsat are insufficient to capture degradation completely[90]. The detection accuracy of higher resolution 5-meter imagery is still only around 80%, which points to the potential limitations of detection using only existing space-borne optical sensors (Manley et al. 2013). Area data can also be estimated based on ground surveys.
2. Due to the specific forest definition chosen by Liberia, deforestation is a binary process: an area is either deforested or it is not within a particular time period. However, degradation is normally treated as a continuous process to some degree or other: for the creation of a reference level we need to know not only the total area that has been affected by degradation, but also the degree of this impact. Along with detecting the degradation, the emissions associated with this degradation are also needed for total degradation emissions to be estimated. Ideally we would like to know the carbon stock loss before and after a

[90] There are now mechanisms being developed to detect in-pixel changes in spectral resolution as a result of a canopy change. See the work of the Carnegie Institution for Science (http://claslite.carnegiescience.edu/en/) and the work of Applied Geosolutions (http://www.appliedgeosolutions.com/)

degradation event, or something that can be related to this loss (for example canopy cover change).

3. Forests are constantly changing even without human disturbance. Between about 1 and 3 % of large trees die each year in a typical tropical forest, with large tree falls often causing large, natural gaps in the forest canopy. Similarly, trees are constantly growing within forest areas and expanding into current non-forest areas. Thus, not all reductions in canopy cover are anthropogenic, and therefore 'degradation', and the natural state for most forests is to increase in biomass through time (so a finding of stability in an analysis may not mean baseline degradation rates are 0). This means that a level of human interpretation or ancillary data is needed to interpret results of changing biomass or canopy cover, and convert them into data on degradation.

In an effort to examine the magnitude of historical degradation in Liberia using the data currently available, a spatial mapping approach was developed and applied, as explained below. However, it should be noted that, as in the above section, this approach can only be used to examine the potential prevalence of degradation and not as a method to estimate degradation activity data.

The landcover map for 2014/15 produced by Geoville/Metria divides the forest class into two useful classes, one with >80% canopy cover and one with 30-80% canopy cover. If this effort were repeated in the future the rates of transition between the two canopy cover classes could be proposed as an approach to estimate a component of degradation. Since in Liberia, there are no non-anthropogenic forest types with a land cover of 30-80% canopy cover, it can be assumed that any areas in this forest class were either degraded or are regrowing following deforestation. One approach to estimating at least a portion of degradation could be to assume areas under the following criteria experienced 'degradation': deforestation was not been detected historically, were in the >80% canopy cover strata in the first land cover map, and moved to the 30-80% canopy cover in the later map. This approach would still miss a significant portion of degradation because of the coarse 2-class approach (for example a change from 100-81% canopy cover, or 70-30%, would be missed) and any degradation that took place but then became undetectable within the time frame of the two maps. Also the mapping method, using RapidEye and Landsat data, is imperfect, so there will be some false detections: for example, in reality a pixel could move from 75 – 78% canopy cover over 2 years, but the first map could incorrectly place it in the >80% canopy cover class, and the next time in the 30-80% canopy cover, and the pixel could be reported as degraded. We have no ground-based accuracy assessment of the Geoville/Metria map, so there is no clarity as to how likely this is to happen. But, given the existing data, this approach is presented below to illustrate the potential magnitude of coarse degradation.

In order to provide a rough estimate of current degradation, we used the Liberia-corrected year 2000 Hansen et al. (2013) and identified areas that were not been deforested between 2000 and 2014. Comparing these areas to the 2015 Metria/Geoville map provides a rough map of coarse degradation in Liberia (Figure A1-1). There is no apparent trend in location of potential degradation with respect to concession boundaries for oil palm, mining, and forest management, or with respect to centers of population.

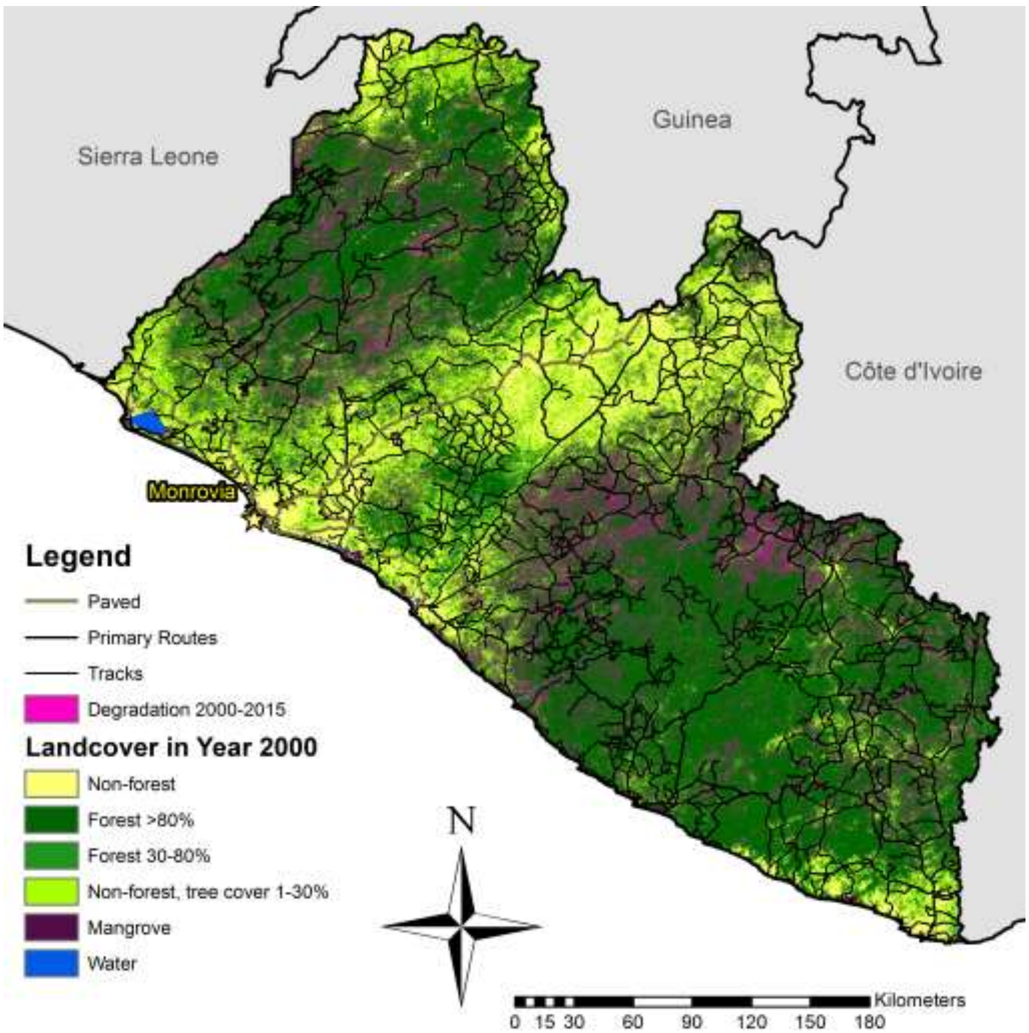

Figure A1-1. 'Degradation' estimated by comparing area moving from >80% Canopy Cover to 30-80% canopy cover between 2002-2013

This assessment indicated that degradation may have occurred on more than twice as much land area as deforestation, and emissions from degradation may have accounted for a significant proportion of total emissions from land use and land use change, depending on the data used to develop emission factors for degradation. However, to produce reliable estimates of degradation, it would be necessary to have older maps that have been sufficiently ground-truthed so that transition between forest cover classes can be known with a high degree of certainty. Because such maps do not exist, the approach used here merely provides order of magnitude estimates of degradation.

Based on the estimates provided here, it is possible that degradation is a substantial source of emissions. It is therefore recommended that Liberia include degradation in the REL as a stepwise addition. It is critical to note that the orders of magnitude estimated vary widely between the two methods described here – activity-based accounting and land-based or spatial accounting. This further points to the need for improved data on forest degradation in Liberia. Further details on specific measurement and monitoring approaches Liberia might adopt for either approach are discussed in below.

Options for Monitoring Degradation in the Future

Many options exist for monitoring degradation, with a wide range of reliability. The accuracy of available methods is often dependent on the main activities that lead to degradation. It would therefore be useful for Liberia to conduct a more thorough analysis to identify the primary drivers of degradation in the country. Following this, a detailed assessment could be done to compare the available methods to monitor degradation. This should entail identifying the relevance of each option to Liberia's circumstances, the required data for each option and the potential to obtain such data, and the costs of monitoring methods. This appendix describes available options for monitoring degradation, using both land-based and activity-based approaches.

Land-Based Accounting:

There are four major possible options we see for monitoring degradation in Liberia using the land-based approach:

- Field surveys,
- Optical remote sensing data,
- Radar remote sensing data, and
- LiDAR remote sensing data.

Ideally, field data would be used in combination with one of the remote sensing methods, but field data could be used alone.

The lowest cost option is the use of field data combined with optical remote sensing data. Radar data combined with field data could provide a higher quality full-coverage option, with no sensitivity to cloud cover and the potential to reduce field effort with time, but is more expensive. LiDAR data can provide very high fidelity products, but is unlikely to be cost effective in the short to medium term; it represents by far the most expensive option.

Details on the four types of data collection, and variants within them, are set out below, as well as justification for their use and potential problems.

1. **Field data**

The least capacity-intensive method to monitor forest degradation is through field data collection. Such data collection could be implemented within an ongoing National Forest Inventory program, which is in general recommended for Liberia in order to improve estimates of Emission Factors and stocks, reducing costs further.

Field data for mapping degradation usually takes one of two approaches.

a) **Unmarked permanent plots**

In this method randomly located plots are set up across study areas (stratified for example by forest type and accessibility) throughout the country. These plots are inventoried using standard methods (e.g. the diameter of every tree over 10 cm in diameter measured within a 1 ha square plot or half hectare circular plot) but are left unmarked: trees are identified by differential GPS and plot centre/corners are marked in a hidden fashion, for example by hammering iron bars into the soil to be refound later by metal detectors. These plots can be revisited every 2-3 years and recensused to estimate changes in carbon stock, and dead trees studied to detect whether their death was due to human degradation (e.g. cut or fire), or due to natural causes. Training manuals exist for such methods[91], and they have been widely used by voluntary sector REDD+ projects.

Such plots are excellent at ascertaining the rates of tree growth, regeneration, deforestation and forest degradation throughout a country, producing reliable results. However, in order to produce narrow confidence intervals, a very large number of such plots are needed – numbering thousands across the country. Further, in order to produce unbiased estimates of degradation, it is important

[91] http://redd.unfccc.int/uploads/2_138_redd_20090302_kyoto_fieldguide.pdf

that local communities do not treat the plots any differently to surrounding forest. As it is often desirable, and sometimes necessary, to involve local communities in setting up and measuring plots, this in practice can be difficult or impossible.

For the above reasons, it may be that unmarked plots are included as part of a NFI approach, but not used as the sole method to estimate the rates of degradation, instead being used to validate other remote-sensing based methods. However, we believe this could potentially represent the sole approach for Liberia, perhaps on a transitional basis, if well designed and implemented.

b) Stump surveys

Here, trained forests or community members, take a more active approach, roaming through a landscape on fixed transects and marking the location of any recent treestumps or other signs of tree clearance. These may be recorded using a field GPS, or perhaps using a mobile phone or tablet using software as Open Data Kit to record the location and take photographs. The latter method may produce high quality data, despite requiring less training.

Examples of such surveys producing active data on degradation can be found in the Mapping for Rights programs[92], which work with communities across west/central Africa

Repeated surveys can produce an idea of the rate of removal of trees from an area, and local increases can quickly be noticed and managed. This approach is often used where active management, for example to reduce illegal logging, is to be combined with monitoring. It tends to be much faster acting, but produces data less easily convertible to carbon stocks, than method a).

Like method a), it is maybe best used as a validation method for remote sensing techniques. Unlike method a) we do not believe it could be used in isolation.

Remote sensing data

Remote sensing data can operate from a satellite, aircraft or unmanned aerial vehicle (UAV or drone). It broadly consists of three different types, which will be discussed in turn:

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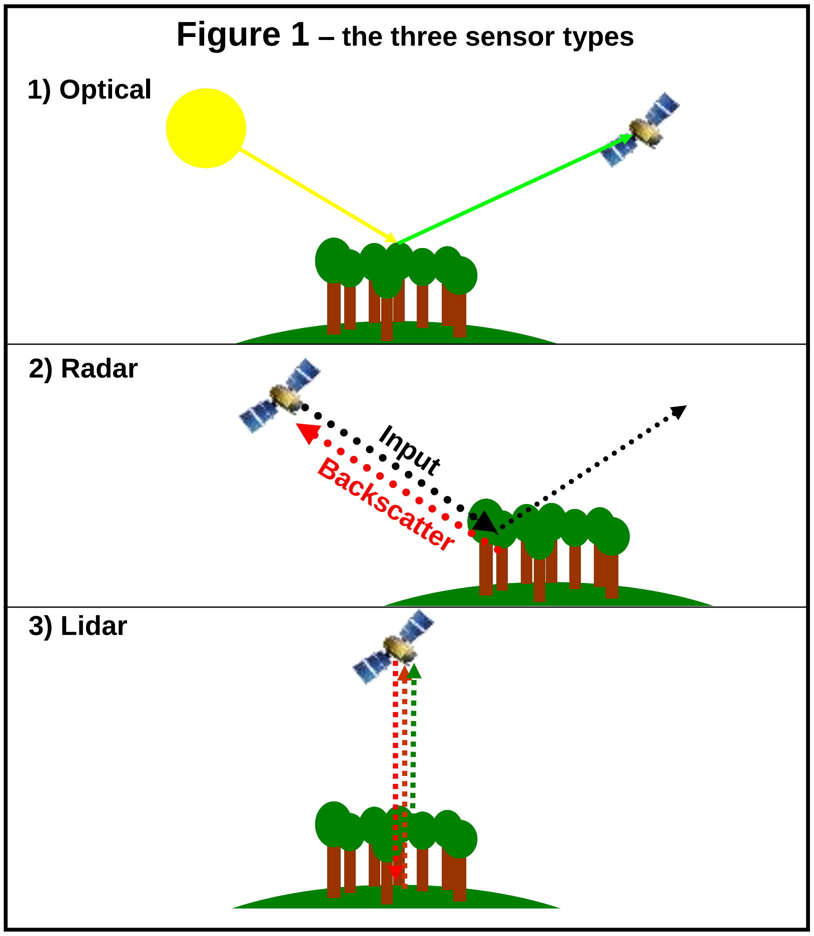
[92] http://www.mappingforrights.org/



2. **Optical remote sensing data**

Optical remote sensing data is the most widely available of the three, with over a hundred satellites collecting data regularly. There are a number of options for free optical satellite data, with the most useful for this purpose being:

- Landsat 8, 30 m resolution, revisit every ~14 days
- Sentinel-2, 10 m resolution, revisit every 3-4 days

The resolutions of these free satellites are too coarse to see individual trees, so instead the hope is to detect degradation through a drop in greenness during the short window after degradation where it is visible. Also, such satellites may be able to produce classified maps by canopy cover level (the G/M map was largely based on Landsat 8 data). However, optical data is not ideal because it cannot see below the top of the canopy, and therefore cannot possibly detect degradation that occurs below the canopy, and because cloud-cover often obscures forested areas, sometimes for years at a time. The frequent observations of new satellites, in particular Sentinel-2, may overcome the cloud cover issue: but the number of scenes that need to be downloaded and analysed to build up cloud-free data is large and may raise costs.

Free optical remote sensing data therefore provides the lowest cost means to assess degradation over the whole country. However, the accuracy of such products may be low: these data are perfect for mapping deforestation, but far from ideal for degradation.

An alternative could be to use paid-for, higher resolution data. Ideally such data would allow the discernment of individual canopy trees (for example Worldview-2/3 data with sub-meter resolution). The G/M mapping used some RapidEye data at 5m resolution, which can discern the canopies of the largest trees. Such data is suitable for mapping canopy-level degradation with high fidelity, but the data itself is very expensive, and processing it is also time consuming, and thus it could only be useful as a sampling tool.

Analysing RapidEye data over a whole country has been undertaken for Guyana as part of their MRV system, with the particular aim of detecting deforestation and degradation[93]. This was a high cost option, both for the purchase of the data and for analysing it. The results are yet to be assessed by a 3rd party, but appear to be good: however the cost and effort involved was very high, and it is not clear that continued monitoring at this resolution will be possible, or even necessary.

Metria/Geoville did have success in Liberia in differentiating two different forest classes, 30-80 % canopy cover and >80% canopy cover, with a training dataset developed using RapidEye (at 5 m resolution) and the final map based on a combination of RapidEye and medium-resolution Landsat data. Separately, FFI were able to map degraded forest in Liberia's proposed reserve Wonegizi using a time series of historical Landsat data and RapidEye. These approaches have promise, and offer the lowest cost recommended option for Liberia.

3. Radar remote sensing data

Radar satellite data looks sideways at the world and can penetrate through the forest canopy to obtain information on forest structure. Therefore radar satellites have been used to map aboveground biomass

[93] Bholanath & Cort. 2015. National Scale Monitoring Reporting and Verification of Deforestation and Forest Degradation in Guyana. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, W3: 315-233. http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-7-W3/315/2015/

directly, and to map degradation. However, they are limited by a saturation point, typically around 150 Mg ha^{-1} aboveground biomass for L-band (the longest, and therefore most sensitive, wavelength currently available), and 50-75 for C-band (which is more widely available).

For Liberia then current radar satellites will not be able to produce continuous biomass maps, as the maximum AGB in the country far exceeds 150 Mg ha^{-1}. But both L- and C-band provide potential routes for mapping degradation directly.

Mitchard and colleagues have used L-band data from the ALOS PALSAR satellite to map degradation in Peru (Joshi et al. 2015) and in Sumatra (Collins & Mitchard, 2015), and have had some success in using it for monitoring in Sierra Leone in a project in partnership with Winrock. However, data availability is somewhat limited and the current products from the only L-band satellite orbiting, ALOS-2, are expensive (around $2000 per 60x70 km scene).

A recent development has been the launch of Sentinel 1a and 1b, two C-band satellites by the EU. These provide free, regular data. Mitchard is developing a product at the University of Edinburgh called SAREDD that aims to use C-band data to routinely map forest degradation, and early results are promising: but this is still very much in a development phase.

Overall radar has potential here. A combination of L-band used to directly monitor biomass and biomass change in the lower biomass parts of the country, and C-band to monitor degradation in the tall forest areas (for example looking for logging damage) could provide a high-tech, high accuracy solution for Liberia. This is presented as a middle cost option.

4. **LiDAR remote sensing data**

LiDAR data uses laser light looking directly down to give tree height. Repeat surveys can therefore see the removal of individual trees, and thus it is the only remote sensing method that can guarantee to map degradation with high accuracy even if the magnitude or size of disturbance is low.

No satellite data is currently collected, so data could only be through aircraft or UAV's, at high cost. We are not aware of good aircraft solutions operating in west Africa, and relying on a plane coming from e.g. South Africa or Europe would be very expensive. On the other hand UAV LiDAR costs are coming down considerably, with complete solutions from Avion Jaune[94] at about $200K, and from Delair Tech[95] at about $400K.

[94] http://www.lavionjaune.fr/index_en.html
[95] http://www.delair-tech.com/en/packages/dt26x-lidar/features/

Owning such a system would allow Liberia to collect repeat transects on an annual basis, providing accurate biomass and biomass change maps and thus really understanding the processes of degradation and regrowth.

Both companies can also collect data on a contract basis for a one-off payment without having to purchase the planes, and independent service companies such as Carbomap[96] can process such data cheaply or provide training and software solutions

In the long-term LiDAR data could be necessary for a comprehensive, high-fidelity degradation monitoring system for Liberia – but the cost is likely to be high.

Current LiDAR data collection by palm oil companies such as Sime Derby could reduce the cost: it is possible the state could share LiDAR costs with plantation development companies, or at least half the costs of revisit. A LiDAR sampling methodology provides the 3rd, most expensive but highest accuracy, proposed methods.

Activity-Based Accounting

Approaches for accounting for forest degradation from a range of relevant forest degradation activities in Liberia are discussed below.

Woodfuel Collection

The analysis of emissions from historical woodfuel collection in Liberia applied to generate initial estimates as offered above were developed using the Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM) methodology[97] . The estimates were developed based on an analysis conducted by a co-author of the WISDOM methodology and reflect emissions from the fraction of non-renewable woodfuel harvest. These estimates were generated by applying a range of regional and global datasets, and can be considered better than IPCC Tier 1. Improvements to the emission estimates could be realized by integrating more spatially explicit, country-specific, and more recent data inputs to the WISDOM model (the estimated emissions listed above represent those for the year 2009).

If Liberia chooses to apply the WISDOM model to account for forest degradation emissions from woodfuel collection under its REDD+ program, it is recommended that efforts be made to both build in-country capacity for its application, as well as collect country-specific data to improve the accuracy of its estimates.

[96] http://www.carbomap.com/
[97] http://www.wisdomprojects.net/global/

The WISDOM model can be tailored to fit Liberia's needs in terms of geographic scope (e.g., Liberia's specific administrative units), and consists of modules on demand, supply, integration and woodshed analysis. Each module requires different competencies and data sources and its contents are determined by the data available or, to a limited extent, by the data purposively collected to fill critical data gaps. Information of relevance to wood energy comes from multiple sources, ranging from census data to local pilot studies or survey data.

The following data sources would improve outputs for each module:

Demand:

Woodfuel demand is largely a function of population and population density, infrastructure, household energy supply needs, and access to woodsheds. As such, the following sources of data can support the estimation of woodfuel demand specifically for Liberia:

- Population census
- Spatial data on infrastructure (e.g., roads, gas pipelines)
- Topography
- Surveys of household energy needs and use

Supply:

Woodfuel supply is a measure of both the existing biomass in woodsheds as well as their productivity. Productivity is an important consideration as it accounts for the ability of biomass stocks to regenerate once harvested for woodfuel use).

The following sources can contribute to the estimation of woodfuel supply:

- Biomass stocks (stocks could be tailored to match national forest inventory data)
- Productivity (mean annual increment)

Integration

Use of spatial data to estimate the demand and supply balance of woodfuel, specific to the desired spatial resolution. This will identify areas of deficit, surplus, and can help plan for future scenarios.

Woodshed analysis

The analysis for the delineation of woodsheds in Liberia, i.e. supply zones of specific consumption sites requires additional analytical steps that may be summarized as:

- Mapping of potential “commercial” woodfuel supplies suitable for urban, peri-urban and rural markets.
- Definition of woodsheds, or woodfuel harvesting areas, based on the level of commercial and non-commercial demand, woodfuels production potentials and physical/economic accessibility parameters. Estimation of harvesting sustainability, of woodfuel-related renewable biomass values at subnational level and of woodfuel induce forest degradation rates.

Selective Logging

Under an activity-based approach for estimating emissions from selective timber harvesting, the accounting methods outlined by Pearson et al. (2014)[98] are recommended, whereby data on harvest volume (activity data) are paired with an emission factor that reflects three emission sources that occur as a result of logging:

1. emissions from the milling, processing, use and disposal of the felled timber-tree,
2. emissions from incidental damage caused by the timber-tree fall and cutting of the log in the forest, and
3. emissions from infrastructure associated with removing the timber out of the forest (e.g. skid trails, logging decks and logging roads).

The method uses the IPCC gain-loss approach, and the total emission factor is the sum of these three sources of emissions, expressed as units of carbon per cubic meter of timber extracted:

$$\mathbf{TEF = ELE + LDF + LIF}$$

Where:

TEF = total emission factor resulting from timber harvest (t C m^{-3})

ELE = extracted log emissions (t C m^{-3}extracted)

LDF = logging damage factor—dead biomass carbon left behind in gap from felled tree and incidental damage (t C m^{-3}extracted)

[98] Pearson T.R.H., S. Brown and F. Casarim. 2014. Carbon Emissions from Tropical Forest Degradation Cause by Logging. Environ. Res. Lett. 9 034017 (11pp). Winrock International. Available at: http://www.winrock.org/sites/default/files/publications/attachments/Pearson%20et%20al%202014%20Logging.pdf

LIF = logging infrastructure factor—dead biomass carbon caused by construction of infrastructure ($t\ C\ m^{-3}$)

The total emission factor can then be multiplied by activity data derived from timber harvesting statistics, typically expressed as volume over-bark harvested in cubic meters, to estimate total emissions from logging operations. Alternately, activity data can be based on area logged, in which case emission factors must be developed as tons of carbon per hectare. This method is likely to be less accurate as it can be difficult to identify all logging areas using remote sensing (Indufor 2013).

The data needed to estimate emissions from timber harvesting are given in Table A1-2. Both Tier 2 and Tier 3 would require original data collection in the REDD+ country. The difference would be in the completeness of data collection, with a Tier 2 being just a limited sampling of timber harvesting sites to develop national factors and Tier 3 being more finely stratified by area and by harvesting practices within the country.

Table A1-2. Requirements and sources of data needed to estimate emissions from timber harvesting

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data
Activity Data	Timber extraction data (volume per hectare or total volume) on an annual basis	FAO Global Forest Resources Assessment	Government statistics, timber concession reporting, mill reporting
	Area of logged forest per year	Limited availability in FAO Global Forest Resources Assessment (often total area of produciton forests only)	Government statistics, timber concession reporting, remote sensing data
	Area of logging roads, skid trails, logging decks	Not available	Government statistics, timber concession reporting, high resolution remote sensing data
Emission Factors	Measurements of logged trees (ELE)	Pearson et al (2014)	Pearson et al (2014) correlation; Fieldwork/REDD+ NFMS
	Extent of incidental damage (LDF)	Pearson et al (2014)	Pearson et al (2014) correlation; Fieldwork/REDD+ NFMS
	Extent of infrastructure (LIF)	Pearson et al (2014)	Fieldwork/REDD+ NFMS

Winrock has developed comprehensive, country-specific standard operating procedures and field inventory approaches for developing emission factors for selective logging that capture the above emission sources[99].

As stated above, activity data reflecting harvested timber volume would need to be available. Official statistics available may likely only reflect legal timber harvest, thus leading to a significant underestimation of emissions from timber harvesting due to the persistence of illegal logging in Liberia. As such, Liberia could endeavour to produce estimates of illegal harvested timber volume through monitoring approaches or by leveraging data from studies that have been conducted that estimate this value. In the case of illegal timber harvest, emission factors may need to differ from legal harvest as illegal timber harvesting may be associated with less associated infrastructure development.

Fire

Emissions resulting from forest degradation due to fire can be generated using global remote sensing products that are freely available. For example, the MODIS burned area product[100] can be used to identify areas that experienced emissions due to forest fire, although at smaller scales this may overestimate emissions from fire due to the fact its resolution is coarse (500m). As such, the results produced by applying this product must be refined not only to exclusively capture only burned area in forests remaining forests (i.e., degradation, rather than deforestation fires), but it should also be subject to careful processing to ensure it accurately reflects the magnitude of fires occurring over the period of interest.

An initial analysis of fire using the MODIS burned area product was conducted. This analysis indicated that fire occurrence and resulting emissions are very low in Liberia, averaging only 225 hectares annually over the Reference Period. It therefore does not seem necessary that Liberia undertake a more rigorous method for monitoring fire.

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[99] Walker, S.M., T.R.H. Pearson, F.M. Casarim, N. Harris, S. Petrova, A. Grais, E. Swails, M. Netzer, K.M. Goslee and S. Brown. 2015. Standard Operating Procedures for Terrestrial Carbon Measurement. Winrock International.
[100] http://modis-fire.umd.edu/pages/BurnedArea.php

Mining

Forest degradation emissions as a result of mining activity can vary significantly, depending on the magnitude and type of mining. Research conducted by Winrock International in Guyana[101] on the impact of gold mining on the carbon stocks of forests surrounding the mines revealed that forest degradation, although observed, overall had an insignificant impact on forest carbon stocks, and represented a very small fraction of overall emissions from deforestation and forest degradation. However, this is likely to vary by country, and mining may have a more significant impact on forest degradation in Liberia, depending on the practices. A similar method of assessing degradation from mining activity could be applied. Under the approach taken in Guyana, mining sites were mapped using high-resolution imagery and a fixed buffer area outside the mining sites served as activity data. Emission factors were developed through field data collection. Such an approach should be taken in concert with mapping of other land use and land use change activities.

Draft Terms of Reference: four potential degradation MRV methods for Liberia

Set out below are terms of reference and rough budgets for conducting a complete MRV cycle for degradation in Liberia. Costs are given for per cycles of data collection plus processing: obviously at least two cycles are needed in order to monitor degradation. Cycles could be as far as 5 years apart, but given the lack of data in this area repeating surveys every 2 years is recommended.

1. Field data only: unmarked field plots

1.1. Background

1.1.1. Degradation and deforestation monitoring can be tracked by repeatedly visiting the same areas and measuring the diameter and height of all trees in that area

1.1.2. This method is conceptually similar to the Permanent Plot remeasurement protocols used to assess the growth and mortality rates, and thus calculate carbon sequestration rates, or intact forest. Therefore, the method can follow broadly the RAINFOR forest plot setup and analysis protocols[102].

1.1.3. However, the accuracy of the method relies on people not treating trees within these plots differently to normal forest areas. For this reason the plots must have no obvious markings,

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[101] Brown, Mahmood, Goslee. Unpublished. Degradation around Minded Areas: Methods and Data Analyses for Estimating Emission Factors. Report to the Guyana Forestry Commission.

[102] http://www.rainfor.org/upload/ManualsEnglish/RAINFOR_field_manual_version_2016.pdf

and community members (who will, and should, be involved in monitoring) must agree not to give away the position of the plots, nor treat them differently.

1.1.4. Though the plots must be unmarked, it is also critical that exactly the same trees are measured on each occasion the plot is revisited. For that reason permanent markers should be used (e.g. iron bars hammered fully into the ground), differential GPS points taken, and photographs collected.

1.2. Number and location of plots

1.2.1. The forest areas of Liberia differ greatly in their risk from deforestation and degradation. Therefore plots should not be set up with equal likelihood of occurring in any forested area, as that would require a larger sample size than is necessary. Instead, forest areas should be stratified based on a) Forest Type and b) Risk Level, and a certain number of plots placed within each.

1.2.2. We would expect a stratification based on two forest types (low and high biomass) and three categories of risk (low, medium and high) based on distance to roads/settlements and protection. Completing this stratification might be within this TOR, or may be separately completed by a different group.

1.2.3. The number of plots within each strata can be determined based on the area of each strata and expected standard deviation of change responses, following standard CDM methodologies[103]. Given the lack of data this would need to be estimated with consultation with experts. It is expected that the total number of plots to be set up across Liberia would be at least a thousand, with a much higher density of plots in the high risk than the low risk areas.

1.2.4. Plots should be placed randomly within each strata. Using a systematic grid is not recommended for this purpose as the distances between each plot would be unchanging, preventing the calculation of statistics as to the spatial correlation of degradation activities.

1.3. Plot measurements

1.3.1. We recommend setting up plots are square and 1 ha in size. This large size reduces the edge:volume ratio, minimising errors caused by plot misplacement on uncertainty over whether trees are ‘in’ or ‘out’ of the plot. Such plots are also less sensitive to the removal or death of a single tree.

1.3.2. Plot location should be given by a random number generation within a strata, using software such as QGIS or ArcMap. However once in the field the plot can be moved slightly (<10 m) from these coordinates to avoid dangerous obstacles such as rivers or cliffs being within the plot. Plots should only be set up if they are clearly ‘forest’ within Liberia’s definition.

1.3.3. Actual plot corners should be recorded using a differential GPS, and iron bars (rebar) hammered into the ground at the plot corners.

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[103] http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.1.0.pdf

1.3.4. Within each plot all trees with a diameter at breast height greater than 10 cm should have their diameter and height measured, and their species identified. RAINFOR tree census protocols should be followed, but by necessity the Point of Measurement cannot be marked and tree tags cannot be used. Trees should however all be given a unique number and their position mapped, as normal with RAINFOR plots.

1.3.5. Hemispherical photos should be captured on every 20x20 m vertex, in order to allow the plot to be repositioned and the fate of trees to be tracked.

1.3.6. During a repeat survey, every effort should be made to re-find trees recorded in the previous survey. If they have died, it should be recorded as far as possible whether the death was natural or due to anthropogenic harvesting.

1.3.7. If is it seen as significant, trees with a diameter between 1-10 cm could be assessed within three 20 x 20 m subplots.

1.3.8. If desired, soil cores or soil pits could be dug in a subset of plots in order to assess changes in below-ground biomass. However, this may be best left to the NFI as this could make the location of the plots obvious.

***1.4.* Biomass calculations**

1.4.1. Aboveground biomass should be calculated using the Chave et al. (2014) equation[104], unless a Liberia-specific equation is developed. Wood density values can come from the Global Wood Density Database[105] on a species basis, or local values used if available.

1.4.2. After a repeat survey, the change in biomass should be separately attributed between tree growth, tree death (natural), and tree death (anthropogenic).

1.4.3. These numbers can then be scaled, using the strata, to the whole of the country. Ideally the strata would be reassessed, using new remote sensing data, at every census.

1.5. Indicative costs

1.5.1. The stratification work would require field data collection throughout the country (potentially as part of a first NFI census), the analysis of remote sensing data, and modelling of degradation risk. These activities are likely to take place anyway, so may not be addition to the degradation work. But we would estimate costs of $300K for 3 months field work by 6 teams, and 60 high-level consultant days to analyse these data, Landsat satellite data, and produce a stratified map. However, on the first occasion, it may be that the M/G map and spatial layers of roads and settlements could be used to produce a lower quality stratification for approximately 20 consultant days, but this will necessitate the collection of more plot data.

1.5.2. Setting up the field protocols, creating the random points, and conducting training would likely involve on the order of 50 days of a high-level consultant.

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104 http://onlinelibrary.wiley.com/doi/10.1111/gcb.12629/abstract
105 http://datadryad.org/handle/10255/dryad.235

1.5.3. Each plot would take 2-5 days for a standard team of 4 field operatives and 1 field scientist/manger to complete. The time taken would increase dependent on the density of forest within the plot. Travel time between plots could be at least 1 day, and the team would need a rest, so an assumption of 1 plot per team per week would be reasonable. Previous fieldwork in Gabon has suggested an overall cost of about $2500/week as a minimum for logistical support, equipment and salary for such a team, but costs in Liberia could be higher or lower depending on how many high capacity local people could be hired.

1.5.4. Assuming 1000 plots were to be set up an indicative cost of US$2.5M would be needed for the field data collection per census.

1.5.5. After each census a team would need to enter data, validate the data, and calculate the carbon storage. This is likely to involve 1 skilled day's work per plot.

1.5.6. A final report after the second census would integrate all the plot data and provide change statistics and error estimates, involving perhaps 50 days of a high-level consultant's time with the support of 2 local staff involved in the data entry and validation process.

1.5.7. *Total cost is thus very dependent on plot numbers chosen, but could be well over $3M.*

2. Low tech: Optical data + Field Data.

2.1. Background

2.1.1. Metria/Geoville and FFI have already shown the capacity for a combination of Landsat and RapidEye data to classify forest by different levels of canopy cover.

2.1.2. In this method Landsat 8 or Sentinel 2 data would be used to map forest canopy cover into 3 broad classes: 30-50%, 50-80%, and >80%. The additional class over the G/M map allows for higher fidelity degradation and regrowth monitoring.

2.1.3. Training and validation data would be provided by a combination of field plots and RapidEye data

2.2. Field plots

2.2.1. Ideally no additional field costs would be involved in setting up this program. As part of an NFI we hope that Liberia will be assessing the biomass and canopy cover of a large number of plots across the country. These could be used to create canopy cover maps from RapidEye satellite data, and to assign biomass values to the different canopy cover classes.

2.2.2. If no NFI were to take place, then hundreds of field plots within each strata (divided by risk and canopy cover) would need to be set up, as per 1. Above. A lower total number of plots would be needed, but an additional parameter, canopy cover, would need to be collected using either hemispherical photographs or an LAI2000.

2.2.3. After two assessments had taken place using this method, a Stump Assessment fieldwork campaign is recommended, where areas that have changed from >80% canopy cover to lower canopy cover classes are randomly visited and it is confirmed whether tree stumps are present. This would allow an independent verification of the method, but is not essential as other data (such as an NFI or LiDAR campaigns) could provide alternative verification.

2.3. Remote sensing data ordering

2.3.1. Either Sentinel 2 or Landsat 8 data could be used for this task. We would recommend Sentinel 2 as it is better guaranteed to be available in the future (2 satellites are guaranteed to be orbiting into the 2030's), whereas Landsat relies on a single satellite, and it has a 10 m resolution rather than a 30 m resolution. Further, it has a higher repeat rate guaranteeing more cloud-free images.

2.3.2. A single, cloud-free mosaic for a single year for the country should be created using the data in 2.3.1, ideally using data from a ~1 month period at the height of the dry season.

2.3.3. Data at a higher resolution is essential to link the field data to the 10-30 m resolution satellite data. RapidEye provides a reasonable balance between resolution (5 m) and cost – for large areas indicative costs are around or below \$1.5/km^2 for an enterprise licence, though processing costs far exceed that. We would recommend ordering RapidEye data for 3-5 areas distributed across the country, covering a total of perhaps 10,000 km^2, a little under 10% of the country.

2.4. Remote sensing data processing

2.4.1. The RapidEye data should be used to make a map of the three canopy cover classes based on the field plot data, using a machine learning technique suitable for classification such as RandomForest, at a 10 m resolution, including texture metrics developed from the high resolution data. This should have an accuracy against 50 % of field plots held back for testing automatically by a normal RandomForest implementation of >95 %.

2.4.2. These high resolution maps should then be used to train and test a country-wide map using the Sentinel-2 data. If Landsat is used, they should first be degraded to 30 m. Again, a technique such as RandomForest would be preferred for dealing with these large training and testing datasets, though if that is computationally too challenging a technique such as a Support Vector Machine could be implemented. This map should have an accuracy >90 %.

2.5. Indicative costs

2.5.1. Landsat and Sentinel-2 data are free, but a system to download and store the data in Liberia could involve a hardware cost of \$20-30K, plus annual maintenance costs of at least \$10K. Alternatively an external consultant could do the remote sensing data analysis, but that might be politically unsatisfactory for Liberia.

2.5.2. RapidEye data purchase cost is expected to be on the order of \$15K for 10,000 km^2.

2.5.3. Analysing the data would probably involve a team of 3 GIS technicians working for 80 days each, under the direction of 1 remote sensing specialist working for 50 days, at a total cost of approximately \$170,000.

2.5.4. *Total cost is thus \$220,000 per survey.*

3. Medium tech: Radar data

3.1. Background

3.1.1. L-band radar data from has been shown to be effective for mapping biomass change directly up to 150 Mg/ha biomass[106], which we estimate represents about half of Liberia's forest area and probably 2/3 of its area of forest change.

3.1.2. Separately, experimental work with C-band radar suggests that degradation an deforestation in intact forest, above the saturation point for L-band radar, can be detected reliably using an algorithm developed at the University of Edinburgh called SAREDD

3.1.3. L-band radar data is only collected by the JAXA satellite ALOS-2 PALSAR-2. This data is charged, at a cost of approximately $2000/scene. Covering Liberia requires 34 scenes:

3.1.4. C-band radar is collected by a number of satellites, but since 2015 free data has been available from the Sentinel-1 satellite series on an approximately monthly basis.

3.1.5. Analysing radar data is computationally difficult and involves specialist skills unlikely to be easily developed in Liberia. Therefore these methods would probably need to be applied, initially at least, outside Liberia by external consultants.

3.2. Field data

3.2.1. As with method 2., field data would need to be collected if not already collected as part of an NFI. This would be for the lower biomass regions in order to locally calibrate a L-band

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[106] http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2011.02551.x/full
http://www.tandfonline.com/doi/abs/10.1080/17550874.2012.695814
http://www.biogeosciences.net/12/6637/2015/

radar-biomass relationship. At least 300 biomass plots would be needed, distributed throughout the lower canopy cover strata. No canopy cover data would need to be collected.

3.2.2. No field data would have to be collected for the C-band SAREDD system, though validation data in the form of stump surveys would be useful for validation purposes.

3.3. Satellite data processing

3.3.1. Level 1 ALOS-2 PALSAR-2 scenes would be downloaded for the year of interest. The scenes would ideally be from a single season, ideally the dry season, collected within a month of each other.

3.3.2. These would be processed to remove terrain effects at a 25 m resolution, and a seamless mosaic created.

3.3.3. Through comparison to the ground data a biomass map, with pixel-level uncertainty map, would be created. A saturation point of the method at approximately 150 Mg/ha is anticipated, but it could be higher or lower based on this analysis.

3.3.4. Differencing of data below this threshold would produce maps of the magnitude of forest loss, in tonnes biomass.

3.3.5. The SAREDD system relies on frequent observations, so every Sentinel-1 scene collected over Liberia would be downloaded and processed into calibrated and filtered stacks at a 50 m resolution.

3.3.6. Areas of low biomass forest would be removed using the ALOS-2 map (the Sentinel-1 method is thought not suited to data with a biomass lower than 100 Mg/ha). The SAREDD algorithm would then be run over data with a higher resolution, producing output maps of degradation through time.

3.4. Indicative costs

3.4.1. ALOS-2 PALSAR-2 data costs would be $68,000 at catalogue prices per survey, though a volume discount might be negotiable.

3.4.2. ALOS-2 PALSAR-2 processing costs (assuming field data has been collected and provided suitably) are estimated at 50 high-level consultant days plus 100 GIS technician days per survey, giving a total processing cost of approximately $125K.

3.4.3. Sentinel-1 data is free, but the SAREDD team at the University of Edinburgh is likely to charge approximately $5/km^2 to provide maps giving the date of degradation or deforestation for a year. Assuming 60,000 km^2 (about half) of Liberia were covered that would produce an indicative monitoring cost of $300,000.

3.4.4. Total cost is thus $493K/survey

4. *High tech: LiDAR Data*

4.1. Background

4.1.1. LiDAR provides the highest fidelity method for mapping biomass

4.1.2. LiDAR data collected over a stratified random sample of 10 % of the country could, combined with a robust stratification conducted elsewhere, provide robust estimates of degradation

4.1.3. Costs are likely to be higher than under the other methods, but this Tier-3 style monitoring system would have higher accuracy.

4.2. Field data

4.2.1. Field data collection would be necessary under the LiDAR study areas. We would recommend at least 300 plots in total

4.3. LiDAR data collection

4.3.1. Highest fidelity maps would be produced from using survey-grade LiDAR with a high point density (at least 5 points per m^2). Full waveform data collection should be considered (e.g. as offered by a combination of Reigl and Carbomap), but a system collecting multiple returns per point should be sufficient.

4.3.2. We recommend LiDAR is collected over a total of 10 % of the country, disturbed among 20 blocks. These would be stratified by forest type and threat.

4.3.3. LiDAR could be collected using either an aircraft or, at potentially lower cost though using a developing technology, a UAV

4.4. LiDAR data analysis

4.4.1. The LiDAR data should be processed to give layers such as Top Canopy Height, Mean Canopy Height, and canopy cover. These can then be related to biomass from the field plots using methods such as those described by Asner et al.[107].

4.4.2. Continuous maps of biomass at a high resolution (20 m) and low, known error, can then be compared from census to census.

4.5. Indicative costs

4.5.1. Indicative costs are hard to give for LiDAR as this is a rapidly advancing technology with costs reducing. But costs are likely to be in the order of $10/ha for data collection and $5/ha for processing. Therefore conducting such a survey over ten percent of Liberia, which is 1,100,000 ha, would be approximately US$16.5 million.

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[107] http://ghislain.vieilledent.free.fr/Wordpress/wp-content/Asner2012-Oecologia.pdf

ANNEX 2: ECONOMIC ANALYSIS OF BASELINE DRIVERS OF LAND USE CHANGE IN LIBERIA

Developed by Brent Sohngen (Sylvan Acres Limited Liability Company), Sukwon Choi, and Shelby Stults

Liberia has a relatively large area of forests and due to national circumstances they have not recently been heavily harvested or deforested. Using developed datasets and models, an analysis was conducted on potential deforestation and degradation drivers to project potential future deforestation and timber harvesting in Liberia. The analysis also addressed future mining activity and palm oil production for Liberia.

Focusing on these three critical sectors, forestry, mining, and palm oil, the authors have been able to locate and use data to conduct statistical analysis on each of the sectors. Importantly, the results should be interpreted with some caution given the sparsity of the data available from Liberia. Data on the timber and palm oil outputs and prices are derived from the UN FAO (2016). These data are collected from local sources, and then are reported to FAO from the government. Data on economic indicators were obtained from the World Bank and other sources. While FAO and the World Bank are excellent sources of data in general, most of the data must originally be collected in Liberia. Given the long running civil conflict, the completeness and uncertainty of the data is unknown. The data on mining outputs was obtained from the British Geological Survey (2016). These data were obtained mainly through government reports and also information on exports over the years.

The report begins by presenting the model developed for the forestry sector. This model consists of a supply and demand system, with prices based on export prices. A supply and demand model is estimated because there appears to be a viable local market for wood. Unfortunately we do not have a time series for domestic wood prices, but we use export prices as a proxy. The report then presents the models developed for the mining sector, focusing on gold, diamonds and iron. Only the supply side of these models is estimated, since the local demand for these minerals is limited and we assume prices are exogenous. These three minerals appear to be the most important sectors for mining in Liberia, although cement has recently become a larger industry. The final section discusses the results for the palm oil sector, for which we also develop a supply and demand model. Given estimates of export quantities, it appears that the largest demand for palm sourced form Liberia is local, so we model a supply and demand system.

The authors also attempted to correlate prices in these various sectors to actual land use change that occurred from 2001 to 2014. This analysis, however, was not successful. We did not test the effect of agricultural prices in this analysis. To better correlate the individual sectors with land use change, a more thorough analysis of what has caused the land use change and where it occurs would be necessary. Aside from general infrastructure development that cannot be attributed to any one sector, there appear to be three main drivers of deforestation in Liberia, agriculture, palm oil development, and mining. Spatial analysis with land use change data could be conducted to determine which of these drivers are primarily responsible for land use change. If other factors like existing development, existing roads, population centers and whatnot are controlled, then it is likely that the land use change can be correlated with prices in markets and a more quantitative assessment of potential future land use changes take place.

Forestry Sector Model

This analysis projects future forest harvesting in Liberia based on an estimation using data from the period 1961 to 2014. The projection is based on modeling a demand and supply system for wood products in Liberia. Data on timber production, exports, and price variables are obtained from FAO FOREST-STAT database (UN FAO, 2016). Other data on income and other factors was obtained from the World Bank (2016).

Figures A2-1 and A2-2 show industrial roundwood production in Liberia, as well as production in several neighboring countries. Total production and export of industrial round wood in Liberia move together between 1961 and 2003 because roundwood harvests have historically been driven by the export market in Liberia. There is a strong cyclical pattern to timber harvests in Liberia related partially to fluctuations in global prices and partly to policy changes in Liberia, such as civil conflict.

During the civil war between 1980 and 2003, the entire economy in Liberia was devastated and the GDP per capita in 2003 dropped to the 17% of its pre-war level in 1979 (World Bank, 2016). In the same period, the production and export of timber increased and then abruptly fell in 1995, recovering during the latter part of the 1990s. During the civil war, revenue from forest sector was linked to the illegal arms trade (Blundell et al, 2003). The UN Security Council placed sanctions on exports between 2003 and 2006, and there was no timber export in that period.

While there is limited detailed data and information on Liberian forest (Halton, 2013), there was wide spread corruption in forest sector during the conflict era. After a review of forest concessions in 2004, it turned out that the total forest concession area was 2.5 times the total forest area in Liberia and 100% of timber companies violated the laws (Blundell et al, 2005). In 2006, after the sanctions were lifted, previous concessions were nullified and new concessions were granted (Blundell et al, 2007). The period after 2007 appears to have significantly more stable timber harvesting than the period before, and timber harvesting appears to be on an upward trajectory.

Figure A2-1. Industrial Roundwood Production and Exports in Liberia (UN FAO, 2016)

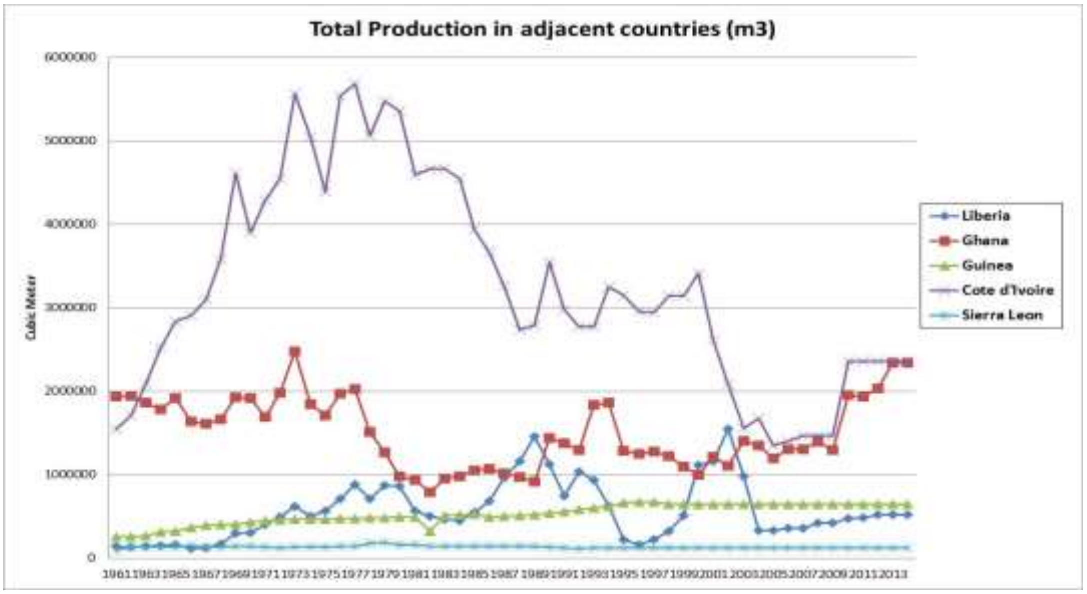

Figure A2-2. Total Industrial Timber Production in Liberia and several adjacent countries (UN FAO, 2016)

Methods

To make future projections, we estimate a supply and demand system. The supply and demand system can then be used to project future outputs based on assumptions about future trajectories in exogenous variables. The supply and demand system we estimate is given as:

Supply: $Ln(QS_t) = \alpha^1 + \alpha^2 Ln(P_t) + \alpha^3 DS_t + \alpha^4 Ln(El\_Nino) + \alpha^5 Ln(labor) + e_t$

Demand: $Ln(QD_t) = \beta^1 + \beta^2 Ln(P_t) + \beta^3 Ln(GDPPCLB_t) + \beta^4 Ln(GDPPCEU_t) + \beta^5 Ln(ImpPEU_t) + \beta^6 Ln(Cote\_P_t) + \beta^7 DC + e_t$

Equilibrium: $Ln(QS_t) = Ln(QD_t)$

Where:

- $Ln(QS_t)$: Natural log of timber supplied in cubic meters (UN FAO, 2016)
- $Ln(P_t)$: Natural log of timber export price (FUN AO,2016)
- $Ln(labor_t)$: Natural log of population aged 15 – 64 (World Bank, 2016)
- $Ln(El\_Nino)$: logged index of the strength of El Nino (NOAA, 2016)
- DS_t: Dummy variable; 1 if during the period of UN sanctions (2003-2006), 0 otherwise.
- $Ln(QS_t)$: Natural log of timber demanded in cubic meters (FAO, 2016)
- $Ln(GDPPCLB_t)$: Natural log of Gross Domestic Product per capita in Liberia (World Bank, 2016)
- $Ln(GDPPCEU_t)$: Natural log of Gross Domestic Product per capita in EU (World Bank, 2016)
- $Ln(ImpPEU_t)$: Natural log of import price in EU (UN FAO, 2016)
- $Ln(Cote\_P_t)$: Natural log of timber export price in Cote d'Ivoire (UN FAO,2016)
- DC: Dummy variable for the period of civil conflict (1980-2003).

The supply side of this model is composed of timber export prices, an index for El Nino, the supply of labor, as measured by population, and a dummy variable for the period of sanctions. The parameter on prices is expected to be positive, as a higher price will induce more output. The El Nino index controls for climatic fluctuations that will affect weather patterns generally and influence the supply of wood from forests. Labor accounts for the supply of labor and should be positively correlated with supply. Sanctions are included as a supply side variable because they reduce investments and efforts to produce wood.

The demand side is composed of export prices, income in Liberia (GDP per capita), income in the European Union, import prices in the European Union, export prices from the Ivory Coast, and a dummy variable for the period of conflict, or civil war. It is expected that the parameter on prices will be negative, and the parameters on income will be positive. The sign on import prices in the EU should be positive, but the sign on export prices from Ivory Coast will be positive or negative. We anticipate that the sign on civil conflict will be positive given the results Blundell et al. (2005).

Results

The results of the empirical estimation are shown in Table A2-1. On the supply side, export prices have a positive sign, as expected, suggesting that higher prices for export logs increase supply. Sanctions have a negative effect, but are not significant. El Nino is also insignificant. Labor supply is negative and significant. This is surprising, but if an increasing labor supply is also available for competing activities, which could reduce the supply of wood.

In the demand system, the price has a negative sign as expected. Income in GDP and income in the EU both have a positive impact upon demand. Import prices in the EU are not significant, although export prices in the Ivory Coast are positive and significant. Thus, if prices rise in the Ivory Coast, then demand for wood increases in Liberia. The conflict dummy variable is positive and significant suggesting that demand for wood was generally higher during the conflict.

Table A2-1. Estimation results of supply and demand in Liberia (n=54, 1961-2014)

Parameter	Description	Estimate	Std. Error
α1	Intercept (S)	41.39***	9.29
α2	Export Price (log)	1.30***	0.29
α3	Sanction	-0.12	0.34
α4	El Nino	0.00	0.01
α5	Labor (log)	-1.83***	0.62
β1	Intercept (D)	-63.44**	28.18
β2	Export Price (log)	-3.67**	1.52
β3	Liberia GDP per capita (log)	1.33***	0.31
β4	EU GDP per capita (log)	6.59**	2.51
β5	Import Price in EU (log)	0.7	0.74
β6	Export Price in Ivory Coast (log)	1.54**	0.64
B7	Conflict Dummy	1.7***	0.52

Historical harvests and the projection of future harvests through 2025 are shown in Figure A2-3. To make the future projections, we make the following assumptions about the exogenous variables:

Labor supply: Rises at 1% per year
GDP per capita in Liberia: Constant
GDP per capita in Europe: Rises at 2% per year

Import prices in EU: Rise at 2% per year
Export prices from Ivory Coast: Rise at 2% per year

Prices and quantities are endogenous, so we predict an equilibrium price and quantity for each historical year with the model and compare it to the actual data. Then we predict the future for a decade with the model and the assumptions above. Based on these estimates, our model suggests that output will increase 3.3% per year. The output data are provided from 1990-2025 in Table A2-2.

The results of the future projection suggest that output falls in 2014, mainly due to the reduction in export prices in the Ivory Coast. We assume that export prices in Ivory Coast begin rising again after 2014, leading to higher projected harvesting in Liberia as well.

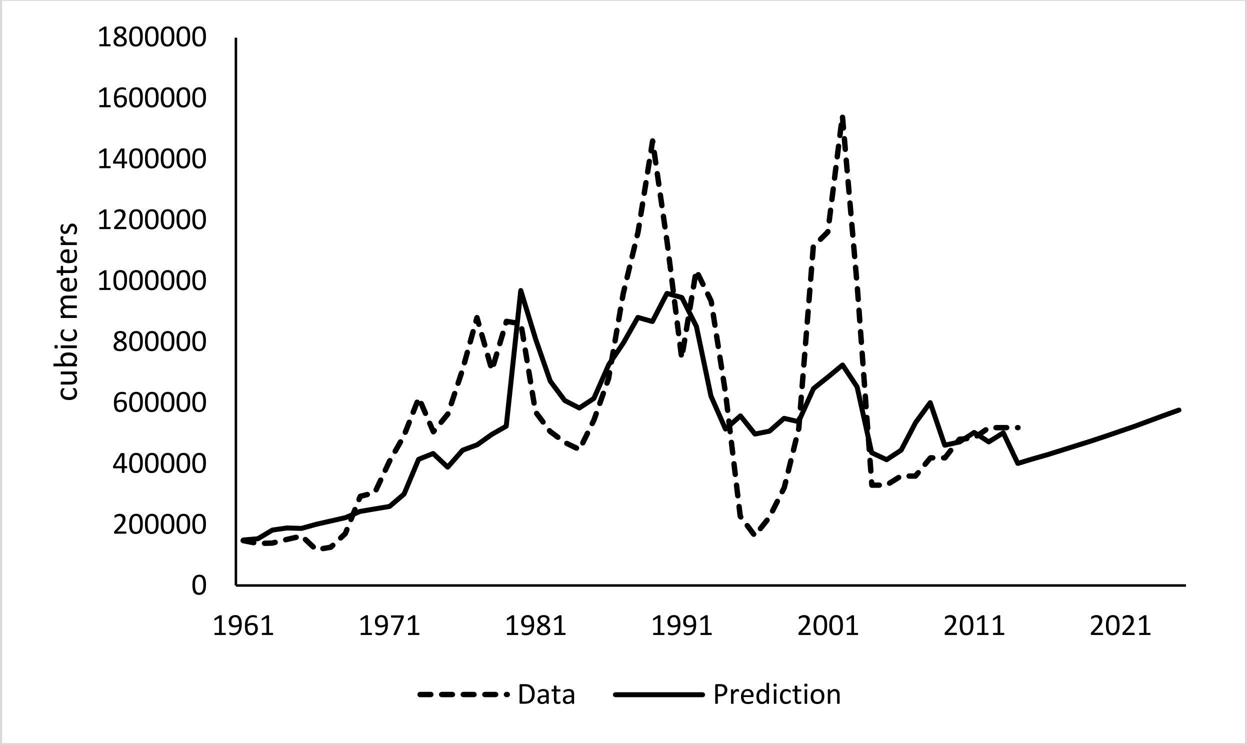

Figure A2-3. Historical actual, historical predicted, and future predicted timber harvests in Liberia. Historical actual data based on UN FAO (2016)

Table A2-2. Timber outputs in Liberia, 1990-2025. Data is actual data from FAO and used as input in the model. Prediction are the predicted values from the model estimated and presented in Figure A2-3

	Data	Prediction
Year	m3/yr	
1990	1,128,049	959,929
1991	746,985	945,686
1992	1,034,988	850,380
1993	934,998	622,852
1994	629,008	514,002
1995	228,000	557,869
1996	163,996	497,453
1997	222,994	507,100
1998	321,001	549,838
1999	516,020	538,622
2000	1,114,036	646,400
2001	1,162,054	684,527
2002	1,544,020	725,047
2003	979,992	652,690
2004	329,984	435,864
2005	329,984	413,200
2006	360,015	444,350
2007	360,015	534,942
2008	419,996	601,187
2009	419,996	460,381
2010	479,980	471,161
2011	483,981	502,351
2012	517,984	472,020
2013	517,984	500,999
2014	517,984	401,663
2015		415,583
2016		430,082
2017		445,087
2018		459,734
2019		474,863
2020		490,491
2021		506,632
2022		523,305

2023	540,527
2024	558,315
2025	576,689

Mining Model

Data on mineral outputs for Liberia and neighboring countries were obtained from the British Geological Survey (2016), which has kept track of data on mining outputs from most countries around the world. The data for Liberia and other countries, while stored in the BGS database, are composed of numerous estimates of outputs given that data were not routinely kept in Liberia. The data for Liberia indicates that cement, diamonds, iron ore are three major commodities produced in Liberia. Gold also is produced. We have not been able to develop a statistically valid model for cement. We have been able to develop models for the other three commodities.

We did not conduct analysis of the spatial location of mines, although in our search for data, we did find several datasets that provide information on where current mines are located in Liberia. The quality of this data, however, is unknown, and it is not clear if historical data are available. We also do not have data on individual mine output. To our knowledge, this type of data is not available publicly as it usually is kept privately by mine owners or operators, unless they are otherwise required to report outputs to the government.

Data on prices were obtained from the US Geological Survey (2014), and data on other economic factors in the countries of interest were obtained from the World Bank (2016).

Of the three mining sectors we analyze, iron ore and diamond mining appear to be the most important commercially by volume and value. To determine how various factors affect mining output in Liberia, we construct a mining supply function for each of the commodities. The main factors expected to influence supply are prices for the commodities, labor supply in Liberia (measured by population), exchange rates, and other factors.

Gold

Starting with gold, the supply function we estimate is given as

$$Ln(Q_t) = \beta^1 + \beta^2 ln(P_{t-1}) + \beta^3 Goldd_t + \beta^4 Goldd2_t + e_t \quad (1)$$

Where,

Q_t = output of gold (ounces per year)
P_{t-1} = lagged real price of gold in US dollars, deflated to 1998 real US$
$GoldD_t$ = 1 if year ranges from 1999 to 2006, 0 otherwise.
$GoldD2_t$= 1 if year ranges from 2007 to 2014, 0 otherwise.

For this model, we explain gold output as a function of gold prices and two dummy variables representing different periods. Prices have the most important impact on output, but it is clear from the data that the period 1999 to 2006 experienced very low gold output, due to civil war and sanctions. We control for the increase in output that occurred after 2006 with a dummy variable for the period 2007-2014.

Table A2-3. Liberia Gold Supply Model, estimated from historical data

Parameter	Description	Estimate	Standard Error
β1	Intercept	-39.596*	21.564
β2	lngoldpricereallag	2.674**	1.309
β3	Golddummy	-3.089**	1.437
β4	golddummy2	0.27	1.548

** Significant at 0.05 level, * significant at the 0.10 level

The parameters in the model generally make sense (G3). The price of gold is positive and significantly different from 0. Higher prices imply increased gold output. The gold dummy variable is large, negative and significant, as expected. This parameter controls for the lower level of gold extraction that occurred during this period. The gold dummy for the period after 2006 is positive, but not significant. Prices have a large impact on rising outputs during this time period in this model.

The historical actual output, historical predicted output based on the model above, and the predicted future output from the model is shown in Figure A2-4 and the output data are provided in Table A2-4. The model predicts relatively stable outputs in the future, in line with the assumption that gold prices remain fairly stable. Should gold prices rise, these outputs would be expected to increase. On the other hand if prices fall, our model would predict that outputs will decline.

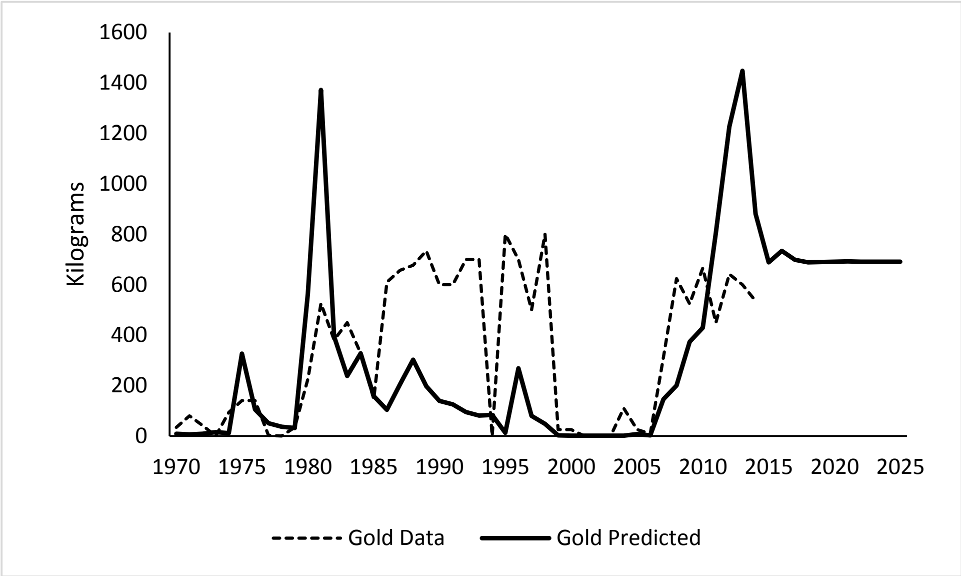

Figure A2-4. Historical output and predictions for the gold model for Liberia

Table A2-4. Gold mining outputs in Liberia, 1990-2025. Data is actual data from British Geological Survey and used as input in the model. Prediction are the predicted values from the model estimated and presented in Figure A2-4

	Data	Prediction
Year	Kilograms/yr	
1990	600	139
1991	600	124
1992	700	94
1993	700	81
1994	0	83
1995	800	13
1996	700	268
1997	500	79
1998	800	47
1999	25	2
2000	25	1
2001	0	1
2002	0	0
2003	0	1
2004	110	1

2005	25	7
2006	9	2
2007	311	145
2008	624	200
2009	524	373
2010	666	428
2011	449	807
2012	641	1,226
2013	600	1,448
2014	535	881
2015		688
2016		734
2017		699
2018		688
2019		690
2020		691
2021		691
2022		691
2023		691
2024		691
2025		691

Iron Ore

The second model for Liberia is the Iron Ore model. This model is estimated as

$$Ln(Q_t) = \beta^1 + \beta^2 ln(P_{t-1}) + \beta^3 ln(Pop_{t-1}) + \beta^4 ln(ER_{t-1}) + \beta^5 IronD_t + \beta^6 YY11 + \beta^7 YY12 + \beta^8 YY13 + \beta^9 YY14 + e_t$$

Where,

Q_t = output of gold (ounces per year)
P_{t-1} = lagged real price of gold in US dollars, deflated to 1998 real US$
ER_{r-1} = exchange rate lagged one year (Official Local Currency versus US $)
Pop_{t-1} = Population from 15 to 64 years lagged one year
$IronD_t$ = 1 if year ranges from 1993 to 2010, 0 otherwise.

YY11 = 1 if year =2011
YY12 = 1 if year =2012
YY13 = 1 if year =2013
YY14 = 1 if year =2014

We use the same variables for the iron ore model in Liberia, except the dummy variable in this case is for the years 1993-2010. During this period, iron ore extraction was 0 based on the data we have obtained. Iron ore extraction recovered in 2011 and rose through 2014, but growth in output appears to have slowed over the last 4 years, so we include individual year dummy variables to account for this trend.

The results of the model are shown in Table A2-5. The parameter on price is positive and significantly different from 0 as expected. The population parameter is negative and significant. This is not expected, but the overall trend in iron ore extraction over the time period has been fairly flat, while population has been increasing, so the parameter estimate makes sense. The 1993 to 2010 dummy variable is negative and highly significant as expected. The individual year dummy for 2011 is also negative and significant. The reason for this is that 2011 output was lower than the average output for the years 1970-1992. Output however increased after 2011 in years 2012, 2013 and 2014 relative to the period before 1993. The individual year dummies for 2012-2014 are not significantly different from 0 indicating that we cannot distinguish output in these years differently from the period before 1993.

Table A2-5. Liberia Iron Ore Supply Model

Parameter	Description	Estimate	Standard Error
β1	Intercept	28.741***	5.95
β2	Lnironpreallag	0.846**	0.338
β3	lntpop1564lilag	-2.306***	0.812
β4	iron0li	-19.402***	0.244
B5	Offexchlilag	0.001	0.006
B6	yy11	-1.833***	0.373
B7	yy12	0.078	0.525
B8	yy13	0.84	0.64
B9	yy14	0.926	0.718

*** Significant at 0.01 level ** significant at the 0.05 level.

The historical actual iron ore output, historical predicted iron ore output (predicted based on model), and the future predicted iron ore output for Liberia is shown in Figure A2-5 and the output data are provided in Table A2-6. Output falls from the 1970s through the 1980s, largely because prices for iron ore were falling. The civil war in Liberia likely also played a role, although when we test for the effects of the civil war explicitly, the effects are not significant. Output falls completely to 0 in 1993, as noted before and remains at 0 through 2010, when iron ore mining commences again in Liberia.

The future prediction is made assuming that iron ore prices remain constant in the future, population rises at the same rate as used in the gold model above, and exchange rate remain constant. The rising trend in output is obtained by adjusting the YY14 data in the future to increase at 0.10 per year. This introduces a modest increase trend in production, which follows the increasing trend from 2011 to 2014, but at a slower rate.

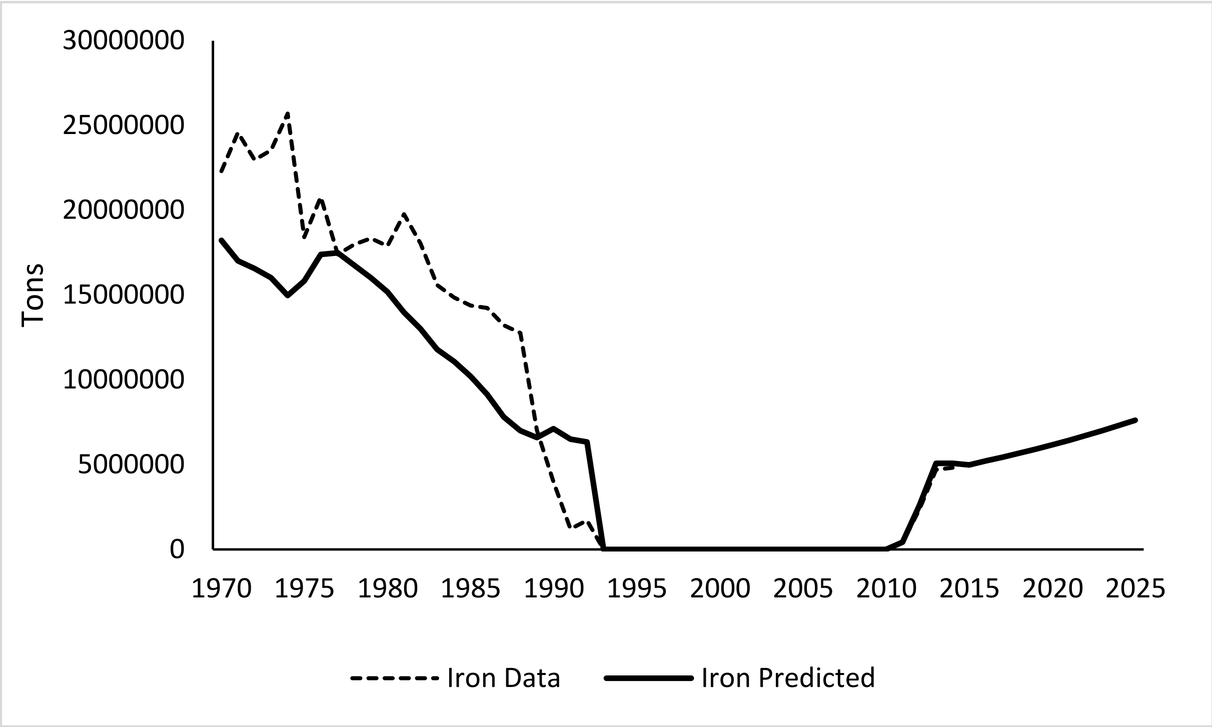

Figure A2-5 Historical iron ore production, historical predicted iron ore production and future predicted iron ore production. All predictions based on the model in G5 above

Table A2-6. Iron mining outputs in Liberia, 1990-2025. Data is actual data from British Geological Survey and used as input in the model. Prediction are the predicted values from the model estimated and presented in Figure A2-5

	Data	Prediction
Year	Tons/yr	
1990	3,981,000	7,108,469
1991	1,200,000	6,494,878
1992	1,710,000	6,321,325
1993	0	0
1994	0	0
1995	0	0
1996	0	0
1997	0	0
1998	0	0
1999	0	0

2000	0	0
2001	0	0
2002	0	0
2003	0	0
2004	0	0
2005	0	0
2006	0	0
2007	0	0
2008	0	0
2009	0	0
2010	0	0
2011	386,968	423,907
2012	2,369,850	2,606,485
2013	4,698,281	5,074,744
2014	4,813,676	5,078,190
2015		4,988,790
2016		5,204,505
2017		5,429,549
2018		5,664,323
2019		5,909,248
2020		6,164,764
2021		6,431,329
2022		6,709,420
2023		6,999,536
2024		7,302,196
2025		7,617,943

Diamonds

The diamond model in Liberia is given as

$$Ln(Q_t) = \beta^1 + \beta^2 ln(P_{t-1}) + \beta^3 ln(Pop_{t-1}) + \beta^4 SanD_t + \beta^5 ConD_t + e_t \qquad (4)$$

Where,

Q_t = output of gold (ounces per year)
P_{t-1} = lagged real price of gold in US dollars, deflated to 1998 real US$
Pop_{t-1} = Population from 15 to 64 years lagged one year
$SanD_t$ = 1 if year ranges from 2003 to 2006, 0 otherwise (sanctions)
$ConD_t$ = 1 if year ranges from 1980 to 2003, 0 otherwise (conflict)

The conflict period is the period over which Liberia was in civil conflict, which lasted from 1980 to 1993. Sanctions were imposed in 2003 and lasted until 2006. We include dummy variables to control for both of these. The price parameter is positive and significant, indicating that diamond mining is positively related to diamond prices (Table A2-7). Population in this case is positively correlated with diamond mining. The conflict period has a positive correlation with diamond output while sanctions have a negative correlation. This makes sense and suggests that the sanctions had the intended impact on diamond outputs. We do not include exchange rates here because they do not have a significant impact and the sanction and conflict variables appear to capture fairly important supply impacts.

Table A2-7. Diamond Supply Model

Parameter	Description	Estimate	Standard Error
β1	Intercept	-37.81***	8.427
β2	Real diamond price (logged and lagged)	0.656***	0.065
β3	Population (logged and lagged)	0.734***	0.143
β4	Sanction Dummy	-1.321***	0.196
β5	Conflict dummy	0.949***	0.141

*** Significant at 0.001 level

The predicted output of diamonds for Liberia is shown in Figure A2-6 and a table of the output data is provided in Table A2-8. Diamond production fell from relatively high levels in the early 1980s to very low levels during the period of sanctions from 2003 to 2006. They have recovered since then. The production level in 2014 represented a significant increase in production which our model does not capture. This increase may have resulted from the opening of a new mine. The prediction from 2015-2025 suggests that mining increases slowly. We have assumed that diamond prices remain constant over this time period, and that population increases.

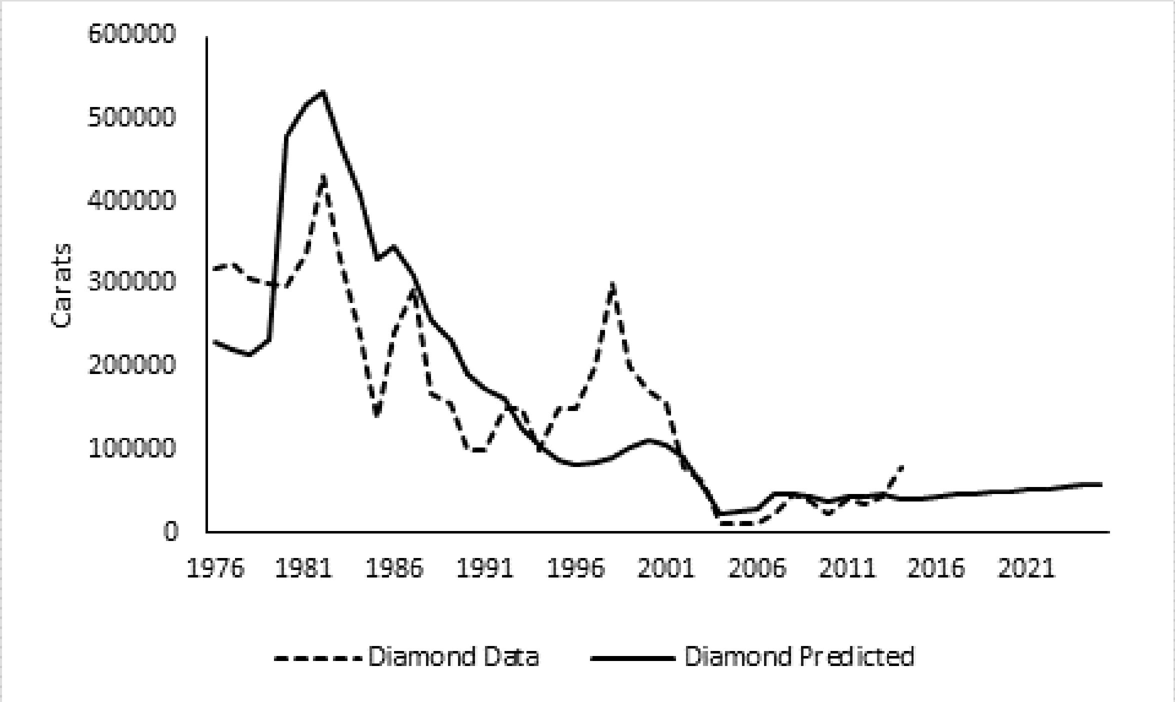

Figure A2-6. Historical diamond production, predicted historical diamond production and future

The three mining models suggest that mining outputs have recovered in Liberia after the civil conflict and the period of sanctions. Based on projected trends in prices globally, our projections suggest that there will be modest continued increases in outputs for these three minerals over the coming decade. These projections are heavily dependent on prices, which are consistently the most important predictor of mining activity, so if future price projections increase or decrease, the future projections will change.

Table A2-8. Diamond mining outputs in Liberia, 1990-2025. Data is actual data from British Geological Survey and used as input in the model. Prediction are the predicted values from the model estimated and presented in Figure A2-6.

	Data	Prediction
Year	Carats/yr	
1990	100,000	191,189
1991	100,000	174,402
1992	150,000	162,470
1993	150,000	126,588
1994	100,000	105,148
1995	150,000	87,428
1996	150,000	81,129
1997	200,000	84,915
1998	300,000	89,896
1999	200,000	101,503
2000	170,000	111,370
2001	155,000	105,756
2002	80,000	91,112
2003	60,000	56,013
2004	11,000	22,234
2005	11,000	24,299
2006	11,000	28,299
2007	21,699	46,024
2008	46,963	45,916
2009	36,828	43,361
2010	22,018	35,970
2011	39,866	42,994
2012	34,271	44,506
2013	44,334	44,982
2014	79,747	38,876
2015		41,636
2016		43,136
2017		44,691
2018		46,302
2019		47,971
2020		49,700
2021		51,492
2022		53,348

2023	55,271
2024	57,263
2025	59,327

Palm Oil Model

The final model developed for this analysis involves a demand and supply system for palm oil. Output in Liberia has been fairly low since the 1960s and has only risen modestly over the time period (Figure A2-7). Liberia reports fairly low levels of exports of palm oil as well, with Liberia only exporting 10% of total palm oil production since 1966. This suggests that a significant proportion of palm oil in Liberia is consumed locally.

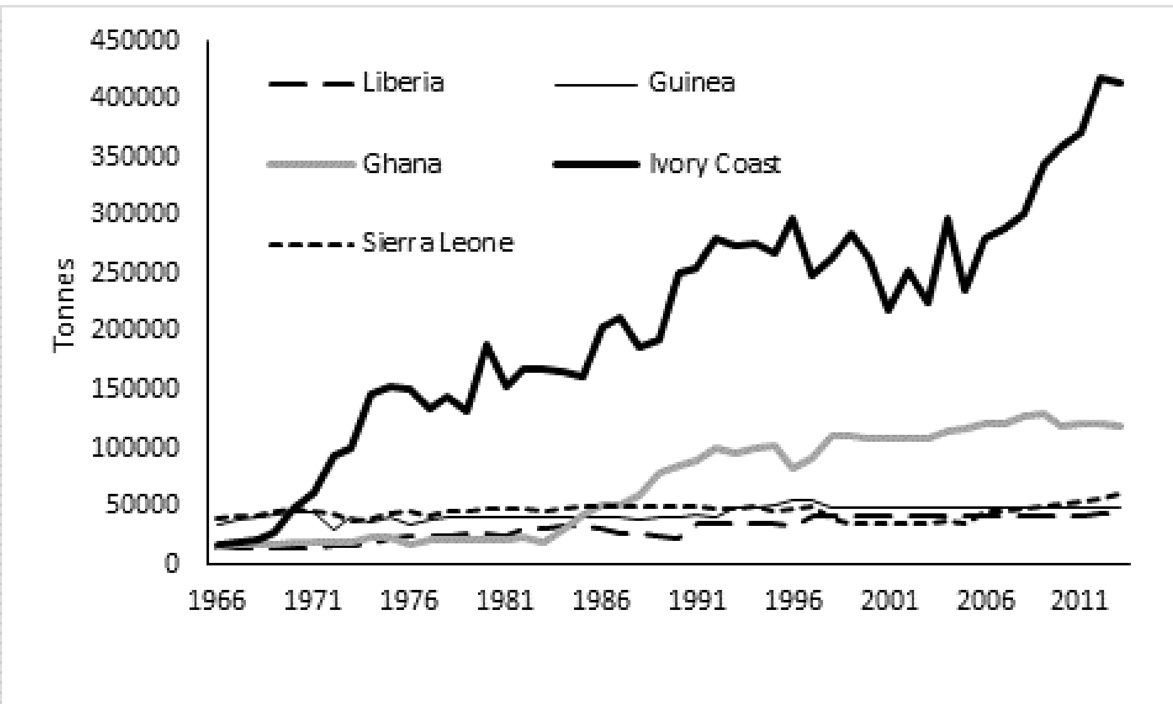

Figure A2-7. Palm oil production in several African countries neighboring Liberia (UN FAO, 2016).

To model palm oil, we use the same demand and supply structure as used for the forestry sector above, although we use some different parameters. For prices, we use an instrument for the price of palm oil in Liberia, substituting the export price of palm oil from Ivory Coast. Ivory Coast produces and exports more palm oil in general, and prices there potentially better represent the value of palm oil production in the region.

Supply: $Ln(QS_t) = \alpha^1 + \alpha^2 Ln(P_t) + \alpha^3 ER_t + \alpha^4 Sanction + \alpha^5 Ln(population) + e_t$

Demand: $Ln(QD_t) = \beta^1 + \beta^2 Ln(P_t) + \beta^3 Ln(USGDPPC_t) + \beta^4 Ln(LiberiaGDPPC_t) + \beta^5 Ln(FrImpprice_t) + \beta^6 Conflict + \beta^7 DC + e_t$

Equilibrium: $Ln(QS_t) = Ln(QD_t)$

Where:

$Ln(QS_t)$:	Natural log of palm production in tonnes (UN FAO, 2016)
$Ln(P_t)$:	Natural log of palm export price in Ivory Coast (FUN AO,2016)
Sanction:	Dummy variable; 1 if during the period of UN sanctions (2003-2006), 0 otherwise.
$Ln(Population_t)$:	Natural log of population aged 15 – 64 (World Bank, 2016)
$Ln(QD_t)$:	Natural log of timber demanded in cubic meters (FAO, 2016)
$Ln(USGDPPC_t)$:	Natural log of Gross Domestic Product per capita in the US (World Bank, 2016)
$Ln(LiberiaGDPPC_t)$:	Natural log of Gross Domestic Product per capita in Liberia (World Bank, 2016)
$Ln(FrImpprice_t)$:	Import price of palm oil in France (UN FAO, 2016)
Conflict:	Dummy variable for the period of civil conflict (1980-2003).

Model results are shown in Table A2-9. The parameters generally make sense with the price variable being negative in the demand function and positive in the supply function. The price parameter in the supply function, however, is not significantly different from 0 and the size of it is fairly small as well. This suggests that the supply function for palm oil in Liberia is not all that sensitive to prices and instead shifts in response to other factors, such as exchange rates and population. It is also likely that palm supply is a function of other factors for which we have not found the proper controls in this analysis, such as the price of land, and biological factors that control palm growth and output.

Table A2-9. Estimation results of palm oil supply and demand in Liberia (1966-2013)

Parameter	Description	Estimate	Std. Error
α1	supply intercept	-15.43***	2.95
α2	palm export price	0.07	0.09
α3	official exchange rate	-0.01***	0
α4	sanction dummy	0.09	0.07
α5	Ln(Population)	1.83***	0.19
β1	demand intercept	-8.27***	1.87
β2	palm export price	-0.55**	0.21
β3	US GDP per capita (2005)	1.73***	0.16
β4	Liberia GDP per capita (2005)	0***	0
β5	palm import price in France (real)	0.59***	0.18
β6	conflict dummy	0.12***	0.04

Using the model in Table A2-9, future predicted palm output is shown in Figure A2-8, and the data for the prediction is provided in Table A2-10. Given relatively modest increases in income per capita in the US and Liberia, the model suggests that palm production increases over the next decade in Liberia, albeit at a relatively modest rate. This increase, while notable, would suggest that palm production in Liberia remains below that in Ivory Coast and Ghana, the two largest producing neighbors.

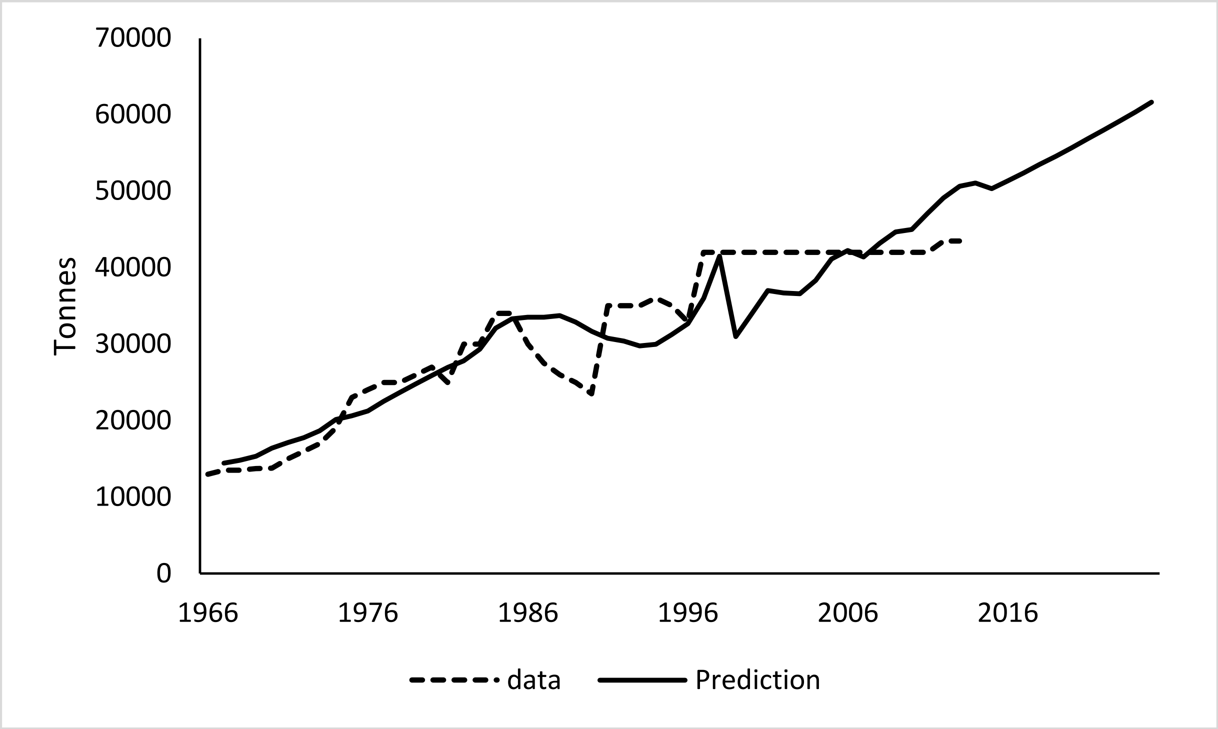

Figure A2-G8. Historical and predicted palm production in Liberia base on model estimation in Table A2-9.

Table A2-10. Palm oil outputs in Liberia, 1990-2025. Data is actual data from British Geological Survey and used as input in the model. Prediction are the predicted values from the model estimated and presented in Figure A2-8

	Data	Prediction
Year	Tonnes/yr	
1990	23,500	31,643
1991	35,000	30,775
1992	35,000	30,418
1993	35,000	29,779
1994	36,000	29,968
1995	35,000	31,240
1996	32,915	32,678
1997	42,000	35,991
1998	42,000	41,487
1999	42,000	30,951
2000	42,000	33,912
2001	42,000	36,983

2002	42,000	36,708
2003	42,000	36,560
2004	42,000	38,318
2005	42,000	41,115
2006	42,000	42,221
2007	42,000	41,394
2008	42,000	43,210
2009	42,000	44,649
2010	42,000	44,976
2011	42,000	47,118
2012	43,500	49,117
2013	43,500	50,661
2014		51,075
2015		50,319
2016		51,347
2017		52,397
2018		53,469
2019		54,563
2020		55,679
2021		56,819
2022		57,983
2023		59,171
2024		60,384
2025		61,623

Discussion

The models provided in this analysis provide an initial look into market trends affecting important extraction sectors in Liberia. Given the long-running civil conflict and the sanctions that were imposed in the early 2000s, the results are surprisingly robust. We were able in all cases shown here, able to correlate factors that would affect supply or demand with the output variables and/or prices. For timber and palm, we developed demand and supply systems because there does appear to be an internal market for these two products. For the mining sector we focused explicitly on identifying an output supply function, assuming that there is little internal demand for the outputs of the mining sectors we analyzed.

The results suggest that outputs for most commodities in Liberia will be stable to increasing. For instance, although wood products output is initially expected to fall in 2015, they are projected to increase after that at a rate of 3.3% per year over the next decade. The reduction is largely due to the abeyance of the current El Nino event. Although the parameter on the El Nino function is not significant, the parameter has an important effect on the modeled outcomes. While some modelers would remove El Nino from the analysis, it has important implications as an exogenous supply shifter and so is maintained. The longer term increase in wood outputs relies largely on the assumed increases in GDP per capita outside of Liberia.

In contrast, gold outputs are projected to remain fairly constant. Gold prices increased substantially through the 2000s, but these increases have abated recently. When looking at the projections our model likely over-estimates the consequences of price changes in Liberia. That is, the high predicted output in 2012 is a function of the very high gold prices. The actual data does not indicate such a large increase in gold output. Other factors that we have not modeled are also affecting gold outputs, but we have not been able to include those in our analysis. We assume that gold prices remain constant in the next 10 years and this drives the moderation in outputs in our model.

Iron ore is projected to slowly rebound from the low period of no production from the early 1990s to 2010. This slow increase is driven by the fact that we increase the dummy variable yy14 by 10% per year. While this increase appears plausible given historical outputs from the 1970s and 1980s, it is important to recognize that this is not tied to any assumed increases in exogenous factors like income. In fact, given historical levels of output and the rapidity of the rise in output from 2010 to the present, it is plausible that output could take another large step upward, particularly if new mines are opened. We are unable to model the future eventuality of new mines opening with this analysis.

Diamond supplies also are expected to remain fairly constant in the future, increasing only modestly. The main reason for this is that we assume that diamond prices are fairly stable in the future. We note that there was a large increase in actual output in 2014, which our model does not capture because this increase was not correlated with a large increase in prices. One issue to consider with the diamond model is that our diamond price is for industrial diamonds, which have been commodified. In contrast, diamonds used in the jewelry trade are extremely valuable, but have large variation in quality, which also affects price. So this large increase in outputs could relate to specific discoveries of diamonds in markets outside of the market for which we observe prices, namely industrial diamond markets.

Finally, we project a 1.7% per year increase in palm oil output in Liberia in the future. This is driven heavily by rising prices for palm oil due to increasing demand elsewhere. Exports have not recently been a large proportion of the total output in Liberia, but they do appear to be increasing. Our trends would include an increase in palm oil exports. One of the limitations of this analysis is that we have not fully modeled the supply side of Liberia, namely the biological components of production. These components would be expected to have important impacts on future projected outputs.

The underlying data on outputs from the UN FAO, World Bank and the British Geological Survey represent the most complete time series data we were able to find, however, there are clearly issues with the data. These issues are not unique to Liberia, as they affect analysis in many countries of the world, but they make inference such as produced in this report more complicated. For example, for the mining sectors, we note that there are many years in the historical record when outputs are set to 0. While it is entirely plausible that mining sectors started and stopped at various times, as appears to have happened in the iron ore mining sector, it is also possible that reporting of mining was limited in the years with 0 reported output. Also some mining outputs likely leave the country illegally. This may be most important with the most valuable minerals that do not weigh as much, such as diamonds in particular, and gold. Unfortunately, we can never know how much output is exported illegally, and we can never know if output historically was truly 0. For the purposes of our analysis, we have assumed that 0's indicate 0 output.

There are also some concerns about the data for palm oil. The output data are flat from 1997 to 2011. This is highly improbable given that outputs are a function of biological production functions. Palm exports, not shown, displayed similar patterns of constant outputs for long periods of time, followed by sudden changes. Although the aggregate output data are problematic, a potentially more important issue in estimating the palm oil supply and demand system is that we lack a biological component in the supply function. There could be a large number of factors influencing supply of palm that are related to annual growth in the underlying resource. These factors include pests, drought, rainfall, etc. Importantly, we did attempt to include an index for El Nino in our estimates, but it was not significant. While these biological factors are important to consider, we note that the factors we have included, which control largely for labor supply to harvest and use palm oil, are also critically important.

Despite concerns with the data, these results suggest that market factors are playing an important role driving outputs in timber, palm oil, and mining in Liberia. The analyses could be improved with additional effort and local data collection. First, for timber there are large fluctuations in the data that are not fully captured by the model. It would be important to work with local partners to try to determine what factors may actually have been at play in causing those fluctuations. If we could identify those and control for them in our model, likely on the supply side but also potentially on the demand side, we could derive a model with better fit for the timber analysis.

Second, an overall concern on the mining models relates to the role of individual mines and output. We suspect that output is heavily influenced by individual mines in Liberia. It would be useful to determine whether data would be available on individual mine openings and closings in Liberia. To obtain this data for the complete historical record we have in this analysis would likely be exceedingly difficult to do for gold and diamonds, and potentially iron ore. Assessing whether this data is available, however, could provide better options for making projections.

Finally, with respect to palm oil production, aside from data, the biggest limitation in the analysis is the lack of a biological control on the supply side. Palm oil is a renewable resource and production of palm oil is tied to growth in the palm resource. Better weather data could be explored to control for the historical influence of weather on palm oil production. Other known large scale events could also be controlled if local experts can provide such information. It would also be useful to consider an alternative type of modeling of palm oil development for Liberia based on structural dynamic methods that directly model the underlying palm oil resource base. Such methods could be developed with the relatively scarce data that already exist.

One component of this analysis that did not work out was estimates of factors influencing actual land use change. Using land cover change data developed from 2001-2014, we attempted to correlate mining, forestry, and palm prices to deforestation rates, but were unsuccessful. Population, not surprisingly, was correlated with deforestation rates. We did not incorporate agricultural prices in that analysis, but agricultural prices likely would play a role. One reason for the difficulty in making the link between prices and deforestation, we suspect, has to do with needing to tie deforestation to specific activities, e.g., mining, palm development, agriculture. If data on the drivers of deforestation were available over time, we could attempt to develop land use change models.

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ANNEX 3: CAPACITY BUILDING STRATEGY

An important component of the development of recommendations for a REDD+ Reference Scenario for Liberia is capacity building to assist the country in developing the skills and knowledge to understand, maintain, and revise the reference scenario within country, to the extent possible. An initial capacity assessment has been conducted through meetings with the relevant entities and review of existing documents, notably Liberia's REDD Readiness Preparation Proposal (described below). While there are certain individuals who have a strong understanding of REDD+ in general, the country currently has limited data on forest biomass and land use, limited technological capacity, particularly in regards to spatial analysis, and limited overall knowledge about REDD+ Reference Levels and their development.

Capacity building activities take many forms, including reports such as this one, which describe the elements of a reference level and the decision points needed; meetings to discuss such decisions and provide additional description and guidance; workshops in which broad components can be discussed, with broad participant; and technical trainings, aimed at specific technical staff who will implement future reference level and MRV activities. This annex provides a capacity assessment for Liberia's REDD+ Reference Level knowledge and expertise, detail on the capacity building activities that have been undertaken to date, and a description of additional capacity building needs that are recommended for the future. At the end of this annex, the capacity building activities described in the MRV Roadmap of June 2016 are linked to the capacity building strategy described here.

Capacity assessment report

Recognizing the overall capacity gaps and need that exist regarding REDD+ in Liberia, WI/CI in consultation with the REDD+ Implementation Unit (RIU) design a REDD+ capacity assessment questionnaire template for the purpose of collecting relevant data to be in as part of Liberia's reference level development capacity building processes. The designed capacity assessment questionnaire template was divided into four main categories, which are summarized below:

I. **General REDD+ Knowledge** on the organization past and present REDD+ activities, plans for future REDD+ engagement, and level of knowledge and expertise on international UNFCCC processes on REDD and IPCC LULUCF monitoring requirements

II. **Remote sensing and GIS expertise** within the organization the number of expertise, training levels and years of experience in this area. This section also focuses on collecting information of the kind of GIS software and used satellite imagery currently used by the organization and the number of staff with the appropriate expertise.

III. **Forest inventory expertise** within the organization the level of expertise that exists in forest inventory, the training capacity of available staff and the years of experience in the area. This section also focuses on identifying the kinds of equipment the organization currently used to conduct forest inventory and the types of forest inventories work carryout. Another information collected about organization is the level of expertise in the used of data analysis software.

IV. **Stakeholder engagement**: this section focuses on levels of efforts undertaken by organization to engage stakeholders or increase stakeholders participation and understanding about their program and project activities. It simply target understanding the most frequently methods used by organization for the purpose of engaging stakeholders.

The REDD+ Implementation Units recommended two key government institutions GIS/ RS departments to be assessed under the current national Reference levels development process, which included the Forestry Development Authority and Liberia Institute of Statistics and Geo-Information Services (LISGIS). The capacity assessment data were collected through the administered questionaire to the head of the GIS/ RS department in each institution. Below are summaries key findings:

I. The Forestry development Authority (FDA):

- The department of research and development is responsible GIS/ RS in the FDA. The department demonstrated involvement in GIS/ RS training and data collection exercise facilitated by Metria/Geoville, and participated in REDD+ training and carbon measurement demonstration training at the Wonegizi REDD+ pilot site organized by Forest Trends and Conservation International. No staff within the department have had training or knowledge in UNFCCC processes on REDD and IPCC LULUCF monitoring requirements.
- The research and development department has a GIS Laboratory that oversees all remote sensing, GIS and forest inventory work. There are currently 13 staff in this lab with 5 staff assigned at the central office and 8 staff assigned at the four FDA regional offices. Within staff that have full employment, 2 staff hold bachelor degree in general forestry, 2 staff hold certificate in GIS/ RS from Ghana and India, 1 staff holds a post- graduate certificate from Nigeria. The average staff working experiences ranges between 1- 8 years respectfully. However, 1 staff holds a certificate in drafting and is being used as the department's cartographer, and has 27 years working experience. The GIS Lab does not have a valid GIS/ RS license software, staff use open source software that were installed by the VPA project. However, there are staff that have training in the use of several GIS software including QGIS, IGIS, ARCVIEW, ARCGIS, IDRISI, EDRAS and ENVI. The department used satellite imagery for its work during the leadership of Mr. Augustin Johnson, but not at present.
- There are 8 staffs with expertise in forest inventory, 2 staffs have a bachelor's degree in general forestry and 4 staff hold a certificate in forest inventory training conducted by Conservation International (Peter Herbs- trainer). The experience of staff in forestry inventories ranges between 6- 11 years. Reports show that the department lack the requirements and necessary equipment needed to conduct forest inventory, nevertheless, staff demonstrated knowledge of the use of

GPS Units (Garmin Max 62), Clinometer, 50 meter tape, diameter tape and declinometer from previous work. In previous years, the department have had expertise in the use of forest inventory methods like Simple random sampling, cluster plots, Forest dense sampling and Agriculture degraded sampling. Staffs also have beginner level of expertise in the used of Microsoft Excel as the data analysis software. The department of research and development does not have stakeholders' engagement and consultation as part of its mandate. The role of the GIS Lab is to produce and interpret GIS/ RS information and maps.

II. Liberia Institute of Statistics and Geo-Information Services (LISGIS)

- The mandate of LISGIS is to compile statistical data on the status of demographic and other socioeconomic indicators and to coordinate the dissemination of official statistics on Liberia. LISGIS involvement in REDD+ activities had been through national land cover and land-use suitability studies conducted by the Land Commission and participation in the ground trothing and plot verification of sample plots produce by Metria/Geoville. No staff within the department have had training or knowledge in UNFCCC processes on REDD and IPCC LULUCF monitoring requirements.
- The department of Geo-Information services and coordination at LISGIS is responsible for acquisition of spatial data and production of spatial information products and producing and disseminating publications/documentations and maps. This department has two main divisions with assigned staffing.

<u>Laboratory</u>

The laboratory has 10 staff, 2 staff holds certificates in GIS from Ghana and Nigeria, while the rest of staff hold Bachelor degree in none GIS related disciplines. The average staffs work experiences range between 4- 8 years.

<u>Cartography</u>

The cartography division has 5 staff which are assigned at the central office and 1 staff that holds a certificate in cartography from the Netherlands. The remaining 4 staff hold Bachelor degrees in none GIS related disciplines.

- Beside staff that are assigned at LISGIS central office, there are 2 staff assigned in each of the 15 counties (30 staffs) which are mainly beginners. These staffs have capacity in using GPS, camera, laptop and A3 map production printer. Information collected demonstrates that most staff have experience in the use of GIS software like ArcGIS (Arcinfo & ArcView inclusive), and QGIS (free version 7). One staff proves to have experiences in ERDAS, Idrisi and Mapinfo (version 2). LISGIS has experiences in the use of satellite imagery like Landsat- for forest cover, Spot- human settlement mapping, and Ikonos- urban planning. LISGIS do not have separate staff for forest inventory, however, three staff are been designated to work with FDA on the REDD+ forest inventory activities after the Metria/Geoville training. All staffs are knowledgeable in the used of forest inventory equipment like GPS units (Garmin, spectra & Tremble), Diameter tape, Tablet/ mobile phone and Clustered plots. One staff has expertise in the use of data analysis software like Microsoft Excel, Microsoft Access, STATA, SPSS and CS pro.

- LISGIS disseminates data and information to stakeholders through the use of the following tools- CensusInfo, LiberiaInfo, Liberia National Data Archive, DevInfo, IMIS, Liberia Data Portal and Open Data for Africa.

III. Capacity building activities conducted

1. Technical Training on RL Development

Between 16-21 April 2016, Winrock International and Conservation International facilitated a four days technical training on reference levels development which focuses on the technical aspects of reference level creation. The aim of the training was to strengthen the capacity within Liberia to establish and maintain a REDD+ Reference Level. Over 40 technical staff with knowledge and experience with forest inventory and/or GIS and remote sensing participated in this training from key national institutions including LISGIS, FDA, SCNL, Green Advocate, Ministry of Lands, Mines and Energy, Land Commission, National Bureau of Concessions. Key topics taught during this training workshop include the followings:

1. Overview of Climate Change, UNFCCC, National REDD+ framework, and the Importance of RLs
    a. IPCC activity accounting methods
    b. Summary of RL and MRV creation
    c. Current Status of Liberia’s activities in REDD+ readiness preparation
    d. Overview on Liberia Land Cover and Forest Mapping project and its specific contribution to REDD+.
    e. Presentation of the Liberia Land Cover and Forest Map 2015
2. Historical Emissions Analysis
    a. Key Decisions in National REDD+ Mechanism Development
    b. Key Decisions in National REDD+ Mechanism Development
    c. Overview of development of draft Reference Level
    d. Land cover change mapping
    e. Developing Activity Data for Deforestation
    21.
3. Historical Emissions Analysis and RL development
    a. *Focused on technical issues*
    b. Hands-on Exercise: Satellite Image Analysis for Land Cover Change

   c. Land Cover Carbon Stock Estimation
   d. Hands-on Exercise: Using existing data for use in carbon estimation
   e. Forest Carbon Stratification Techniques
   f. Carbon Stock Sampling Design & Plot Distribution
   g. Carbon Stock Sampling Design, Field Measurements, and Analysis
4. RL development and next steps
   a. Hands-on Exercise: Carbon Stock Estimation Creation
   b. Create Deforestation Emission Factors
   c. Combining Activity Data and Emissions Factors
   d. Hands-on Exercise: Historical Emissions - Bringing the components together
   e. Moving from Historical Emissions to RL
   f. Hands-on Exercise: RL Creation

Capacity Building efforts undertaken within Reference Level development project

Introductory training on reference levels

In September 2015, an initial meeting was held with the REDD Technical Working Group and staff from Winrock International and Conservation International Liberia. During this meeting, a presentation was given describing what a reference level is, and what is required for a country to develop a REDD+ Reference Level. Guidance from the UNFCCC, the Carbon Fund, and the IPCC as relates to reference level development was provided; the basic decisions that must be made were explained; and an overview of the technical components was given.

Forest Definition Workshop

In January 2016, FDA sponsored a Forest Definition Workshop, during which Winrock International provided key presentations on forest definition and reference levels: 1) Overview of a REDD+ Forest Definition, 2) Options for Liberia's Forest Definition, and 3) Overview of development of a Reference Level for Liberia. The first presentation provided a general understanding of the components of a forest definition and how this is addressed in the REDD+ context. The second presentation described the implications of various definitions in the context of Liberia. These set the stage for breakout sessions held during the workshop, and ultimately for the adoption of a forest definition for Liberia.

In February 2016, following the Forest Definition Workshop, a second meeting was held with the RTWG. During this meeting, the status of reference level development was described, with particular attention to the critical decisions that must be made by Liberia and what the implications are for various options. Additionally, the analysis done to date (and described in detail in this report) was described, with the intention of clarifying any questions and assisting in finalizing the necessary decisions.

Technical Training on REL Development

In April 2016, Winrock provided a week long training for technical staff in Liberia to gain an understanding about REL creation and maintenance, using suitable country-specific data related to activity data and emission factors. A key to the success of this training was the coordinated interaction with the appropriate Government agencies (at the national and sub-national levels) to provide necessary policy guidance and direction to ensure that REL development is in line with the central government regulations and provincial socio-economic development targets.

The aim of the training was to strengthen the capacity within Liberia to establish and maintain a REDD+ Reference Emission Level. By the end of the training participants were expected to:

- Gain an understanding of the components of REL creation
- Participate in a hands on example of REL creation
- Understand technical steps required to create REL
- Know the types of data that must be developed to create activity data and emission factors
- Understand the implications of using global, regional, and country-specific data.

This training was geared to the technical staff who have knowledge of and experience with forest inventory and/or GIS and remote sensing, both of which are necessary for the development of a Reference Level.

This training only focused on the technical aspects of reference level creation. It did not include training on stakeholder engagement, policy development, or REDD+ strategy creation. It also did not comprehensively address field data collection and analysis required to estimate carbon stocks, though these topics were introduced.

Additional Capacity Building Needs

The work conducted above along with other workshops and trainings undertaken in Liberia on REDD+ readiness have introduced the concepts necessary to develop an REL and MRV mechanism. However, in order to develop the in-country capacity to develop a reference level, additional capacity building will be required in Liberia, so that certain technical gaps can be filled and country representatives can provide the necessary oversight where additional support from outside sources will be needed. In addition to targeted capacity building, supporting documentation that provides stepwise guidance and standard operating procedures are necessary to ensure that the methods developed can be replicated in the future.

This section highlights recommended capacity building efforts and supporting documentation geared towards the RTWG, the RIU, policy makers, and technical GIS and forest inventory staff, so that improvements can be made to the recommended reference level. Table A3-1 provides a listing of recommended trainings, with additional descriptions in the text below.

Table A3-1. Training needs in order of importance.

Training/Supporting Documentation	Importance	Justification
Forest Carbon Stock Development	High	Liberia must develop its own carbon stocks to develop emission factors for deforestation
Reference Level Development	High	This training is essential to consolidate the work done to date and use country-specific data to develop the RL
Geospatial Training	High	It is important to understand the use of geospatial products to assess forest cover change and what products can be used to do so.
Standard Operating procedures	High	It is necessary to develop standard operating procedures so that work can be replicated in the future using the same methods.
Emission Calculation Tools	High	Tools provide a framework for emission calculations, so that these can systematically be replicated as data is updated.
Destructive Sampling for Allometric Equation Verification/Development	Medium	It is important for Liberia to verify whether its forest can use existing allometric equation, but this training will depend on resources available.
Guidance Documents	Medium	Guidance documents tailored for Liberia would provide information on how to develop the different aspects of the RL and MRV (e.g. emission factors for deforestation, activity data for deforestation etc.)
Developing Emission Factors for Logging	Low	The focus in first stage should be on deforestation. If degradation is assessed a decision must be made on whether Liberia follows and landscape based approach or an activity based approach. If an activity based approach is chosen and emissions from legal logging are considered significant, this training will be important.

Biomass Data and Analysis to establish Emission factors

This training is the highest priority of the trainings outlined here as it is essential for Liberia to develop Tier 3 country specific forest carbon stocks. As stated in this report, Liberia currently lacks the necessary forest inventory data needed to develop such emission factors for its REDD+ program. Liberia would benefit from a targeted training on forest carbon inventory development. This training would consist of a field component and a classroom component for forest inventory staff.

For the field component, participants should be trained on the field measurements necessary to assess carbon stock in forest each carbon pool (see Figure A3-1) for the strata identified in the 2000 land cover classification and the current forest classification.

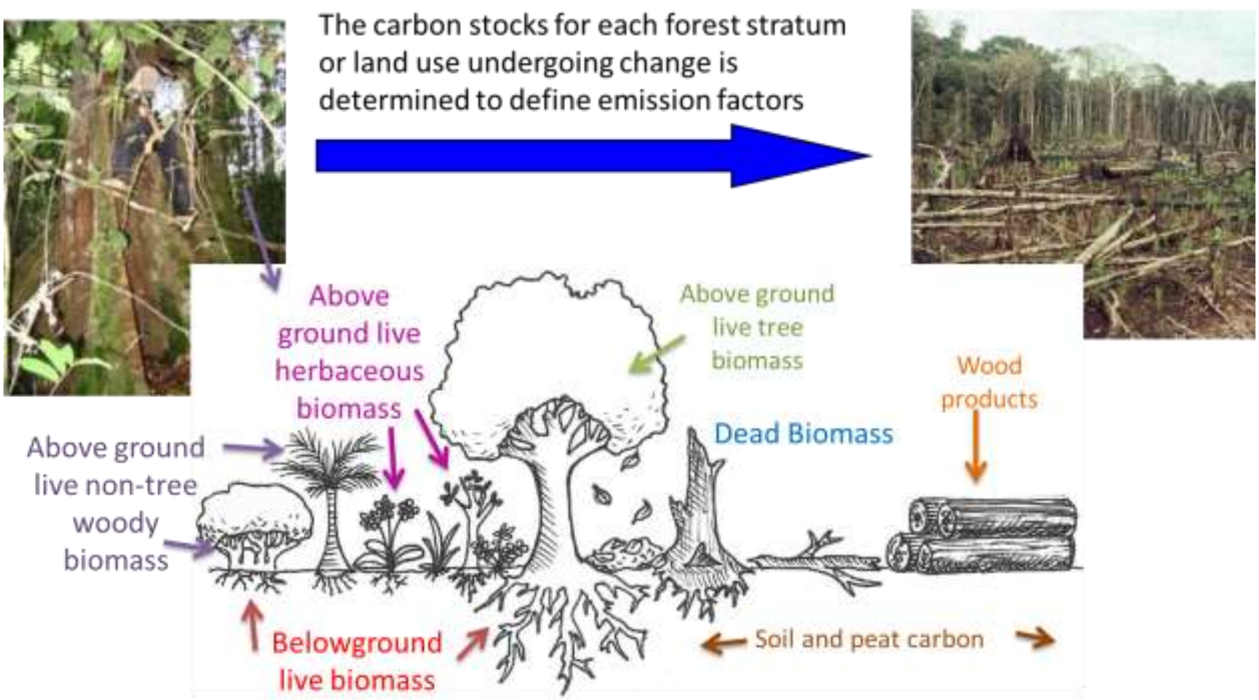

Figure A3-1. Forest carbon pools and definition of an emission factor for deforestation.

Directly following the field work, participants should be trained in the analysis of the carbons stocks measured. This analysis should include a lab component, for sample analysis, and a hands-on classroom component where participants are taught how to derive carbon stock estimates per forest strata based on the measurements taken.

Training on geospatial products used for REDD+

This training will focus on the LISGIS staff and the FDA research and development department's GIS Laboratory. The goals are (1) to introduce the basis of remote sensing (RS), available RS platforms, RS techniques for image procession and interpretation for the forestry sector, the skills and technical requirements for implementation of the RS into the forest change monitoring, (2) to provide opportunity for the participants to experience the use of this technology through hands-on practices and (3) to present a broad brush study on the use of global land cover datasets to quantify the CO_2 emissions from forestry sector.

Training on destructive sampling for allometric equation verification (and development if needed)

As noted in this report, Liberia does not have specific allometric equations to estimate biomass from basic field measurements. Allometric equations are used commonly to estimate tree biomass from measurements of DBH or DBH and height. Different equations give different estimates for tree biomass because each is designed for a specific forest and climate type. Before applying a regression equation to estimate forest biomass, it is necessary to destructively sample a few trees to check the appropriateness of an existing equation or, if no equation is found to be appropriate, develop a new equation.

A training to conduct this work would also consist of two steps. Field work focused on destructive sampling and a hands on classroom session focused on data entry and analysis.

The field teams would to visit logging blocks where felled trees remain on site (i.e. before logs have been hauled away). This will avoid the need to cut additional large trees for the sole purpose of destructive harvest measurements. To verify the applicability of the selected biomass equation, trees of a range of DBH (small, medium, large trees) should be measured. Trees that were cut previously for timber will be measured, and smaller trees can be cut and measured in unmanaged areas so that no new tree felling will occur within logging blocks without prior permission from the concession.

Following field training and data collection, class room based sessions will strengthen the capacity of participants in laboratory procedures, and data entry and analysis required to transform field measurements into meaningful information to be used in forest carbon monitoring systems. This aspect of training is highly recommended as it ensures that participants understand the treatment of data collected in the field, how it translates into meaningful parameters, and the importance of precision and accuracy of data collection when in the field.

Training on emissions from logging

With logging as the largest estimated source of GHG emission from degradation, Liberia should assess emissions from this activity. The objective of this training would be to support Liberia in the measurements and data analysis necessary to estimate emissions from forest degradation from logging. As with the other trainings it would consist of a field component and a classroom component.

Participants will be trained in the field on how to take the measurements necessary to develop emission factors from selective logging. In the classroom participants would use a tool assess the emissions associated with logging damage, logging infrastructure and the emissions from the actual log.

It is important to note that emission factors developed using this method require reliable estimates of timber volume harvested.

Annex 1 of this document includes more explicit steps for developing emissions estimates for selective logging, as well as other activities that result in forest degradation.

Follow up hands-on training on Reference Level

Once sufficient data are collected to estimate the reference level with Liberia specific emission factors for the activities under Liberia's RL, a follow up hands-on training on RL establishment. The goals of this training workshop are to build an understanding of the components of RL creation, and related data and analysis requirements using data developed for Liberia. The workshop will be designed to include a mixture of presentations and hands-on exercises with geospatial and carbon data. Topics that will be covered in this training workshop include:

- REDD+ Review
- Reference Level Development Planning
- Historical Emissions Overview
- Historical Deforestation Emissions
- Historical Degradation Emissions
- Creation a RL

The training will be an opportunity for the technical staff at national and regional level to gain understandings about RL creation as well as being able to participate in hands-on exercises for developing a RL considering Liberia-specific circumstances and using appropriate data and methods. One major outcome from this training should be the development of a reference level using a tool that Liberia will use in its MRV.

Provide SOPs and Computing Tools Tailored for Liberia

All data collection must be conducted following SOPs that specifically speak to the realities of the forest in Liberia. These SOPs must provide step by step instructions on the data that needs to be collected to complete a full forest carbon inventory, destructive sampling approach and logging field measurements together with quality assurance and quality control procedures.

Tools for data entry and analysis should also be developed in order to streamline data analysis for each component. Both the SOP and the computing accounting tools for logging emissions, carbon stock assessment and destructive sampling will help to achieve quality assurance and control in the development of deforestation emission factors.

Guidance Documents

Liberia would benefit from a suite of guidance documents outlining the development of National Forest monitoring system for REDD+ (NFMS), which provides information on the technical requirements for establishing a NFMS to produce the data and information inputs that will be used to establish the RL/REL and that will feed into the MRV system. The guidance series should be divided into multiple modules describing different steps and technical components required to establish the NFMS and estimate historical emissions to develop the RL/REL. Each module would describe, in a step-wise manner, the good practice guidance needed to produce transparent, complete, comparable, and consistent estimates of gross and net emissions with low uncertainties based on use of the Intergovernmental Panel on Climate Change (IPCC) framework methodologies and tailored for Liberia.

Key Actions from MRV Roadmap

The MRV roadmap, finalized June 2016, provides a section on “key activities for capacity development.” In that section, seven themes are addressed, some of which have an administrative focus (i.e. “establish institutional arrangements”) and some of which have a technical focus (i.e. “improve national forest monitoring”). It is important to note that many of the items described in the MRV roadmap have been completed, or are in process, as part of Liberia’s ongoing REDD+ activities, including the REL/RL development. Here is provided the summary of key actions from the MRV roadmap, with additional notes related to capacity building activities discussed in the strategy above.

Activity	Responsible agencies	Other stakeholders and potential (international) partners	Timeframe	Link to RL/REL Capacity Building Strategy
1. Establish institutional arrangements				
1.1 Establish steering/coordination body for the REDD+ NFMS/MRV system	EPA, FDA, MFDP	**LISGIS**, Ministries, CSOs, INGOs, WB FCPF, RSPB/SCNL, donors	Immediate (within first 6 months)	Recommend this be highly engaged subset of RIU/RTWG
1.2 Establish technical working group(s) and facilities within FDA and with partners	FDA, EPA	**EPA**, **LISGIS**, MoA / MoGD / MIA / MoPEA / MLME, RSPB/SCNL, CSOs,	Short-term (within first year)	Highly engaged TWG needed
1.3 Establish a mechanism for local engagement and exchange of capacities, experiences and data between national and local forest monitoring activities	FDA	**CSOs,** RSPB/SCNL, Communities, NGOs	Short-term	Critical for further developing in country expertise and capacity
1.4 Develop a framework to engage with research and higher education institutions	FDA	**Universities**, **research institutions**, LISGIS, WRI, CI, EPA, RSPB/SCNL	Short-term	Critical for further developing in country expertise and capacity
2. Improve national forest monitoring: activity data				
2.1 Decide on a forest definition	FDA, EPA	**FAO/UN-REDD**, WB FCPF, Wageningen University	Immediate	Stakeholder workshop held in January 2016, with definition approved by FDA MD

2.2 Update and improve national forest map and/or land use map	FDA, LISGIS	**International consultants**, **FAO/UN-REDD** and other institutes for training	Short-term	2014 forest cover map developed by Metria Geoville; recommend it be updated annually if possible; crucial improvements include detailed land use mapping (esp. active plantation and timber harvest)
2.3 Estimate changes in forest area at national level	FDA, LISGIS	**International consultants**, **FAO/UN-REDD** and other institutes for training	Short-term; recurrent	Annual forest change has been mapped for 2000-2014. Should continue into future, with stepwise improvement (e.g. inclusion of detailed land use and addition of degradation monitoring)
2.4 Estimate activity data for forest degradation	FDA, LISGIS	**International consultants**, **FAO/UN-REDD** and other institutes for training	Medium-term (within 2-3 years); recurrent	This will require improved data collection as described in Annex 1.
2.5 Estimate activity data for enhancement, sustainable management of forests and/or conservation	FDA, LISGIS	**International consultants**, **FAO/UN-REDD** and other institutes for training	Medium-term; recurrent	This will require improved data collection and is viewed as a longer term objective
3. Improve national forest monitoring: carbon stocks and emission factors				
3.1 Design/update and implement a national forest inventory and carbon measurement system	FDA	**FAO/UN-REDD**, RSPB/SCNL, consultancies/CSOs	Short-term	Critical for establishing Tier 1 emission factors. Additional detail provided in “Guidance on Developing a National Forest Inventory for Forest Carbon Sampling”
3.2 Develop factors for: Carbon Conversion, Expansion Factors, Wood Density and Root/Shoot Ratio, and convert existing forest and forestry data into carbon	FDA, Universities, research institutions	**FAO/UN-REDD**, RSPB/SCNL, consultancies	Medium-term	Needed factors depend on design of NFMS; some factors recommended in RL report (e.g. R/S ratio)

3.3 Assess different drivers/processes of change and their carbon impact in order to develop emission factors	FDA	**FAO/UN-REDD**, RSPB/SCNL, consultancies/CSOs	Medium-term	Initial driver analyses have been conducted (see e.g. R-PP, REDD+ Strategy); these could be improved and expanded
4. Improve estimation and international LULUCF, GHG inventory and REDD+ reporting capacities				
4.1 Engage in technical support and training for national GHG inventories and for upcoming REDD+ reporting	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL, World Bank FCPF	Immediate	Critical ongoing effort
4.2. Assess historical national GHG inventories for the LULUCF/AFOLU sector, appraise gaps and needs for alignment in the context of REDD+ and ensure streamlining of REDD+ and GHG reporting in National Communications and Biennial Update Reports	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL	Short-term	Critical ongoing effort
4.3 Decide on a forest reference emission level (FRL/FREL), which is based on historical data and adjusted for national circumstances	FDA, EPA	**World Bank FCPF**, Universities, research institutions, Winrock International, FAO/UN-REDD, RSPB/SCNL	Short-term	Initial FREL described in current report, with recommended step-wise improvement detailed
4.4 Develop technical annex of the BUR, to make the REDD+ results available for technical assessment, in the context of results-based payments	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL	Medium-term	
4.5 Ensure that the data collected in the context of the MRV system or NFMS is used in the above exercises for the LULUCF sector to ensure consistency between the GHGs	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL	Short-term	

inventory the BUR annex for REDD+ and the reference level				
4.6 Submit an "MRVS interim measures report", including the FRL and performance reporting for the target landscapes	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL	Short-term (end 2016)	MRV should be conducted in accordance with methods used for FREL/FRL
4.7 Submit an "MRVS interim measures report", including the FRL and performance reporting for the whole country as baseline and model for continued performance reporting	EPA	**RIU**, **LISGIS**, International partners (WRI, CI, FFI, VPA), RSPB/SCNL	Medium-term (mid 2017)	MRV should be conducted in accordance with methods used for FREL/FRL
5. Prepare for MRV of REDD+ activities on the national level				
5.1 Adapt and develop the national forest monitoring for local/landscape-scale REDD+ demonstration activities	FDA	**World Bank FCPF**, LISGIS, NGOs, communities, RSPB/SCNL, WRI, FAO/UN-REDD	Short-term	Nesting should follow best practices; see for instance, http://www.v-c-s.org/wp-content/uploads/2016/07/Nesting-Options-1-Jul_Eng_final.pdf
5.2 Test approaches and options to derive forest reference (emission) levels	FDA, EPA	**World Bank FCPF**, Universities, research institutions, Winrock International, FAO/UN-REDD	Short-term	Described within current REL report
5.3 Develop foundations and data sources for a REDD+ safeguard information system	FDA, EPA	**World Bank FCPF**, RSPB/SCNL, NGOs, FAO/UN-REDD	Medium-term	
6. Implement a program for continuous improvement and capacity development				
6.1 Design and implement a capacity development program building on available national capacities and international support where needed	FDA, EPA	**World Bank FCPF**, FAO/UN-REDD, GOFC- GOLD, GFOI, WRI, Silvacarbon, RSPB/SCNL	Short-term to Medium-term	

6.2 Implement a program to “train the trainers” and to multiply capacities within the country, perhaps establish a dedicated training unit for REDD+ monitoring aiming for sustainable training capacities	FDA, EPA	**World Bank FCPF**, **FAO/UN-REDD**, GOFC-GOLD, GFOI, Silvacarbon, RSPB/SCNL	Short-term to Medium-term	
6.3 Establish a team of (international) experts that can serve for backstopping and advisory group for key decisions to be made	FDA, EPA	**World Bank FCPF**, **FAO/UN-REDD**, International partners (Winrock International, WRI, CI, FFI, VPA), RSPB/SCNL	Medium-term	
6.4 Seek partnerships with regional organizations and international partners (i.e. South-South cooperation and student/staff exchange etc.)	FDA, EPA	**Universities**, **research institutions**, FAO/UN-REDD, International partners (Winrock International, WRI, CI, FFI, VPA), RSPB/SCNL	Medium-term	
7. Continued national and local communication mechanism on REDD+ monitoring				
7.1 Conduct a series of regional workshops to inform about REDD+ and MRV among national, regional and local actors, in order to both inform and seek input from different stakeholders; in particular involving local communities	FDA, EPA	**Communities**, NGO/CSOs	Short-term to Medium term	
7.2 Produce communication plan, communication materials on REDD+ and monitoring	FDA, EPA	**NGOs**, FAO/UN-REDD, WB FCPF	Short-term	
7.3 Establish and maintain REDD+ monitoring web-site with relevant information and outreach materials	FDA, EPA	**NGOs**	Short-term	

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