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Preface

This report discusses economic barriers to participation and progress in REDD Readiness preparation among non-Annex 1 forest countries. The report provides an economic-theoretical framework for discussing cost-effective building of reporting capacities for REDD, it discusses the participation and progress of the REDD countries, and it provides an example of the costs and time that could potentially be saved by using high-resolution satellite data to estimate reference levels and monitor changes in the forest reserves of REDD countries.

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Brita Bye

Abstract

The framework for REDD+ (Reducing Emissions from Deforestation and forest Degradation, conservation and sustainable development) was negotiated under the United Nations Framework Convention on Climate Change (UNFCCC). The goal was to provide monetary incentives for developing countries to reduce greenhouse gas emissions from deforestation and forest degradation. Countries that participate in the REDD programme (REDD countries) are expected to report on the carbon stored in their forest reserves and the emissions caused by deforestation. The countries' reporting will serve as a basis for receiving results-based payments for emission reductions achieved. In addition, REDD countries are encouraged to improve their acquisition of data on types of forest, drivers for change in forest areas, and ecosystem services and natural resources associated with forests (e.g. carbon capture and biodiversity). Finally, REDD countries are encouraged to develop and implement conservation strategies to preserve their forests and reduce emissions. In this report we aim to identify barriers to the countries' progress in their REDD preparations, and to discuss potential time and cost savings through increased use of high-resolution satellite imagery in reporting changes in forest cover.

Participation in REDD activities is voluntary, and countries that participate are expected to develop monitoring, analysing and reporting capacities, that is a National Forest Monitoring System. Several data sources may be used when building capacities, including remote sensing data such as aerial photos and satellite data in addition to ground observations. In general, both detailed information (reference data) and less detailed and more general information (complementary data) are needed to build sufficient capacities to give an overall impression of various types of forest cover in a country. Ground observations are always considered reference data, while for some forest types high-resolution satellite data may be used as a substitute for ground observations when estimating forest cover. As a general rule, however, remote sensing data are viewed as complementary data.

The multitude of data and methods available to estimate carbon pools also imply that the costs of obtaining these estimates vary considerably across countries. Furthermore, the costs depend on the ambition level and previously built forest monitoring and management capacities of a country. Cost considerations are important for choosing the methodological approach that will be used for building reporting capacity, for comparing running costs with the potential for results-based payments, and for evaluating the replicability of the system in other REDD countries. Reducing the costs of REDD-related efforts will likely to help progression in existing REDD countries as well increasing the willingness to become a REDD country.

REDD efforts appear to progress slowly; we find that as of 2015, most of the REDD countries had limited carbon-pool reporting capacity for their forests and very few had reached the stage of managing their forest reserves to reduce greenhouse gas emissions. Our theoretical analysis indicates that a lack of financial incentives caused by uncertainty about verification requirements and payment schemes is likely to delay progress. This seems to be confirmed by the empirical analysis of the progression of different REDD countries (based on data provided by FAO FRA), as countries where the payment and verification criteria are negotiated seem to have progressed faster. The question thus arises whether there is a way for REDD countries to progress faster before detailed agreements between donors and the forest countries are negotiated and signed. One suggestion is to make high-resolution satellite data freely available. These data may be used as reference data when estimating changes in forest cover and they offer high flexibility with respect

to meeting many quality and/or verification requirements, and reduce the cost of the uncertainty concerning the details of verification and payment schemes in future agreements.

This report provides an estimate of the costs of supporting a wider use of high-resolution satellite data in REDD countries. Based on information from FAO FRA about costs in the SEPAL project,[1] we estimate the annual cost of purchasing high-resolution data for the lowest capacity REDD countries to be USD 403,546. The cost of building sufficient reporting capacity to meet the quality requirements of FAO FRA's SEPAL project (which we assume is sufficient to qualify for result-based payments) over three years would be approximately USD 3.6 million (see section 6.2). We estimate the annual cost of purchasing high-resolution data for the higher capacity REDD countries at USD 2.0 million. Finally, if all REDD countries were to make annual purchases of high-resolution data for the period 2017-2020 with the same coverage to that of the SEPAL pilot countries, the estimated present value of the cost, using a 4% discount rate, is USD 22.8 million. The use of high-resolution data to monitor changes in forest cover permits reporting capacity on better than the lowest quality level (Tier 1 in IPPC's guidelines) already in year two of a monitoring programme. The costs may be as low as 3% of the costs of using ground observations only as reference data, and reporting can start 4-6 years earlier than the average time used to build a more traditional National Forest Monitoring System based mainly on ground observations.

[1] See section 5.3 for more about the SEPAL project.

Sammendrag

Rammen for REDD + (Reduksjon av utslipp fra avskoging og skognedbrytning, bevaring og bærekraftig utvikling) ble forhandlet under FNs klimakonvensjon (UNFCCC). Målet var å gi monetære insentiver til utviklingsland for å redusere klimagassutslippene fra avskoging og skogforringelse. Land som deltar i REDD-programmet (REDD-land) forventes å rapportere nivået på karbonlagret i landets skogreserver, og utslippene som følge av avskoging. Landets rapportering brukes som basis resultatbaserte betaling for oppnådde utslippsreduksjoner. I denne rapporten søker vi å identifisere barrierer for progresjon i REDD forberedelsene, samt diskutere potensiell tid og kostnadsbesparelser fra økt bruk av høyoppløselige satellittbilder i rapporteringen av endringer i skogsdekket.

Kompleksiteten i landenes beslutningsprosess er viktig i kartleggingen av potensielle barrierer. Deltakelse i REDD + -aktiviteter er frivillig, og land som deltar forventes å utvikle et nasjonalt skogsovervåkingssystem (NFMS). Dette krever at REDD-landet bygger overvåking, analyse og rapporteringskapasitet. Land som bygger opp disse kapasitetene, sies å være i Readiness-fasen. Flere datakilder kan brukes når landene bygger REDD Readiness-kapasiteter, inkludert flyfoto og satellittdata i tillegg til bakkeobservasjoner. Generelt er både detaljert informasjon (referansedata) og mindre detaljerte og mer generelle opplysninger (komplementære data) nødvendige for å bygge tilstrekkelig kapasitet. Bakkeobservasjoner regnes alltid som referansedata, mens høyoppløselige satellittdata kan brukes som referansedata ved estimering av skogsdekket. Ved hjelp av den oppbygde kapasiteten må REDD-landet estimere sine skogressurser og karbon lagret i stående biomasse, samt utvikle planer for å redusere den nåværende utslippsbanen fra avskoging og skogforringelse. Disse estimatene må i de fleste tilfeller verifiseres av en tredjepart. Til slutt må REDD-landet utføre politiske tiltak for å redusere utslippene. Utslippsreduksjonene må estimeres og verifiseres. REDD-land mottar ofte økonomisk støtte fra flere givere for å hjelpe dem med å bygge kapasitet og planlegge REDD-strategien.

Denne rapporten er delt inn i seks kapitler: Først, i kapittel 1 og 2 gis en innledning og bakgrunnsinformasjon om hvordan verdens REDD-aktiviteter er organisert. I kapittel 3 analyseres det teoretisk hvordan en kan optimere kvaliteten på rapporteringen for til den laveste mulige kostnaden. Den teoretiske modellen inkluderer alle relevante hensyn fra REDD-landene på Readiness-stadiet. Basert på denne analysen diskuteres mulige barrierer for kapasitetsbyggingen. I kapittel 4 brukes data fra FN til å identifisere hvordan disse barrierer påvirker deltakelsen og fremdriften i REDD-Readiness-forberedelsene. Kapittel 5 diskuterer bruk av satellitt data i REDD sammenheng. Til slutt gir kapittel 6 en empirisk illustrasjon av mulige kostnadsreduksjoner som kan oppnås ved å subsidiere REDD-landenes bruk av høyoppløselige satellittdata sammenlignet med bruk av mer tradisjonelle skogsovervåkningsmetoder basert på bakkeobservasjoner.

Fra og med 2015 finner vi at de fleste REDD-landene hadde begrenset rapporteringskapasitet for karbonlageret i sine skoger, og svært få hadde nådd stadiet for å redusere klimagassutslippene fra avskoging. Det framstår derfor som om REDD-arbeidet utvikler seg langsomt. Vi finner i vår teoretiske analyse at en mangel på økonomiske insentiver forårsaket av usikkerhet med hensyn til verifikasjonskrav og betalingsordninger, vil forsinke Readiness-forberedelsene. Dette ser ut til å bli bekreftet av den empiriske analysen av utviklingen i ulike REDD-land, hvor land hvor betalings- og verifikasjonskriteriene er ferdig-forhandlet synes å ha kommet lengst.

For å øke progresjonen, har det blitt fremmet forslag om å subsidiere bruk av høyoppløselige satellittdata. Siden disse dataene kan brukes som referansedata ved estimering av endringer i skogsdekket, gir de fleksibilitet med hensyn til å oppfylle kvalitets- og/eller verifikasjonskrav, og vil dermed kunne redusere kostnadene ved usikkerheten knyttet til fremtidige avtaler om verifikasjons- og betalingsordninger. For tiden har bruk av satellittdata med høy oppløsning vært begrenset i REDD Readiness-forberedelsene siden de er relativt kostbare å bruke. Basert på informasjon fra FN, anslår vi at den årlige kostnaden ved å kjøpe høyoppløselige satellittdata for gruppen av REDD-land med lavest kapasitet til USD 403 546, og kostnaden for å bygge tilstrekkelig rapporteringskapasitet over tre år for å oppnå FNs kvalitetskrav, til å være omtrent USD 3,6 mill. Vi anslår årlige kostnader for å kjøpe høyoppløselige satellittdata for gruppen av REDD-land med noe høyere rapporteringskapasitet til USD 2,0 millioner. Til slutt, hvis alle REDD-land kjøper høyoppløselige data gjennom perioden 2017-2020, vil den estimert nåverdien av kostnaden ved en 4% diskonteringsrente være 22,8 millioner USD. Kostnadene ved bruk av høyoppløselige data for denne typen skogovervåkning kan således være så lave som 3% av kostnadene ved kun å bruke bakkeobservasjoner som referansedata, og det er mulig å begynne å rapportere 4-6 år tidligere enn ved et mer tradisjonelt system basert på bakkeobservasjoner.

Contents

1. Introduction

Deforestation[2] and forest degradation[3] through agricultural expansion, conversion to pastureland, infrastructure development, destructive logging, fires etc., account for nearly 25%[4] of global greenhouse gas emissions. This is more than the entire global transport sector and second only to the energy sector[5]. The REDD[6] initiative was established in 2007 to create a financial value for carbon stored in forests. The programme offers developing countries incentives to preserve their forests and invest in low-carbon paths to sustainable development. In addition to the focus on reducing deforestation and forest degradation and thereby also reducing emissions, the REDD initiative encourages forest conservation, sustainable forest management and enhancement of forest carbon stocks. Hence the initiative is usually referred to as REDD+.

All participation in REDD+ activities is voluntary. A REDD country will be expected to and assisted in developing a National Forest Monitoring System (NFMS). A REDD country may be in one or more of three stages: a) the Readiness stage, b) the Result-based demonstration stage, or c) the Result-based action stage. The Readiness stage (also called REDD Readiness) involves building of monitoring, analysing, and reporting capacities in order to obtain estimates of i) the forest reserves; ii) the effect of economic activities on forest reserves attributable to deforestation and forest degradation; and iii) the effect on forest reserves of conservation measures. Several bilateral, multilateral and international initiatives aid in building capacity at the Readiness stage to help increase the monitoring capacity of REDD countries.[7] When countries have completed building capacities during the REDD Readiness stage, they must, in most cases[8], verify their estimates (Result-based demonstration). REDD countries must also develop a strategy for conservation policies and then implement these policies (Result-based implementation) before result-based payments will be made.

The Readiness stage involves building the capacity to report on several aspects of a country's forest resources and services from this resource such as forest inventory[9] (standing biomass), changes in and degradation of the forest resource, types of forest, drivers for changes in standing biomass, other ecosystem services and resources associated with the forest resource (e.g. carbon capture and biodiversity). To reach the stage where forest countries can benefit financially from their efforts, they must report on the status of and change in certain required indicators. Building and maintaining monitoring capacities may represent a considerable cost for many countries if the necessary infrastructure is not present.

There are several approaches to building readiness for obtaining estimates of forest resources and services. Reference data are high quality data used to produce detailed information for country-specific parameters. Less detailed and general information, referred to as complementary data, are also needed to provide an overview of various types of forest cover. In particular, ground-based reference data are necessary for reporting on the more detailed services produced by the

[2] A large number of trees lost in the same area at the same time.

[3] Gradual removal of trees from an area.

[4] Norges internasjonal klima- og skoginitiativ, Statusrapport 2015. Klima- og miljødepartementet.

[5] http://www.un-redd.org/

[6] REDD is the acronym for Reducing Emissions from Deforestation and forest Degradation

[7] The REDD countries are non-Annex I developing countries with large forest reserves. Parties to UNFCCC.

[8] This depends on the agreements the forest countries have signed with their donors. For example, this may apply to all members of the Carbon Fund.

[9] Requires knowledge of tree species, diameter at breast height, height, site quality, age and defects.

forest reserves, like biodiversity, whereas aeral data are essential for monitoring changes in forest cover and obtaining uncertainty estimates of the predicted emission reductions reported through the REDD mechanisms. Historically, national forest-monitoring systems were based entirely on ground observations, and many countries have such a ground-based monitoring system in place. Low-resolution satellite data with good coverage have also been available at low or zero cost. Ground observations are still the main source of reference data, but high-resolution optical satellite data (< 5m) may be used as part of the reference data to calculate emissions due to changes in the forest cover through deforestation and forest degradation. Reference data are important in REDD because country-specific emission factors are necessary for reporting at a sufficiently high-quality level. However, it is necessary to use a mixture of methods in order to be able to complete all the REDD reporting requirements.

There are currently several high-resolution satellite data sources, but they are relatively expensive compared to other, lower resolution, satellite data, and coverage has been limited (Böttcher et al., 2009). The availability and coverage of high-resolution satellite data are increasing as new satellite projects are launched. This should lower the cost of using high-resolution and SAR[10] (Synthetic Aperature Radar) satellite data in the future. Increased availability could thus reduce the cost of building readiness and thereby increase forest countries' participation, progression and commitment to active forest management as part of REDD+.

The large number of data sources and methods used to obtain estimates of changes in the amount of carbon stored in countries' forest reserves imply that the costs of obtaining these estimates vary considerably across countries. The costs also depend on the countries' ambition level for forest management and for reporting emission reductions due to REDD+ activities (see also the discussion in chapter 3). In addition, previously built capacities related to forest monitoring and management affect relative costs. In NORAD's (the Norwegian Agency for Development Cooperation) evaluation of Norway's International and Climate Forest Initiative (NICFI), the evaluation panel writes that "here has been little attempt by REDD+ country governments, donors and other MRV (Measurement, Reporting and Verification) actors to estimate current budgets across all donors or to assess the economic costs and benefits of different approaches and of achieving higher levels of precision. This is despite the fact that current costs appear to far exceed Readiness Preparation Proposal budgets, and that the overall costs of MRV and reference level establishment in some countries are likely to be substantial" (NORAD 2013, pp. xviii). And further, "Consideration of cost is important for making informed decisions between different approaches, for comparing running costs with the potential for results-based payments, and understanding the feasibility of replicating systems in other REDD+ countries." (NORAD 2013, pp. xxi). These statements indicate that cost efficiency in the building of reporting capacity efforts could be improved by more informed decision-making. REDD countries are developing countries, and participation in REDD is voluntary. Thus, helping forest countries to reduce the cost of their REDD-related efforts and increase their probability of meeting the requirements for payments may help progression in Readiness preparations

In 2015, more than 80 percent of the REDD countries had little or no reporting capacity on the carbon pool in their forests (Romijn et al., 2015), indicating that REDD Readiness efforts were progressing slowly. The NICFI evaluation panel also points to the lack of final decisions and guidance from UNFCCC (United Nations Framework Convention on Climate Change) on MRV (Measurement,

[10] See Appendix C for more information.

Reporting and Verification) modalities (NORAD, 2013). The evaluation panel notes that the lack of such guidelines makes it challenging for forest countries to determine their system needs, capacity, and institutional requirements, and continues “The prospect of results-based payments as a financial incentive is an important factor for maintaining the momentum for MRV system development and for the sustainability of the systems developed. This implies that where agreements for results-based payments have not yet been established, momentum may not be maintained, and that resolution of uncertainty over the optimal institutional structure is a critical constraint to progress.”

To ensure good progress in REDD Readiness preparations, it is important to understand the challenges faced by the REDD countries, with respect both to requirements to be fulfilled and to financial considerations, and to discuss how countries may cost-effectively build reporting capacities. If a REDD country does not anticipate that it will be able to meet the quality requirements for result-based payments, given its available resources, it is unlikely that the country will make good progress in their Readiness preparations. It is also important to consider how uncertainty about the payment criteria affects Readiness preparations. Understanding these challenges may help us find solutions that encourage REDD countries that are currently not being very active to step up their Readiness preparations, and ultimately help improve the success of international REDD efforts.

The main objective of this report is to shed light the main barriers for participation and progress of non-Annex I forest countries in their REDD efforts, and discuss the cost of using high quality satellite imagery to reduce these barriers. First, we present a theoretical analysis of the principles necessary for cost-effective building of reporting capacity, and the costs of diverging from the cost-effectiveness principles. Cost-effective reporting is particularly important, as REDD countries are typically developing countries and building the capacity to report to REDD may require large investments. Cost-effective building of the necessary reporting capacity may increase reporting from REDD countries and move them faster through the three stages of the REDD process. This discussion provides a normative view of what costs and benefits, synergies, and trade-offs a REDD country should consider employing in order to achieve the best quality reporting for a given amount of resources. In addition, the optimization problem provides a benchmark for the discussion on why some countries seem to stall in their Readiness preparations. To provide an understanding of the complexity of the REDD countries’ decision-making problem, we describe the current organization and reporting requirements for REDD in chapter 2.

The second goal of the report is to discuss the participation and progression by REDD countries in the REDD process (see chapter 4), using an analysis of the principles underlying the cost-effective solution as a basis for the discussion. The aim is to see whether there is any systematic explanation for why some countries are delayed in their Readiness preparations. We analyse the countries’ progress in the Readiness stage using data from FAO FRA (Romijn et al., 2015). We compare the differences in Readiness among i) all non-Annex I UNFCCC tropical forest countries; ii) those in this group that are connected to UN REDD, and iii) those that are associated with the Carbon Fund. The differences in progress among these three groups of countries provide insight into some of the main barriers to countries’ Readiness progression.

Third, we illustrate empirically the costs of providing REDD countries that currently do not report at all or that report very little with free high-resolution satellite data for them to increase their reporting level. Our point of departure is that uncertainty about the payment vehicle and the verification criteria makes it profitable for forest countries to postpone their Readiness preparations as long as this uncertainty exists. One reason is that the countries must make sure that they build the correct level of capacity to receive payments. If a country wishes to ensure that it is building the correct capacity level to meet future quality requirements, the country would have to rely heavily on expensive reference data. The uncertainty about quality requirements thus imposes an additional cost on the forest country when it is building reporting capacities. The empirical illustration shows the magnitude of the cost of providing REDD countries with subsidised reference data in the form of high-resolution satellite data. The illustration uses the observed costs of producing the FAO reports in the SEPAL project, where high-resolution satellite data were used as the major reference data source. This illustration provides a benchmark, which may inform later evaluations of how high-resolution or SAR satellite data may provide a lower cost alternative to traditional forest management methods for building and increasing reporting capacities.

This report focuses on the economic aspects of the decision-making problem, and not on the more technical aspect of the efficiency of the various methods of obtaining an estimate of forest reserves or the potential for reducing the uncertainty of the estimate by means of remote sensing data.[11] Thus, this report is limited to analysing and evaluating the cost aspects of building reporting capacity at the Readiness stage. This means that we do not discuss the practical implementation or the political aspects of REDD+. The analysis may identify possible economic barriers hindering the progression of countries with respect to REDD-related reporting. The analysis may also indicate future steps to take to reduce monetary costs and time associated with REDD efforts.

[11] See Næsset et al. (2015) or Gibbs et al. (2007) for a description of different methods for building capacity.

2. Background

REDD+ is a result of a series of international initiatives. In 2005, Costa Rica and Papua New Guinea proposed on behalf of rainforest nations that action should be taken to reduce emissions from deforestation in developing countries. In 2007, in Bali, the Conference of the Parties (COP) decided to adopt REDD+, and the UN-REDD programme was established in the autumn of 2008. The REDD+ methodological framework was further developed at subsequent COP meetings, with the largest number of decisions being made at the meeting in Warsaw in 2013, where results-based finance was introduced. In 2015, REDD+ was included in the Paris Agreement.

2.1. REDD+ initiatives[12]

The Bali agreement on REDD activities prompted many organizations to become involved in the REDD initiative. At the Bali meeting in 2007, Norway's International Climate and Forest Initiative (NICFI) was introduced, and it was announced that Norway would support REDD efforts by up to NOK 3 billion (USD 500 million) annually. The Forest Carbon Partnership Facility (the Carbon Fund), which is hosted by the World Bank, was also founded at the Bali meeting and became operative in 2011. In addition, several other organizations are now involved in REDD efforts, such as the Amazon Fund, the Congo Basin Forest Foundation, the Forest Investment Programme (World Bank) and the Central Africa Regional Programme for Environment. In this section, we give a brief description of the most important REDD+ initiatives. See Chapter 4 for more information about the progress of various initiatives.

The UN REDD programme[13]

The United Nations Collaborative Programme on Reducing Emissions from Deforestation and forest Degradation in developing countries (UN REDD) was launched in 2008 and builds on the convening role and technical expertise of the United Nations Food and Agriculture Organization (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP). UN REDD intends to create incentives for developing countries to protect, manage, and wisely use their forest resources, and in this way, contribute to conserving biodiversity and to the global fight against climate change. In addition to the environmental benefits, UN REDD offers social and economic benefits. UN REDD provides technical and financial support to developing countries to help them develop the capacities necessary to implement REDD+. REDD countries receive support to build capacity to monitor their forest resources and to change the trajectory of policies leading to deforestation and degradation. Ultimately, countries will also receive financial compensation for documented reductions in Green House Gas (GHG) emissions attributable to reduced deforestation and degradation in their country. The REDD+ initiative seeks to encourage as many forest countries as possible to participate. As of 2016, 64 forest developing countries are listed as UN REDD countries.

To avoid, reduce and capture forest carbon emissions, any country planning to engage in REDD+ activities must have a monitoring system that is compliant with the measuring, reporting and verification (MRV) processes agreed upon by UN FCCC COP, and that provides accurate data on level and changes in forest reserves and the impact on emissions. These MRV systems are designed to use field inventory data combined with satellite data and available technology to produce

[12] The acronym REDD refers to reducing emissions from deforestation and forest degradation in developing countries, and the "+" represents the role of forest conservation, sustainable management of forests and the enhancement of forest carbon stocks in developing countries.

[13] See http://www.un-redd.org.

greenhouse gas inventories and establish reference emission levels. Countries are also required to develop national forest monitoring systems (NFMS). It has been recognized that NFMS can monitor REDD+ activities as well as playing an MRV role in their implementation.

The Forest Carbon Partnership Facility initiative

The Forest Carbon Partnership Facility (FCPF) is a multilateral REDD+ initiative established in 2007. Originally, the partners in the FCPF were the World Bank, the Nature Conservancy and nine donor governments. The FCPF includes forest developing countries, financial contributors (which are both private and non-governmental organizations) and a number of international organizations. The goals of the FCPF are to provide countries with financial and technical assistance that will allow them to benefit from their REDD+ efforts, to explore performance-based payment systems for REDD+, to test how biodiversity can be conserved within the framework of REDD+ and to disseminate the knowledge gained. The FCPF funds these activities through the *Readiness Fund* and the *Carbon Fund*. The Readiness Fund helps forest developing countries to prepare to participate in a future large-scale system of positive REDD+ incentives. The Carbon Fund pays the countries for their demonstrated MRV capabilities in accordance with negotiated contracts for verified reductions in emissions compared to a reference scenario. Both funds receive financial support from a number of governments, private companies and non-governmental organizations. Contributors to the Readiness Fund are known as Donor Participants, Contributors to the Carbon Fund are known as Carbon Fund Participants and developing countries participating in the FCPF (both funds) are known as REDD Country Participants. In 2016, there were 47 FCPF-REDD country participants.

Initiatives from Norway and other donor countries

Norway has been involved in REDD since the beginning at the Bali conference in 2007, and Norway's International Climate and Forest Initiative (NICFI) was established at the same time. The main ambitions for the Norwegian initiative are formulated in a NCFI status report of 2015. Until 2016, one of the NICFI's main goals was for forest emissions to be included in a new international climate regime. This goal was achieved in the 2015 Paris Agreement. The NFCI's current goal is to help make the international Climate Regime an effective means of achieving emission reductions from forests in developing countries (NICFI, 2015).

The first countries to receive bilateral support from Norway for REDD activities were the Democratic Republic of Congo and Brazil in 2008. In 2009, Norway also started cooperation with Tanzania and Guyana. Later, collaborations were initiated with Indonesia (2010), Mexico (2010), Ethiopia (2011), Vietnam (2012), Colombia (2013), Liberia (2014), Peru (2014), and Ecuador (2014). Germany and the UK are also involved in several bilateral and multilateral agreements with REDD countries. Germany has their own programme entitled the REDD Early Movers Programme (REM).

As of 2016, all payments for verified reductions in emissions from REDD+ activities have been conducted on a bi- or multilateral basis, between the forest country and one or more donor countries. Brazil was the first country to receive results-based payments through its bilateral agreement with Norway. The Brazilian state of Acre also receives financing from REM. In addition to Brazil, Guyana has received compensation through their bilateral agreement with the Norwegian government for verified emission reductions.

The Green Climate Fund[14]

The Green Climate Fund (GCF) was established at Conference of the Parties (COP 16, Cancun 2010) to support projects, programmes, policies and other activities in developing countries (parties). The GCF was designated an operating entity of the Financial Mechanism of the Convention COP 17 (Durban 2011), where its governing instrument was approved. The GCF is to play a key role in channelling new, additional, predictable and adequate financial resources to developing countries to promote the paradigm shift towards low-emission and climate-resilient development pathways in order to attain the goals set by the international community to combat climate change. Pursuant to Article 9, paragraph 8, of the Paris Agreement and UNFCCC decision 1.CP/21, paragraph 58, the GCF as an operating entity of the Financial Mechanism is also to serve the Paris Agreement, which was adopted at COP 21.

The Board of the GCF established a separate activity area under the Readiness and Preparatory Support Programme to support the formulation of national adaptation plans (NAPs) and delegated authority to the Executive Director to approve up to USD 3 million per country for these activities. The Board further defined the scope and operational modalities of the Project Preparation Facility (PPF), which received an initial allocation of USD 40 million and will assist Accredited Entities in developing project proposals. Rwanda's Ministry of Natural Resources became the first to benefit from the PPF, for the preparation of the Rural Green Economy and Climate Resilient Development Programme.

As of August 2016, 50 countries had been approved for support under the Readiness and Preparatory Support Programme, which has received an initial allocation of USD 30 million. The proposals focus on helping member countries to develop projects and programmes in line with national climate strategies and the GCF mandate. More than USD 14 million had been committed to supporting these areas of work and nearly 40 additional proposals are under development. As this instrument is relatively recently started, the first countries are only at the Readiness stage. The GCF may channel most of the REDD compensation for the UNFCCC in the future.

2.2. Financing of REDD activities

Forest developing countries may receive financial and technical support for REDD activities from several sources (some of which are described above). The three major categories of donors are:

- UN REDD and other UN programmes linked with REDD; the Food and agricultural organization of the United Nations, the UN Environmental Programme and the UN Development Programme.
- The Forest Carbon Partnership Facility (FCFP) and the Forest Investment Programme (FIP), both facilities under the World Bank, and is the Green Climate Fund (GCF).
- Bilateral and multilateral agreements with donor countries and private foundations.

Some REDD countries receive some or all their funding directly from UN REDD and FAO provides courses in and technical support for modelling. Other REDD countries receive some or all their funding from the FCPF for readiness (the Readiness Fund) and reductions (the Carbon Fund). The FCPF in turn receives its funding from several governments, private companies and non-government organizations. In some cases, a forest country may finance some or all its REDD+

[14] Source: "Sixth Report of the Green Climate Fund to the Conference of the Parties to the United Nations Framework Convention on Climate Change, 18 August 2016.

activities through agreements with donor countries; either bilateral agreements, such as the agreement between Brazil and Norway, or multilateral agreement, such as those between Colombia, Germany, the UK and Norway. REDD countries may also be expected to finance some of the efforts themselves.

The complexity of financing sources for REDD+ activities is illustrated in Table 2.1 for forest countries participating in the FCPF.

Table 2.1 Financing sources for REDD+ activities for forest countries participating in FCPF. 2007- 2015. N = 31

Source	Amount (1000s of USD)
FCPF Readiness Fund grant disbursements	
Total	32 089
Amount of non-FCPF investment received under the Readiness and Preparation Process for REDD+	
Total	185 645
UN-REDD programme	24 557
Government of Norway	25 225
Other bilateral financing by donor countries	68 934
Own financing by the forest country	5 726
Other financing	65 204
Amount of non-FCPF investment received for implementation of Emission Reduction Programmes	
Total	735 793
UN-REDD programme	690
Government of Norway	78 356
Other bilateral financing by donor countries	84 579
The World Bank's Forest Investment Programme (FIP)	495 430
Other financing	76 739

Source: Forest Carbon Partnership Facility (2015): Annual Report.

The purpose of the Green Climate Fund is to direct funding for climate policies to developing countries. This may reduce the complexity of financing in the future. At present, however, many parties are financing REDD+ activities, creating a large number of separate agreements with forest countries concerning their obligations with respect to building capacities in their REDD Readiness stage and for producing verifiable emission reduction reports.

2.3. Guidelines and reporting requirements[15]

In addition to the UN guidelines and requirements, donor countries and other financing partners may negotiate additional requirements into their agreements with REDD countries. These requirements may vary, and we therefore only discuss the UN guidelines and requirements in the following.

What is to be reported to the UN?

Building of technical and institutional capacity is key to developing strong national forest monitoring systems (NFMS). In order to be able to report to the REDD mechanism, it is necessary to establish national measurement, reporting and verification (MRV) systems in the forest countries based on the IPCC Good Practice Guidelines (GPG). The UN IPCC secretariat of the UN FCCC COP (UN Conference of Parties) works with the practical implementation of the guidelines. The Guidelines are developed by GFOI (Global Forest Observations Initiative), which collaborates with the Group on Earth Observations. FAO assists in collecting the data needed for these guidelines. FAO also helps countries with the statistics they need to report to UN FCCC.

[15] The main source for this information is http://www.un-redd.org.

The MRV function includes three main components:

1) A greenhouse gas (GHG) inventory, which provides a framework for estimating and reporting GHG emissions and removals for the forest sector.
2) A satellite land monitoring system (SLMS), which employs remote sensing to collect data on land use and forest area change due to human activities.
3) A National Forest Inventory (NFI), under the UN-REDD NFMS strategy, which is a tool for measuring forest carbon stocks and stock changes in the field as part of the MRV function of the NFMS.

Countries are also assisted in developing their Forest Reference Emissions Levels (FREL) and Forest Reference Levels (FRL). The UNFCCC has defined FREL and FRLs as benchmarks for the performance of each country in implementing REDD+ activities and mitigating climate change through action related to their forests. FREL only include emissions from deforestation and degradation, whereas FRL include both emissions by sources and removals by sinks. This means that FRL also includes removals by sinks through enhancement of carbon stocks. According to the UNFCCC, these benchmarks must be established in order to assess a country's performance in carrying out REDD+ activities.

Measuring forest carbon emissions at the national level involves estimating and monitoring changes in two key variables:

- The area of deforestation and degradation (activity data).
- Terrestrial carbon stock densities per unit area (emission factor).

In addition, the need for data on drivers and activities causing forest carbon change and the need to develop country capacities have been highlighted as central components in the development of REDD+ MRV systems.

According to UN-REDD's website, REDD countries are encouraged to report on;

i) the status of and changes in deforestation and degradation,
ii) near-real time forest degradation monitoring,
iii) land use change patterns and drivers of degradation and deforestation,
iv) monitoring of wildfires and burnt areas,
v) biomass mapping,
vi) sub-national hot-spot monitoring, and
vii) forest type mapping.

The greater the uncertainty of the numbers reported, the lower the payments. Thus, the forest countries are also encouraged to calculate the uncertainty of their estimates of the factors listed above. The requirements for documentation of uncertainty in order to qualify for payments are not consistent across the various bilateral and multilateral agreements, and detailed UN requirements for the payment vehicle had not been negotiated as of 2016.

UNFCCC COP provides guidelines for REDD+ countries on modalities for FREL and FRLs. These include guidelines for submission of information and on the technical assessment of FREL and FRL submissions. Key points in these decisions with respect to the scale, scope and other requirements for the construction of FREL and FRLs suggest that they should be:

i) expressed in tons of carbon dioxide equivalent per year.
ii) consistent with national GHG inventories. Countries should not use incompatible data, land cover maps, etc. for FREL and FRLs. If the forest definition used for FREL and FRL construction is different from the one used in the national GHG inventory, an explanation should be provided as to how and why it differs.

iii) transparent, providing information on and the rationale for FREL and FRL development. Countries are expected to submit information on the data used for developing FREL and FRL, including historical data and details on national circumstances. If adjusted, they should submit details of how national circumstances were considered.

The decisions enable developing countries to improve their FREL and FRL estimates over time by incorporating better data, employing improved methodologies and, where appropriate, additional pools. The guidelines also suggest that countries update their FRELs and FRLs periodically to take account of new knowledge, trends or changes in scope and methodologies. Countries using subnational FRELs and FRLs as an interim measure are expected to make the transition to a national FREL and FRL.

The IPCC tier concept

To obtain an estimate of the GHG inventory, forest countries must estimate changes in five carbon pools: above-ground biomass, below-ground biomass, dead wood, litter, soil organic matter, and non-CO_2 GHG emissions for six categories of land use: forestland, cropland, grassland, wetland, settlements and ‘other land’, as well as changes between land uses. Estimates of the states of these pools are then used to obtain an estimate of the GHG inventory by applying the IPCCs Tier method.

The IPCC classifies the methodological approaches in three different tiers, according to the quantity of information required and the degree of analytical complexity:
Tier 1 employs the gain-loss method and the default emission factors and other parameters provided by the IPCC to estimate changes in biomass. Simplifying assumptions are made about some carbon pools. Tier 1 methodologies may be combined with spatially explicit activity data derived from remote sensing.[16]

Tier 2 generally uses the same methodological approach as Tier 1 but applies emission factors and other parameters that are specific to the forests, climatic regions and land use systems of the country. In addition, all five pools are covered explicitly in Tier 2.

At Tier 3, higher-order methods include models and can utilise data from national ground monitoring programmes to address national circumstances. Such systems may be GIS-based combinations of forest type and age-class/production systems with connections to soil modules, integrating several types and sources of data. These systems may include a climate dependency and provide estimates with inter-annual variability.

Tier 1 is also called the *default method*, and the IPCC guidelines aim to provide the information needed for any country to implement Tier 1, including emission and removal factors and guidance on how to acquire activity data. Tier 2 usually uses the same mathematical structure as Tier 1, with countries providing data specific to their national circumstances. This would typically require fieldwork to estimate the necessary values. Tier 3 methods are generally more complex, and normally involve modelling, higher resolution land use and land-use change data.

Progressing from Tier 1 to Tier 3 generally represents a reduction in the uncertainty of GHG estimates, but increases the complexity of measurement processes and analyses. Lower tier methods may be combined with higher tier methods for less significant carbon pools. There is no need to progress through each tier to reach Tier 3. In many circumstances, it may be simpler and more cost-effective to transition directly from Tier 1 to Tier 3, rather than to produce a Tier 2

[16] The stock change method is not applicable at Tier 1 because of data requirements.

system that is later replaced. Data collected for developing a Tier 3 system may be used to develop interim Tier 2 estimates.

Data requirements

There are several ways to build readiness in order to obtain estimates of forest resources and services. One method is to use remote sensing data to determine forest cover and the type of vegetation cover in an area (aerial photos and satellite data), another is to use ground observations. These methods may also be combined, in that remote sensing data can to *some* extent replace ground observations. There are two classes of data used to obtain estimates of forest resources and services; *reference data*, which contain detailed information about the area analysed, and *complementary data*, which provide less detailed picture of a larger area to show the relative proportions of different types of land cover. Ground-based observations are the classic type of reference data. Remote sensing data and SAR data may also be used in the production of reference data (Reiche et al. 2016) in combination with ground observations. Coarse or medium resolution satellite data may complement the reference data to make sure that all types of forests are covered in the right proportions, to enable the uncertainty of the estimates to be calculated and thereby enhance the quality of the reports.

As of today, it is necessary to use a combination of various data sources and methods to be able to complete all the REDD+ reporting recommendations. Ground-based reference data are necessary to report on the more detailed services produced by the forest reserves, like emission factors and biodiversity. High-resolution satellite data may be used in combination with ground observations to obtain estimates of the current situation and changes in the standing biomass of a forest area. High-resolution satellite data may therefore reduce the need for ground observations when estimating the carbon pool. Reference data, and in particular ground observations, are gathered on smaller forest areas. Complementary data are essential for providing a picture of how large a proportion of the forests these reference data are relevant for. By including good complementary data, it is possible to estimate the uncertainty related to the reported emission reductions achieved through policy measures in the implementation stage of the REDD mechanisms.

Many REDD countries lack monitoring capacities for their national forest inventories. Building monitoring capacity using mainly ground observations as reference data may be relatively expensive. An alternative is to supplement ground observations with high-resolution satellite data when possible to report on emissions related to changes in forest cover. This would permit these countries to establish monitoring and reporting capacities for changes in the carbon pool faster than if a national forest inventory were to be built using ground observations only. Countries need some ground observations in order to be able to report on biodiversity and other more detailed information to REDD+, but using high-resolution satellite data whenever possible is a time-saving solution for reporting on certain aspects of the REDD initiative. One challenge is that high-resolution and SAR satellite data are not freely available to the forest developing countries (Reiche et al. 2016), as they are relatively costly. Thus, even if high-resolution and SAR data are cheaper than using ground observations, they are still too costly for the REDD countries to use. However, as new satellite projects are launched, there is a hope that the greater availability and better coverage of high-resolution satellite data will lower the future cost.

3. Minimizing the costs of reporting to REDD+

The criteria above set the framework for the forest countries' decisions with respect to their Readiness preparations. In this chapter, we present a formal model for cost-effective building of reporting capacities, to better understand the considerations a forest country must make in the readiness stage to be cost effective. This model provides guidelines and principles for cost effective capacity building.[17] The theoretical model is used to discuss possible barriers to progression in REDD Readiness preparations.

When modelling the criteria for cost-effective Readiness preparation, several factors needs to be taken into consideration. Participating in the REDD initiative is voluntary, and the countries are sovereign in deciding their level of commitment and the speed and progression of their Readiness preparations. As forest resources have an alternative value for most countries, conducting conservation policies to reduce emissions from deforestation and forest degradation has both a political and economic cost for the REDD countries, as well as gains. It is thus of vital importance that the incentive structure provided by the REDD mechanism reduces the barriers and other costs to make it desirable for the governments of forest countries to participate actively in REDD.

Forest developing countries must build reporting capacities for their national forest inventory, monitoring and remote sensing, and a GHG inventory in the Readiness stage of their REDD programme in order to receive payments for documented emission reductions. Some of these capacities have already been built in some countries, at least partially, in connection with i) other UN reporting to FAO FRA and/or UNFCCC, ii) preservation of endangered species and national parks, and iii) other economic and conservation issues associated with their forest reserves. Since no payments have been made between international partners when it comes to existing UN reports, the verification process in the REDD+ initiative will in general imply a tightening of the quality requirements. Thus, most countries must build additional capacities to report to REDD.

Most forest countries collaborate with multiple partners to finance their REDD efforts: the FCPC, donor countries through bilateral and multilateral agreements, as well as the Green Climate fund. The previous lack of international guidelines on the REDD+ initiative and potential future guidelines from UNFCCC create uncertainty for the forest countries with respect to how to ensure that they build reporting capacities that meet all reporting needs in the future (De Sy et al, 2012). In addition to their present and future REDD+ reporting requirements, forest countries also have other reporting obligations concerning emissions from their forest resources, to FAO FRA, the UNFCCC and donor countries/private organizations in bilateral REDD projects. Previously built capacity for this reporting may in some instances support the capacities needed to satisfy future UN requirements. This also creates uncertainty with respect to how best to develop a REDD strategy. However, we do expect there to be clear overlaps and synergies between the required REDD reporting and reporting needed to achieve the Sustainable Development Goals (SDG) of the UN FCCC, for example. It is crucial for forest countries to coordinate capacity building effort if they are to be cost-effective.

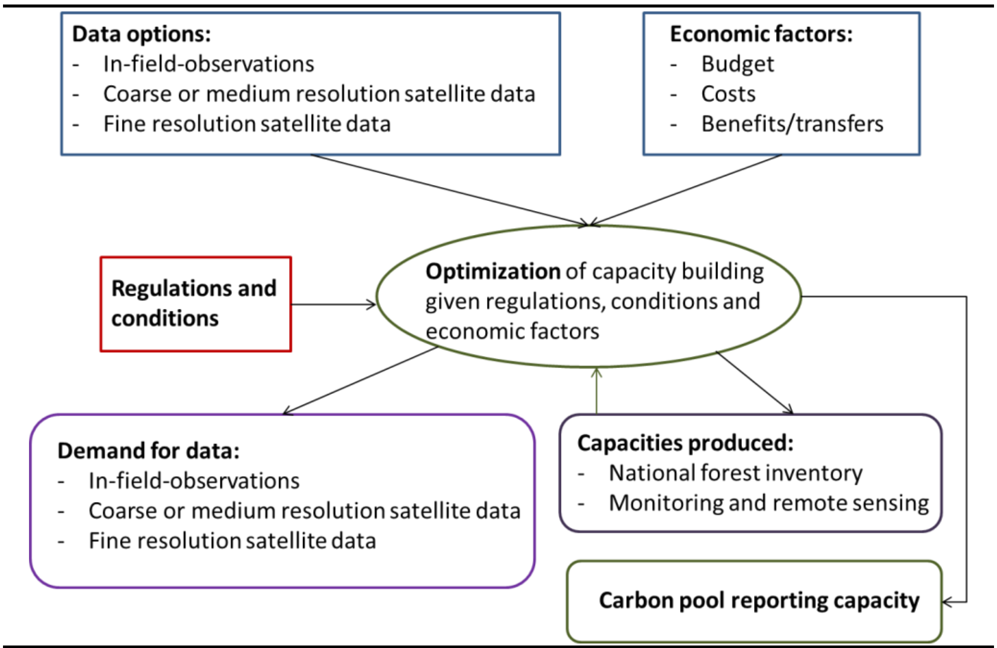
[17] Whether or not the forest countries allocate their resources optimally to maximize their reporting output is an empirical question, which must be tested.

3.1. Main considerations for forest countries

For activities to be REDD-related and for the emission reductions achieved to qualify for compensation from the international community, all emission reductions resulting from REDD activities must be documented according to agreed criteria and verified by a third party. To document and report emission reductions in a REDD context, REDD countries must have the capacity to produce statistics over their forest resources (forest inventory) and the carbon stored in their forests (carbon inventory). In addition, they must have the capacity to estimate the current/historical trend in changes in their standing forests and forest carbon storage (reference level of deforestation and degradation), and how policy measures affect these trends. These reports must be submitted to a third party, which verifies the soundness of the reported calculations. Finally, REDD countries may receive financial compensation from their international REDD partners for the emissions saved/avoided.

Figure 3.1 provides an overview of the main aspects of the decision-making process necessary for building capacity for reporting to REDD+. Appendix B contains a mathematical representation of the decision-making problem in Figure 3.1.

Figure 3.1 Analysis of the forest countries' optimization problem



The building of additional REDD+ reporting capacities is costly for a forest country, both in direct expenses and because of the lost profits from alternative uses of the forest area (logging, development, etc.). Besides the grants and transfers received, countries must themselves allocate resources for building the various reporting capacities. In addition, the country must itself also allocate resources to the building of various reporting capacities. The different funding sources all invest in the process of building Readiness and may set differing regulation criteria and conditions for the process and results. This means that the source of financing to some degree determines the quality criteria forest countries must meet when reporting their REDD efforts to their partners.

The costs of obtaining and analysing the various types of data required to build reporting capacity vary depending on existing infrastructure, time spent, wages, data costs, hardware requirements and other costs. The mix of data determines the quality of the reports, as represented by IPPC's tier levels. These contain requirements with respect to the use of reference data, i.e. mix of ground-based observations and high-resolution satellite data, as well as criteria for reporting the uncertainty of the estimates and using best-practice analytical tools to assure the quality of the forest countries' reports to REDD. These may be the requirement by a partner (a bilateral donor country, the Carbon Fund, etc.) for Readiness plans to be approved. In addition, donor partners may regulate the criteria for the verification of emission reductions claimed by the forest country, and these criteria may significantly influence how a forest country chooses to build reporting capacities.

Very few such payment schemes and verification agreements are currently in place. This causes uncertainty for the forest countries regarding the requirements of future payment schemes and the benefits to the country (through payments) of building the reporting capacity. Moreover, the forest resources have valuable alternative uses (logging, replanting, mining, etc.), and abstaining from these uses is costly fora forest country that is deciding how to build reporting capacity in REDD Readiness preparations. Finally, forest countries must take account of their current and previously built NFI, monitoring, and remote-sensing capacities, and consider the extent to which the existing capacities may be inputs for further carbon pool reporting capacity to report emission reductions attributable to their REDD efforts.

Taking all these requirements and concerns into account, the forest countries may choose to optimize their use of different data sources to build reporting capacity in the Readiness stage of REDD. For forest countries to be cost-effective, they must weigh the benefits of their level of reporting capacity against the costs of constructing/maintaining that reporting capacity. They must do this for all types of data that may be used and for all types of reporting capacities. They must also consider the synergy effects of building reporting capacities, as the building of both forest inventory and remote sensing and monitoring capacities may be used to construct carbon pool reporting capacity. In the following we provide further details of the implications these requirements and concerns have for a forest country's decision-making.

3.2. What characterizes cost-effective building of reporting capacity?

This section sums up the marginal considerations necessary to achieve cost-effective building of reporting capacities. See Appendix B for a mathematical representation of the decision-making problem and the marginal considerations.

Determining the data sources[18]

For capacity building to be cost-effective, forest countries must decide how to use different data sources to estimate i) their forest resources, ii) the level of deforestation and degradation, and iii) the impact on the carbon pool in their forests. Of relevance to this decision is the marginal price of obtaining and analysing different types of maps relative to the quality of map information. The quality of information is important since the reporting must satisfy the regulations and conditions required by either a donor partner or the UNFCCC's regulations regarding the REDD initiatives.

Regarding how much to spend on different data sources, a forest country should increase the use of a data source as long as the benefits of using this data source exceed the costs at the margin. The costs include the cost of acquiring and analysing the maps, as well as the countries' marginal cost of funds resulting from

[18] See Appendix B for mathematical expressions of the optimization problem and the first order conditions.

the shadow price of using this type of resource on REDD preparation and not on other activities (see also the section on “Zero consumption, the cost of quality constraints and delayed capacity building” below for a discussion of shadow prices).[19] A forest country should also include the marginal benefits (in the form of synergy effects) that achieving national forest inventory and remote sensing and monitoring capacities has on carbon pool reporting capacity. These synergy effects must be considered when determining the necessary capacity level and the type data to use.

In addition to weighing the cost of the production of one reporting capacity against its benefits, including the synergy and pay-off effects, forest countries must weigh the cost-benefit ratio of building one type of capacity against all other capacities in the use of a data source. If the cost-benefit ratios are not the same, a country may increase output and/or reduce costs by moving the use of the data source to an application with a better cost-benefit ratio. Different activities therefore must be weighed against each other with respect to the use of all data sources.

Finally, forest countries need to weigh the costs and benefits of using different types of data in the building of reporting capacity, because ideally, the benefits relative to costs should be the same for all data sources used. If these cost-benefit ratios differ, the country may increase its output and/or reduce costs by using more of the data source in the application with the most favourable cost-benefit ratio.

Interpretations

Consider the following thought experiment to gain insight into the practical implications of this analysis. Assume that the time used to process information from different satellite data sources in the building of a particular reporting capacity are approximately the same per unit (e.g. ha or km^2), and that the cost of using freely available low/medium-resolution data is lower than using commercial high-resolution data. For the sake of simplicity, assume further that there are no synergy effects in building reporting capacity, and no effect on the pay-off or additional requirements with respect to the quality of the reporting. Given these assumptions, for the country to be using the cost-effective solution, the benefits, in terms either of extra benefits per produced unit or of higher productivity must be higher by the same proportion as the cost ratio for the use of commercial relative to subsidised satellite data. If this cannot be achieved for any level of data use, the country should only use the cheapest source of satellite data in building a particular reporting capacity. If synergy and/or pay-off effects exist, or if there are additional quality requirements associated with building reporting capacity (for example a requirement that reference data must be used), these must also be considered with respect to both cost and benefits. The same cost/benefit comparison must be conducted with respect to the use of all types of data, including ground observations as compared to different types of satellite data.

It is reasonable to assume that the cost per unit is highest for ground observations and for commercial high-resolution satellite data. There is one exception to this expectation, which is when a forest country has already built a significant capacity using ground-based observations, for example, for other purposes (such as conservation of national parks and/or endangered species). The use of reference data may have large synergy benefits and may increase the funding from REDD since the quality of the reporting probably increases with extensive use of such data. Furthermore, some use of reference data may be required to meet the

[19] The exception to this rule is when the marginal benefits never exceeds the marginal cost, in which case the country is better off not using the data source in order to build a particular reporting capacity (see the discussion of corner solutions in section 3.3).

requirements of collaborating donors in building an estimate of the reference levels.

Variations in cost-effectiveness across countries

Existing reporting capacities significantly affect the relative cost ratios. A major component of building reporting capacity is associated with building infrastructure, routines and training. When these are established, the marginal cost of a currently used data source is lower than the marginal cost for a country without an established capacity for using the same data source. So even if the cost of purchasing the data is the same for all countries, it is still cost-effective for countries to use a different data mix, as countries differ with respect to existing capacities, wage levels and other costs of relevance for producing an estimate of the carbon pool in their forest reserves. This implies that it may be cost-effective for countries with existing capacities for a certain type of data, to continue to use that type of data.

Another important factor is that the marginal cost of funds and opportunity cost with respect to forest reserves vary considerably across countries. It is therefore not cost-effective for all countries to use the same data mix unless the costs of planning and optimizing data use outweigh all other economic considerations, which is unlikely.

Zero consumption, the cost of quality constraints and delayed capacity building

A forest country may choose not to use a particular data source for building a particular reporting capacity if the marginal cost of using this data source for that particular capacity always exceeds the marginal benefit. This case is referred to as a *corner solution* in economic literature. One may expect a corner solution if one data source has a high marginal cost/price relative to others, e.g. ground observation in the case with no prior built NFI or expensive high-resolution satellite data. The probability of observing zero demand for a data source also increases with the alternative value of using funds/resources for other purposes, such as building hospitals or roads. One may expect the costs of funds to be relatively high in developing countries, especially in cases where the country itself finances a significant proportion of the costs of building reporting capacity.

If a country would have chosen not to use a data source for building reporting capacity when no quality requirements are present (i.e. the country has chosen a corner solution), adding a requirement of using a particular data source as reference data impose an increase in costs for the country building this reporting capacity. If these regulations and conditions affect how a forest country chooses to use various types of data in building capacity, the regulations impose additional costs compared to the cost-effective solution without any additional quality requirements. These additional costs are referred to in economic literature as *shadow prices*. The magnitude of these costs depends on the difference between the cost-effective solution with and without the quality requirements.

Also of importance for corner solutions are the expected benefits of building capacity, for examplein the form of external funding. These benefits may be low if the country does not expect to produce sufficient quality reports to receive funds from the REDD mechanism with their available resources, or if external funding of capacity building for this activity is not sufficiently large. In these cases, the probability of corner solutions increases for the more expensive types of data used in building reporting capacity. In addition, the shadow price increases if the forest country is required to use this data source in building capacity in order to participate in REDD.

If the expected pay-off from emission reductions is low relative to the costs of building capacity (as is the current case for many REDD countries), and/or the alternative value of not preserving the forest resources is high (due, for example, to industry interests), it could be optimal for some forest countries not to build readiness at all, or to delay the building of capacity until the uncertainty with respect to payment vehicle and data/quality requirements are fully resolved. The existence of quality requirements, imposing high shadow prices and additional costs on the production of reporting of adequate quality, may thus affect the share of countries participating in the REDD programme. There is a clear conflict of interest with respect to the wish to ensure adequate reporting quality and the number of countries that will engage in reducing deforestation and degradation through the REDD programme.

Uncertainty

In the absence of quality requirements, it is reasonable to assume that extensive use of the more expensive reference data would not be cost-effective. The reason is that, due to the difference in prices, the additional benefits would have to be relatively large for reference data (compared to the benefits of other types of data) for extensive use of reference data to be optimal. Uncertainty about quality requirements and how they relate to payment schemes may therefore significantly affect participation by and progression of the efforts of REDD countries. Active participation without a knowledge of future requirements yields uncertain benefits because countries risk being unable to meet quality requirements, and because they risk building too much reporting capacity. The result could be that some or all of their REDD efforts were in vain. This indicates that it is optimal for many REDD countries to postpone capacity-building until reporting requirements are known. This uncertainty may delay Readiness preparations, thereby prolonging the period before any conservation measures are carried out. Reducing this uncertainty may therefore be of great value for forest preservation and for reducing emissions.

Failure to achieve the cost-effective solution

The cost-effective solution provides guidelines for how forest countries *should* use their economic resources efficiently to obtain the best possible quality reporting to REDD, given the costs of using different data sources in building reporting capacity, available funds, and the alternative value of funds and forest resources. This is not the same as saying that all forest countries presently apply these guidelines when organizing their efforts.

Forest countries may have several reasons for not choosing the cost-effective solution. First, this solution may not even have been considered when planning the efforts. Second, even if the countries wish to utilize their resources as economically as possible, there may still be other obstacles to the cost-effective solution:

i) REDD countries may not take into consideration that existing forest inventory and remote sensing and monitoring capacity can be used in building carbon pool reporting capacity and to achieve other synergy effects in the reporting to various authorities. This may result in suboptimal capacity building and a suboptimal relative weighting of capacities, causing use in excess of the optimal use of some data sources in the building of carbon pool reporting capacity.

ii) Fe forest countries may not know all relevant costs and benefits with certainty, for example because of uncertainties with respect to the payment vehicle or other verification conditions for reported emission reductions. This may affect all aspects of their efforts.

iii) There may be other additional considerations relevant to the effort, such as political and or legal restrictions/obligations that override the economic considerations.

Diverging from the principles of the cost-effective solution increases the costs and/or reduces the quality of forest country reporting to the REDD mechanism. This is challenging for many REDD countries, as many of them are some of the poorest in the world. Being unable to reach a cost-effective solution limits countries' ability to instate policies that reduce deforestation and degradation through the REDD mechanism. Another consequence is that less is known about changes in the carbon stored in forest areas of the world. Thus, every attempt to come closer to a cost-effective solution will be a win-win situation, both for the REDD initiative and for the forest countries.

4. Progress and capacity-building status

NORAD (2013) points to several issues that may be delaying progress and participation in REDD. These include the lack of final decisions and guidance from UNFCCC on MRV modalities, as well as lack of prospective results-based payments as a financial incentive. The cost-effectiveness analysis explains how and why these barriers delay progress and reduce participation in REDD. This chapter looks at capacity–building progress in different groups of countries as an indication of the magnitude of this problem.

Very few REDD countries have finished their Readiness preparations and started the execution phase. As of 2016, the only payments that had been made as compensation for REDD activities were on a bilateral level between the forest country and one or more partner countries. Examples are the Norwegian and German collaboration with Brazil through the Amazon Fund and Norway's collaboration with Guyana. No compensation has yet been paid through the Carbon Fund. But several countries are at the stage where policies to reduce deforestation and degradation are to be implemented and negotiations about the payment scheme are ongoing. We provide a brief update of progress below.

4.1. An assessment of countries' reporting capacities

By 2016, 69 of the 152 non-Annex I UNFCCC members (45.4 percent) were REDD and/or Carbon Fund members.[20] Most of these have started their Readiness preparation process, receiving Readiness preparation grants from donor countries, through private funds or through the FCPF. An assessment of REDD countries' progress in their Readiness preparations entails an evaluation of their progress on their reporting capacity status with respect to forest inventory, remote sensing and monitoring and carbon pool.

Romijn et al. (2015) used national reports to FAO FRA to construct three indicators on the capacity to produce reports for 99 tropical Non-Annex 1 UNFCCC countries for the years 2005, 2010, and 2015. The indices are for remote sensing and monitoring (RSM), national forest inventory (NFI) and carbon pool reporting (CPR) capacities, and all the indices may take the values low, limited, intermediate, good and very good (see Table 4.1 or Romijn et al., 2015). For example, remote sensing and monitoring capacity measures the reporting of forest maps to FAO FRA, and forest inventory capacity measures the reporting of changes in forest areas. "Low" on the index means no reporting at all. It is possible to obtain an "intermediate" score by using low/medium resolution satellite data only, in combination with IPPC Tier 1. To get a higher score, in-country observations and Tier 2 or Tier 3 need to be applied. See Table 4.1 for a complete definition of the index indicators.

[20] There are 64 REDD member countries and 5 countries which are a member of FCPF but not a REDD member.

Table 4.1 Indicators used to assess a countries' national forest monitoring capacities in FAO FRA

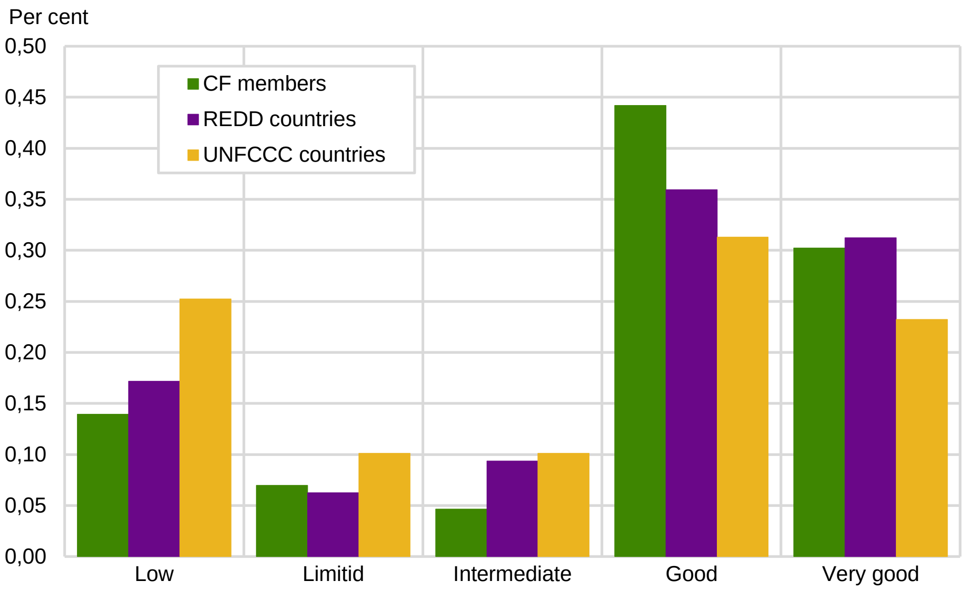
Indicator	Label	Description
Forest area change monitoring and remote sensing capacity	Low	No forest cover map
	Limited	One forest cover map (external)
	Intermediate	Multiple forest cover maps (external)
	Good	One or more forest cover map(s) (in-country), most recent produced before 2000 for 2005 assessment; before 2005 for 2010 assessment; before 2010 for 2015 assessment
	Very good	Multiple forest cover maps (in-country), most recent produced after 2000 for 2005 assessment; after 2005 for 2010 assessment; after 2010 for 2015 assessment
Forest inventory capacity	Low	No forest inventory
	Limited	One forest inventory (external)
	Intermediate	Multiple forest inventories (external), or in-country, but no full cover of all forest
	Good	One or more forest inventories (in-country), most recent produced before 2000 for 2005 assessment; before 2005 for 2010 assessment; before 2010 for 2015 assessment
	Very good	Multiple forest inventories (in-country), most recent produced after 2000 for 2005 assessment; after 2005 for 2010 assessment; after 2010 for 2015 assessment
Carbon pool reporting capacity	Low	No reported carbon stocks
	Limited	Above ground biomass (AGB) reported using Tier 1
	Intermediate	Minimum AGB and soil reported using Tier 1
	Good	AGB reported using Tier 2 or Tier 3
	Very good	More than one pool reported using Tier 2 or Tier 3

Source: Romijn et al. (2015).

While reporting capacities increased considerably during the period 2005 to 2015, a substantial share of the countries in this dataset have a low reporting capacity on all three (between 17 and 25 percent) (Romijn et al., 2015). As funding is often granted only for building infrastructure, but not for maintaining it, some countries have difficulties maintaining their capacities over time (Romijn et al., 2015).

To gain further insight into the current reporting capacity status of the 64 of the 99 non-Annex I tropical forest UNFCCC countries that are registered as REDD countries, we apply the dataset used in Romijn et al. (2015). To assess whether participating in the REDD initiative has a positive effect on a country's ability to monitor and assess emissions from deforestation and forest degradation, we compare the present reporting capacities of three groups: UNFCCC non-Annex I forest countries, REDD countries and Carbon Fund member countries. All these groups overlap, but not all UNFCCC non-Annex I forest countries are REDD members and even fewer are members of the Carbon Fund. Figures 4.1 to 4.3 show the distribution of the three reporting capacity indices for the 99 UNFCCC non-Annex I forest countries, the 64 REDD+ countries and the 43 Carbon Fund members for which we have information in Romijn et al.'s dataset for the year 2015.

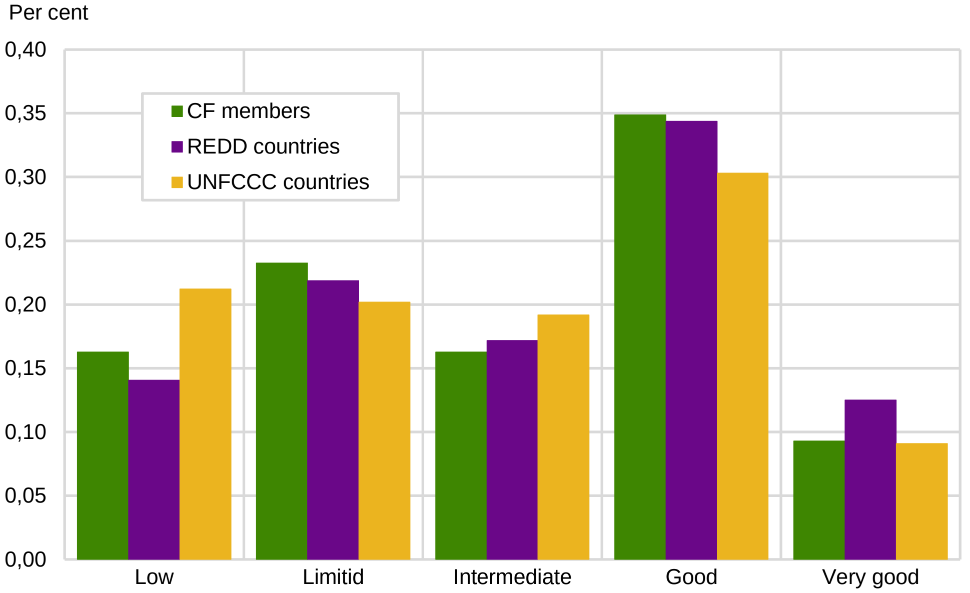
Figure 4.1 **Monitoring and remote sensing capacities in Non-Annex 1 tropical UNFCCC, UN REDD and Carbon Fund (CF) member forest countries in 2015. Per cent. N = 99, 64 and 43 respectively**



Source: FAO FRA dataset in Romijn et al. (2015).

From Figure 4.1, it appears that RSM capacity is higher in the REDD countries than in the rest of the UNFCCC countries, as there is a lower proportion of countries in the low capacity group and higher proportion of countries in the high capacity group compared to the entire group of non-Annex I UNFCCC countries in the dataset. This focus on RSM capacity is even stronger in the 43 FCPF member countries. This indicates that there are clear incentives for REDD and FCPF member countries to increase their RSM capacity. We also see a significant number of countries with no or very little RSM capacity, among REDD and FCPF member countries.

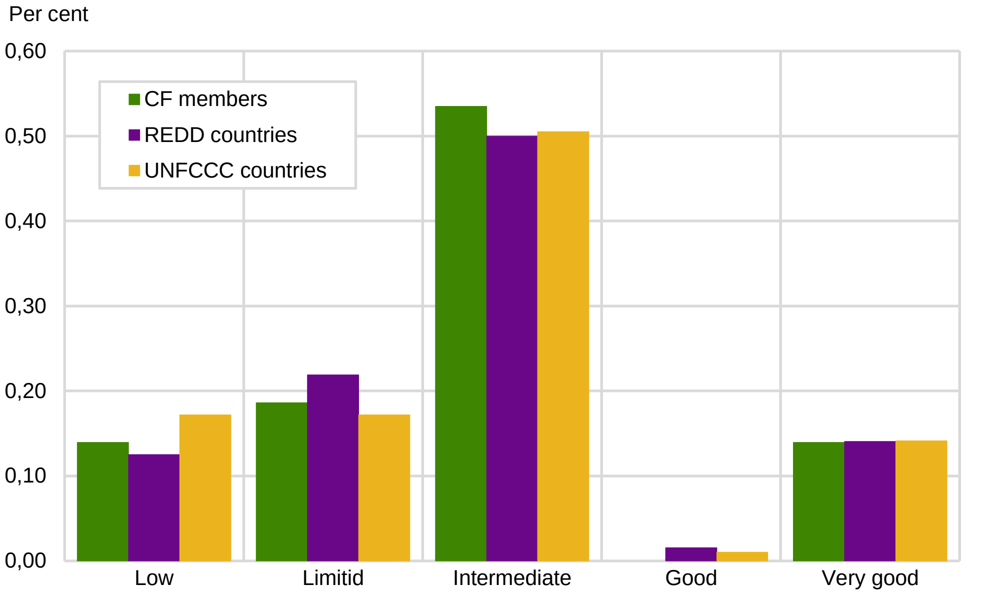
Figure 4.2 **Forest inventory reporting capacities in Non-Annex 1 tropical UNFCCC, REDD and Carbon Fund (CF) member forest countries in 2015. Per cent. N=99, 64 and 43 respectively**



Source: FAO FRA dataset in Romijn et al. (2015).

Figures 4.2 and 4.3 do not display any such clear trends among the different groups of countries. The *carbon pool* reporting capacities (as measured by the UNFCCC countries reporting to FAO FRA) do not seem to be higher for REDD and FCPF member countries than for the average non-Annex I UNFCCC country (see Figure 4.3). This indicates that the main incentives to build capacities within the REDD system, as of now, are connected to their building RSM capacities. This is a result of a step-wise adaption in many countries, focusing on estimates of the status of and changes in forest cover in the initial phase of their Readiness preparations. This implies that, as of 2015, REDD Readiness preparations among the countries in this dataset fell short of the level where most countries were able to report their reference level for the status of and changes in their forest reserves, or emission reductions attributable to policy measures to reduce these emissions.

Figure 4.3 Carbon pool reporting capacities in Non-Annex 1 tropical UNFCCC, REDD+ and Carbon Fund (CF) member forest countries in 2015. Per cent. N=99, 64 and 43 respectively



Source: FAO FRA dataset in Romijn et al. (2015).

4.2. FCPF member countries

The most advanced countries appear to be those that have a close collaboration with either a donor country or an international/private fund. A possible explanation is that this group of countries is strongly motivated and more closely followed up with respect to their Readiness preparations. They have a clearer prospect of payments and less uncertainty with respect to verification criteria. The progression of countries with a close bilateral collaboration with donor countries (see the discussion of the Norwegian government's REDD partners in section 4.3) and countries that are members of the Carbon Fund (discussed in this section) will be discussed in more detail to learn how these collaborations may affect a country's REDD Readiness.

Of the 64 REDD countries, 45 are accepted as FCPF members and collaborate with the Carbon Fund. The 45 countries that participate in the Carbon Fund comprise approximately 65 percent of all REDD countries. Before a REDD country may receive money from the Carbon Fund, it must undergo a rigorous evaluation process, as the Carbon Fund only supports programmes that are submitted by a government or a government encoded entity, operate on a significant scale, are based on sound policies and have verifiable effects. A REDD country must first apply to have its Readiness Preparation Proposal (R-PP) accepted by the FCPF

Participation Committee (PC). This is followed by an eight-step process for the country to become eligible to receive payments through the Carbon Fund.[21]

Step 1. Countries that have prepared a Readiness Preparation Proposal (R-PP) and that have made progress towards REDD Readiness may apply or authorize an entity within their country to apply to the Carbon Fund by submitting an Emission Reductions Programme Idea Note (ER PIN), using the template provided by the FCPF.

Step 2. Carbon Fund Participants and the World Bank review a country's ER PIN, taking into account any input from a Technical Advisory Panel. Based on this review, Carbon Fund Participants may accept the ER PIN into the Carbon Fund pipeline, and allocate funding (up to USD650,000) to further develop the idea into an ER Program.

Step 3. The World Bank, as Trustee of the Carbon Fund, and the REDD country (or authorized entity) sign a Letter of Intent.

Step 4. With technical assistance from the World Bank, the country (or authorized entity) develops the programme idea into a fully-fledged programme design that is documented in a draft ER Programme Document (ER PD). Based on the draft ER PD, the due diligence process is performed by the World Bank and the Fund Management Team, taking account of input from a Technical Advisory Panel, if any. The due diligence process includes overall programme appraisal and assessment of social and environmental safeguards, reference level, monitoring system, and institutional arrangements. Based on the feedback received during the due diligence process, the REDD country (or authorized entity) improves the programme design and finalizes the ER PD.

Step 5. After the country has made significant progress towards REDD Readiness. The country prepares and submits a Readiness Package to the FCPF Participants Committee (a governing body of the FCPF). Based on an assessment of the country's progress towards REDD Readiness, the FCPF Participants Committee (PC) endorses the country's R-Package.

Step 6. Once the R-Package has been endorsed by the PC, the country (or authorized entity) can submit the final ER PD for review and potential selection by the Carbon Fund Participants into the Carbon Fund portfolio.

Step 7. Once the ER Programme is accepted by the Carbon Fund Participants into the Carbon Fund portfolio, the World Bank drafts an Emission Reductions Payment Agreement (ERPA) based on terms agreed by the REDD country and Carbon Fund Participants. The ERPA is signed by the REDD country entity and the World Bank as Trustee of the Carbon Fund.

Step 8. The ER Programme is then implemented, progress with implementation is reported, and once verifiable emission reductions are generated and independently verified, payments are made to the REDD country, and emission reductions are transferred to the Carbon Fund Participants.

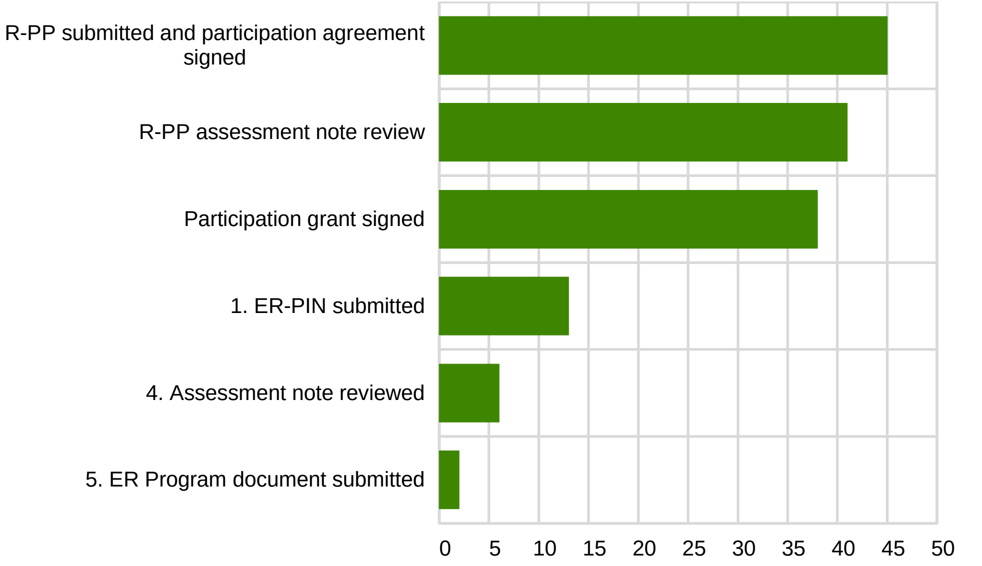
Of the 45 FCPF-REDD countries currently participating in the FCPF, 37 countries have signed Readiness Fund grants and 18 countries are in the Carbon Fund pipeline. As of 2016, no compensation for emission reductions have been paid through the Carbon Fund. However, several countries are at the stage where policies to reduce deforestation and degradation are soon to be implemented. As of

[21] Source: The FCPF Carbon Fund. Piloting REDD+ programs at scale.

2016, 5 countries are in the pipeline to have their emission reduction plans approved. Two of them (Costa Rica and Democratic Republic of Congo) have had their Emission Reduction (ER) Programme Document (PD) signed, and are to start negotiating an agreement with the Carbon Fund to receive payment for verified emission reductions. This endorsement of the Readiness Package by the FCPF Participants Committee means that they have finished step 5 and commenced step 6.

When the ER PD has been reviewed, negotiations about the conditions for payments for verified emission reductions by the forest countries may be initiated. The implication is that no countries have made agreements with the Carbon Fund regarding payments for avoided emissions as of 2016. This also implies that the financial incentives to build carbon pool reporting capacities are still relatively low for all the FCPF member countries. This may help explain why we do not see any increase in carbon pool reporting capacity among REDD and FCPF member countries compared to other non-Annex I UNFCCC countries (see the discussion of Figure 4.3).

Figure 4.4 Progress of REDD countries accepted for the Carbon Fund



Source: FCPF Dashboard.

Figure 4.5 illustrates the status of the progress of various countries in the FCPF funds as of 31 March 2016.[22] In all, 45 countries have had their R-PP submitted and assessed by the PC, and 38 countries have had their participation grant signed. Of these countries, 13 have presented their Emission Reductions (ER) Programme Idea Note (PIN) to the Carbon Fund, and 12 countries have submitted a Mid-Term Progress Report. Six countries have had their assessment note reviewed and two countries have had their R-packages endorsed.

4.3. Bilateral partner countries; the case of Norway[23]

Norway's International Climate and Forest Initiative (NICFI) supports efforts to reduce greenhouse gas emissions resulting from deforestation and forest degradation in developing countries. NICFI provides support for the measurement, reporting, and verification (MRV) of emissions in forests under the REDD+

[22] Source: FCPC Dashboard; Revised March 31, 2016.

[23] Source for this information is: Real-Time Evaluation of Norway's International Climate and Forest Initiative Contribution to Measurement, Reporting and Verification, September 2013 (NORAD, 2013).

scheme. This information is essential if developing countries are to receive payments based on achieved emission reductions.

According to “Real-Time Evaluation of Norway’s International Climate and Forest Initiative Contribution to Measurement, Reporting and Verification” (NORAD 2013), NICFI’s work on MRV and reference levels made a major contribution to the debate on these issues in the UNFCCC negotiations. The activities supported by NICFI have provided valuable practical lessons on MRV and reference levels and relevant research. These lessons have enabled Norway to develop crucial evidence-based submissions to the UNFCCC to clarify aspects of MRV for negotiators, and have been viewed by negotiators as valuable for their discussions.

All countries have made progress on the measurement aspects of MRV and there is evidence of progress on reference levels in most countries receiving NICFI support, but reporting and verification have much further to go in all countries. In the *Democratic Republic of Congo* (DRC), good progress has been made through UN-REDD support, especially with capacity building. Despite a low level of initial capacity, progress has been good in terms of implementing supporting activities for MRV and reference levels. Through effective multilateral support, MRV and reference level work in DRC are becoming a Central African Forestry Commission benchmark. NICFI support has been highly effective in developing the national MRV system and reference level in *Guyana*. The success in Guyana is attributable to the existence of a clear financial incentive, clearly defined and effective institutional arrangements and the timely provision of good technical advice. Guyana had a clear road-map at an early stage which all actors have bought into. NICFI’s involvement in *Indonesia* has been effective in supporting some planning and technological developments, but overall progress has stalled due to delays in establishing the MRV institution, which is one of the requirements of the agreement between Norway and Indonesia on REDD+. In *Tanzania* there has been a modest improvement to forest monitoring capabilities. Bilateral support to Tanzania is given through a series of discrete projects that have not yet fed through to developments at national level. There is no agreement for results-based payments with Tanzania, and hence limited incentive for establishing an MRV system, and there is a lack of financial incentives for government staff to undertake data entry or engage in systematic data management.

The success of Guyana[24]
On 9 November 2009, Guyana and Norway signed a Memorandum of Understanding (MoU) regarding cooperation on issues related to the fight against climate change, reducing emissions from deforestation and forest degradation in developing countries, protection of biodiversity, and promotion of sustainable, low carbon development (REDD+). An accompanying Joint Concept Note (JCN) laid out the framework for taking the Guyana-Norway co-operation forward. It set out how Norway would provide Guyana with financial support for REDD+ results, and formed the basis for the first payment from Norway to Guyana. The current version of the Joint Concept Note is the third update and is intended to guide the partnership for the period from June 2014 to June 2015.

The Joint Concept Note states how Norway is providing, and will continue to provide, financial support to Guyana, based on Guyana’s delivery of results as measured and independently verified or assessed against two sets of indicators:

1. *REDD+ Performance Indicators:* A set of forest-based greenhouse gas emissions-related indicators. Results against these indicators will be independently verified according to the established practice of the partnership.

[24] Source for this information: “Joint Concept Note for partnerskapet med Guyana”. https://www.regjeringen.no/contentassets/6a81714468874be7bf210dd4d09cfa33/joint-concept-note-2014-15.pdf

These indicators will gradually be replaced as a system for monitoring, reporting and verifying (MRV) emissions from deforestation and forest degradation in Guyana is established. The development of the MRV system is guided by the MRV roadmap.

2. *Indicators of Enabling Activities*: Indicators are identified that can be independently assessed through publicly available information about progress on a set of policies and safeguards to ensure that REDD+ contributes to the achievement of the following goals: protecting the rights of indigenous peoples, ensuring environmental integrity and protecting biodiversity, ensuring continual improvement in forest governance and providing transparent, accountable oversight and governance of the financial support received.

Norwegian financial support is primarily channelled through a multi-contributor financial mechanism, the Guyana REDD+ Investment Fund (GRIF). The support is financing two sets of activities: i) The implementation of Guyana's Low Carbon Development Strategy (LCDS) ii) Guyana's work to build capacity to improve overall REDD+ and LCDS efforts.

The Government of Guyana is responsible for making the necessary data for assessing performance against the given indicators publicly available. The continuation of result-based financial support from Norway to Guyana will depend on publicly observable progress on forest governance. Guyana and Norway have agreed that the necessary information for assessing Guyana's delivery on the indicators will be easily and publicly accessible. Independent assessment of the information determines the degree to which the requirements of the REDD+ enablers have been met.

Guyana is being paid for its performance through an incentive structure, which rewards the country for keeping deforestation below an agreed reference level. Norway and Guyana have decided to pilot this incentive structure on a national scale. Once an international regime is in place, the partnership will be adjusted accordingly. Payments due to Guyana will be calculated by applying an interim carbon price of USD5/ton CO_2, as established in Brazil's Amazon Fund. However, this price will only be used if Guyana's observed deforestation rate is below the agreed level.

5. Using satellite data for MRV in REDD

As discussed above, a large percentage of REDD countries have so far only achieved a relatively low reporting capacity through their Readiness efforts. It appears that they have mainly focused on building monitoring and remote sensing capacities (see the discussion in section 4.1). Most countries have yet to arrive at the stage where carbon pool reporting capacities have been increased; neither REDD nor FCPF member countries appear, on average, to have a higher carbon pool reporting capacity than other non-Annex I forest countries. This implies that the current REDD incentives have so far promoted increasing monitoring and remote sensing capacities, but carbon pool reporting capacities, which are essential for documenting emission reductions to REDD, are lagging.

Slow progress in Readiness preparations due to lack of financial incentives has been discussed by several institutions, including NORAD (2013). To improve progress in the period before general UN guidelines are in place and most REDD countries have a signed agreement concerning the verification process and payment schemes, measures needs to be implemented to reduce the effect of the lack of financial incentives. One such measure is to subsidise purchases of high-resolution satellite data, which may be partially used as reference data when calculating changes in the carbon pool of the standing biomass. This would increase REDD countries' flexibility with respect to meeting several quality requirements without having to build extensive infrastructure, which is often necessary when ground observations are used as reference data. At present, high-resolution satellite data are relatively costly and too expensive in relation toe to the expected benefits for many REDD countries. This may explain why some REDD countries appear to be adopting a wait and see attitude before building their carbon pool reporting capacity. Subsidising high-resolution satellite data will reduce the cost of uncertainties with respect to the formulation of future financial incentives,[25] which in turn would probably accelerate progress in Readiness preparations for many REDD countries.

5.1. Current data use and reporting capacity

In order for a country to be able to report the reference level of its forest stock, deforestation, and forest degradation, it needs a Satellite Land Monitoring System (SLMS) (Pekkarinen, 2016). By using high-resolution satellite data, as opposed to medium and low-resolution satellite data, forest countries can report faster on forest area changes and forest degradation.

Data from US Landsat satellites are most commonly used for monitoring REDD activities. The Landsat satellites provide free 30m imagery, with acquisitions going back to 1972. Landsat satellite data, including archived Landsat data, became free and open to users in 2008. In 2015, the European Union's Copernicus programme launched the first Sentinel 2 satellite. The data policy of the EU Copernicus programme is free and open data, making the 10m medium resolution data from Sentinel 2, together with Landsat data, now available for all uses at no cost.

Landsat and Sentinel 2 data are in the category medium (10-30 m) resolution and have proved to be valuable data sources for national and international forest monitoring. Some claim that medium resolution data have far too low-resolution to be used to measure forest degradation. This is because these datasets do not contain enough detail to map smaller area changes, like removal of single trees. When using low or medium resolution satellite data, supplementary information sources

[25] Whether or not it is socially optimal to subsidise the use of high-resolution satellite data is not discussed in this report.

that can serve as reference data are therefore generally needed and required for REDD estimation and reporting.

Gathering all the reference data by ground observation is as a rule more time consuming and requires more man power than acquiring some of the necessary information using high-resolution satellite data and/or airborne sensors in cases where high-resolution satellite data may be used as reference data. The lack of available high-resolution satellite data at a low cost appears to be a limiting factor for tropical forest monitoring (Reiche et al. 2016). Reducing the cost of high-resolution data might lower the bar for participation and increase the quality of reporting by REDD and other Non-Annex I forest countries, and it would help these countries monitor their forests in order to qualify for financial compensation for reductions in deforestation and forest degradation. Making high-resolution satellite data more readily available would also provide other benefits such as algorithm development and capacity building in developing countries, since the data could be more widely used (Reiche et al, 2016).

Using the numbers from Romijn et al (2015), we can deduce what data are currently in use and how this affects reporting capacities. It is clear from these data that having good forest area monitoring and remote sensing capacity does not always imply good carbon pool reporting capacity (see Table 5.1). One reason may be the low-resolution of the data collected through remote sensing. Romijn et al (2015) found that as of 2015, eleven (11) REDD countries[26] had “very good” carbon pool reporting capacity, meaning that they could report more than one carbon pool,[27] using Tier 2 or Tier 3 reference data. These countries include Costa Rica, Ecuador, Ghana, Guatemala, Guyana, India, Jamaica, Mexico, Myanmar, Nepal, and Zambia (see Table 5.1). These REDD countries contain 22.4 percent of the forests in the UN REDD program. At the same time, 29 REDD countries with 63 per cent of the forests in the REDD programme only Tier 1 carbon pool reporting capacity or less (Romijn et al, 2015). Having Tier 1 reporting capacity means that the country applies a fairly simple approach, often using freely available data such as low (>30m) resolution satellite data to monitor changes in forest cover. The use of lower quality satellite data generally leads to large uncertainties, which in turn tends to lead to several simplified assumptions.

[26] As listed on the UN REDD programme website in November 2016.

[27] A carbon pool is a reservoir of carbon. The carbon pool can either accumulate or release carbon. Carbon pools relevant for forests are above ground biomass, roots, dead wood, and soil carbon.

Table 5.1 Groups of REDD countries by carbon pool reporting capacity and monitoring and remote sensing capacity. Note that the table does not sum to 100% because not all REDD countries were rated on their capacities in the study by Romijn et al. (2015).

		Monitoring and remote sensing capacity	
	Country capacity	**“very low”, “low”, “intermediate”**	**“good”, “very good”**
Carbon pool reporting capacity	**“very low”, “low”, “intermediate”**	**10.8%,** **Lower capacity countries (19):** Central African Republic, Chad, Equatorial Guinea, Fiji, Gabon, Guinea, Honduras, Nigeria, Solomon Islands, Togo, Vanuatu, Pakistan, Burkina Faso, Benin, Cameroon, Guinea-Bissau, Liberia, Malawi, Zimbabwe	**63%,** **Higher capacity countries (29):** El Salvador, Colombia, Indonesia, Malaysia, Panama, Sri Lanka, Argentina, Bangladesh, Bolivia, Democratic Republic of the Congo, Kenya, Peru, Paraguay, Philippines, Samoa, Suriname, Viet Nam, PDR Lao, Papua New Guinea, Bhutan, Cambodia, Congo, Côte d’Ivoire, Dominican Republic, Ethiopia, Madagascar, Sudan, Uganda, Tanzania
	“very good”, “good”	**0%,** None	**Highest capacity countries (11):** **22.4%,** Costa Rica, Ecuador, Ghana, Guatemala, Guyana, India, Jamaica, Mexico, Myanmar, Nepal, Zambia

Source: Romijn et al. (2015).

5.2. Lessons learned from Norwegian bilateral REDD+ projects

NICFI supports MRV through bilateral agreements with Guyana, Mexico, Indonesia, Tanzania, Brazil and Ethiopia. NICFI also supports international MRV initiatives such UN-REDD/FAO, FCPF and GEO-FCT/GFOI. The specific amount of money used by NICFI on MRV in bilateral agreements is not easily identifiable, since the MRV money is integrated into broader financial initiatives (NORAD, 2013). Table 5.2 indicates that countries receiving bilateral support for MRV activities from NICFI (based on NORAD, 2013) have had variable achievements in terms of becoming able to report on their carbon pool as well as improving their forest area change and remote sensing capacities. The approach used in their MRV efforts also varies across countries, as only Guyana used high-resolution data.

Table 5.2 MRV support received from NICFI (NORAD, 2013), and progress in forest area change monitoring, remote sensing capacities and carbon pool reporting capacities between 2010 and 2015.

Bilateral partner country	MRV support given by NIFCI by 2013		Forest area change monitoring and remote sensing capacities		Carbon pool reporting capacities	
	Million NOK	% MRV expenses	2010	2015	2010	2015
Brazil	--	--	Very good	Very good	Good	Very good
Ethiopia	--	--	Good	Good	Intermediate	Intermediate
Guyana	7.3	2%	Low	Very good	Intermediate	Very good
Indonesia	22.5	5%	Very good	Very good	Intermediate	Intermediate
Mexico	57	12%	Very good	Very good	Intermediate	Very good
Tanzania	111	24%	Intermediate	Good	Intermediate	Intermediate

Sources: Romain et al. 2015, NORAD 2013, UN FAO.

Guyana is a success story with respect to rapid build-up of carbon pool reporting capacity. In 2010, Guyana did not have the capacity to report their carbon pool and had no forest area change monitoring and remote sensing capacities in place (Romijn et al, 2015). Guyana built this up with relatively little financial support (NORAD, 2013) after a bilateral agreement with clear financial incentives for REDD+ was signed by Norway and Guyana in October 2009. At this point, Guyana received an initial payment of USD 30 mill. The country was further promised approximately USD 250 million in the period up to 2015, when the final amount would depend on Guyana’s performance according to a methodology set out by the two countries in November 2009.

Central to Guyana’s technical MRV strategy have been reliance on space data, including high-resolution wall-to-wall satellite data from the Rapid Eye satellites (5m), to provide a detailed overview of the country’s forest resources. Guyana’s Forestry Commission submitted their first results report in 2011, just two years after the signing of the agreement between Guyana and Norway. According to Romijn et al (2015), Guyana’s carbon pool reporting capacity was “very good” in 2015.

The clear financial incentives are probably one of the main reasons why reporting was possible just two years after the agreement was signed. In addition, NORAD (2013) lists a number of other reasons for the high efficiency in Guyana: the MRV system was implemented by a single, efficient institution; there was continuity in the process management from start to finish; and that there was early, good technical planning. Finally, Guyana is a small country with forests characterized by being small and homogeneous. Several elements of the process followed in Guyana are transferable to other forest countries, however, even if the contextual details vary from country to country (NORAD, 2013). One of these elements is the use of high-resolution data for monitoring deforestation and forest degradation (GFOI, 2016).

5.3. High-resolution satellite data

In most cases, high-resolution data can replace ground observations as reference data when a country is to map forest cover and area changes related to deforestation and/or forest degradation. Moreover, once such high-resolution satellite data are collected, they can also be used for many other monitoring purposes, related to both forest and carbon stock, as well as other tasks that require geospatial information. According to the Global Forest Observation Initiative

(GFOI), using high-resolution data for national forest monitoring (GFOI, 2016) permits:

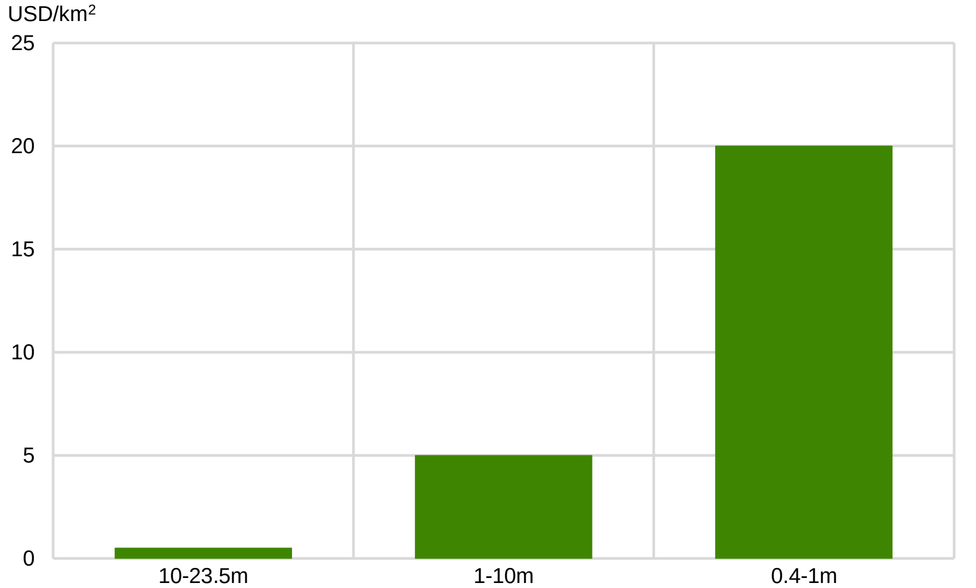
- detection of forest area changes associated with degradation
- improving the accuracy medium-resolution data
- the use of training data for change detection algorithms
- the production of removal factors, since the high-resolution data provide a good basis for mapping forest types and stock

All these are necessary to enable a country to produce sufficiently good carbon pool reporting capacity (Tier 2 and Tier 3). In addition, high-resolution data may be provided as public information for third party verification of reduced emissions from deforestation and degradation. This means that high-resolution satellite data may be used to cover several functions in building REDD MRV capacities.

High-resolution satellite data could play an important role in the provision of timely and detailed forest information. So why are high-resolution data not used to a greater extent by REDD countries in Readiness preparations? GFOI (2016) lists three main reasons that limit the use of high-resolution data (GFOI, 2016, pp. 122):

1) They cost more to acquire than datasets with lower resolution[28](see Figure 5.1 for a comparison of prices for data at different resolutions),
2) The processing costs of these data are likely to be higher because of the larger data volume, and
3) These data may not be available for entire countries for a sufficient number of time periods to permit collection of the data necessary for REDD reporting.

Figure 5.1 Prices for remote sensing data at different resolutions.[1] USD per km²



[1] Airborne SAR is not included, but costs about 345 USD/km2 (Böttcher et al.et al 2009).

Following Guyana's example, using high-resolution data may be one way to quickly increase the reporting capacity of REDD countries. But as mentioned in the GFOI report (2016), the three major challenges of data costs, processing time, and coverage, in terms of both time periods and national area, need to be overcome. In addition, there may be further limitations, as GFOI also points out that "the use of high-resolution data continues to be the subject of research", GFOI, 2016, pp. 122).

[28] All high-resolution data has to be purchased commercially, while core data (low-resolution data) are available for free.

Resolution

SEPAL, which is FAO's Space Data and Product Management System, is set up to aid countries with data processing. In the SEPAL project, FAO and the Norwegian government work together to improve the capacity of developing countries to monitor and report on their forest resources and changes in forest area. The project facilitates countries' access to earth observation data sources, including high-resolution satellite imagery, and to an easy-to-use platform for processing and interpreting this data. SEPAL has created a cloud-based computing interface that allows quick access to remote sensing data as well as to high-performance computing facilities. This technical assistance by SEPAL has the potential to reduce the challenges related to processing time for high-resolution data. The SEPAL system will mainly be used to permit countries to produce and access satellite-generated forest maps and other related products faster, which in turn will permit reporting and compensation for verified emission reductions. The SEPAL system is being piloted in 13 countries over a period of 3 years. The 13 SEPAL pilot countries are: Democratic Republic of Congo (DRC), Ecuador, Guyana, Colombia, Mexico, Nepal, Nicaragua, Paraguay, Peru, Tanzania, Uganda, Vietnam, and Zambia (Jonckheere, 2016).

6. Cost analysis

This chapter uses an example to estimate the costs of acquiring high-resolution satellite data in order to increase capacities for reporting deforestation and forest degradation monitoring. To illustrate the potential for cost and time savings by increasing the use of high-resolution satellite data, we compare the costs and time currently required to establish a self-sustaining National Forest Monitoring System (NFMS) with the projected costs of monitoring forests using high-resolution satellite data. Estimates are based on the budgeted expenses for the 13 pilot countries in FAO's SEPAL project, as well as experiences from Guyana.

As high-resolution satellite data are used very little for REDD purposes, it appears that this data source is too costly for monitoring large parts of currently unmonitored forests, or forests for which no reporting takes place. We use cost data from the SEPAL project to estimate the cost of increasing the use of high-resolution satellite data to reach a reporting capacity sufficiently for REDD+ requirements. Because high and low capacity countries have different needs, we estimate their costs separately:

(1) *For lower capacity countries*, i.e. countries with the lowest remote sensing and carbon pool reporting capacity, we estimate the costs of a) building the necessary *remote sensing capacity* and b) the costs of *carbon pool* REDD+ reporting using high-resolution satellite data.
(2) *For higher capacity countries*, i.e. countries with high reporting capacity for remote sensing, but with low carbon pool reporting capacity, we estimate the cost to increase carbon pool reporting using high-resolution data.
(3) Finally, we estimate the costs of widespread use of high-resolution satellite data in all REDD countries. We predict the annual cost of acquiring high-resolution data for all forested area in REDD countries as well as the total cost of purchasing all these data in the period 2017-2030.

To obtain an estimate of the potential cost and time savings achieved by replacing ground observations with high-resolution satellite data as in the SEPAL project, we compare these estimates to the average time it takes to build sufficient reporting capacities according to FAO's rule-of-thumb. These rule-of-thumb estimates are based on their experience of building a NFMS system based on current best practice.

6.1. Empirical cost analysis

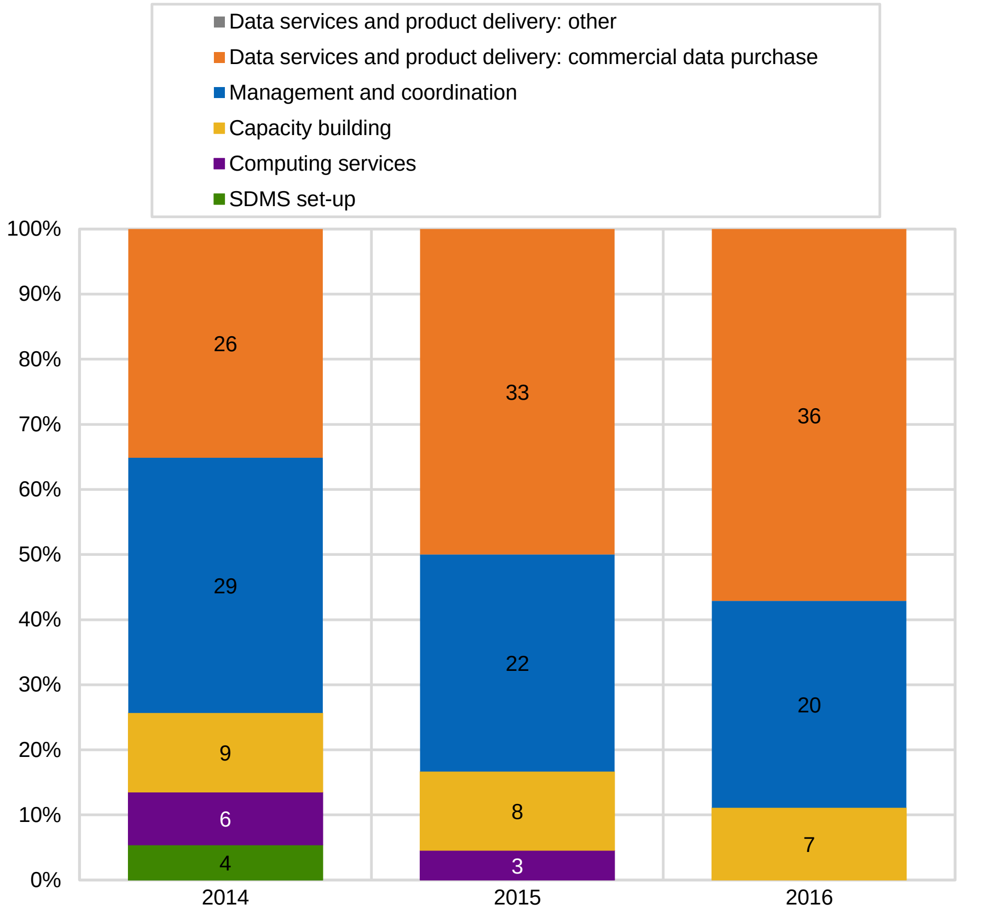
What would it cost to acquire the high-resolution data for REDD countries with low forest area change and remote sensing capacity necessary to enable them to report to REDD? To answer this question, we use information from FAO and the SEPAL project, which budgeted a three-year project for the cost of purchasing commercial high-resolution data for 13 pilot countries to improve the reporting capacities of these countries. Note that the budgeted data do not necessary imply full data coverage for the countries. The complete budget is provided in Appendix D, Table D.2.

"Data services and product delivery: commercial data purchase" is a large expenditure item as a percentage of annual budgets, accounting for roughly one third of the total budget (see Figure 6.1). The rest of the budget is used for other expenses which are: SMDS[29] Satellite Monitoring System set up (year 1 only), Computing services (years 1 and 2 only), Capacity building, and Management and

[29] Space Data Management System (SDMS) (Acquire, Query, Process and Deliver Earth Observation Data and Forest Information Products to Developing Countries)

coordination. The budget included costs for purchases of the following data types as needed for the specific country: Radar, SAR, L-band SAR 10m for annual cloud-free coverage, ScanSAR for Early Warning, QuickBird and RapidEye.

Figure 6.1 Distribution of various budget items for 13 SEPAL pilot countries

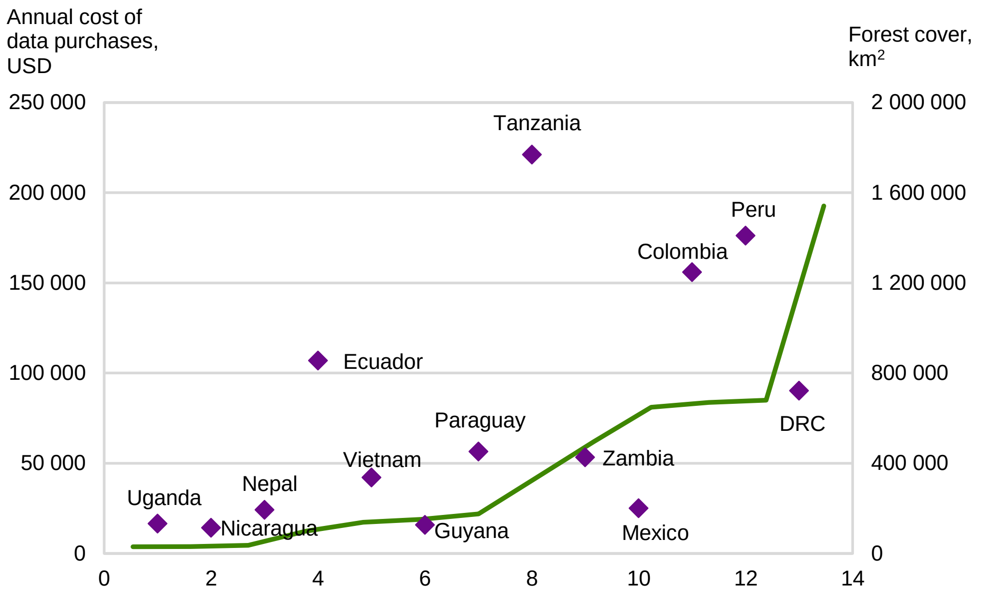


The data needs and mix will depend on national circumstances, and the costs can therefore only be estimated. An initial prediction can be made based on the budgeted costs (USD 2014-values) over three years of implementing the SEPAL system in the pilot countries. This is clearly a very small sample (13 observations), which may not be representative of the population of REDD countries. Therefore, the estimated numbers should be interpreted with caution. And, as mentioned, national circumstances vary. Nonetheless, we use these estimates as our first, rough approximation to the costs that would be incurred by other REDD countries purchasing high-resolution data with the same coverage as the SEPAL countries.

Predicted average cost of providing data per km^2

Figure 6.2 shows a plot of budgeted data purchase costs and the size of the forest area for the 13 SEPAL pilot countries. Figure 6.2 indicates that the size of the country's forest area is an important factor in explaining the cost of high-resolution data, although there many other factors probably also contribute to the cost of providing a REDD country with high-resolution satellite data. Thus, we use forested area to estimate the mean cost of data per km^2.

Figure 6.2 Annual costs of high-resolution data and size of forest area to be monitored for the 13 SEPAL pilot countries



When these data were used, the model that best explained the variability in the cost numbers used a log transformation of both data cost and forest cover in the regression model. These log transformations have two additional benefits: they reduce heteroskedasticity (unequal variance across observations) and the estimated slope coefficient may be interpreted as an elasticity.

The relationship between forest cover to be monitored and cost of data was estimated statistically using Ordinary Least Squares. The estimated relationship is given in equation (1). The estimated expected value of natural log of cost E(LN_COST) is approximated here by a linear function of the natural logarithm of forest cover to be monitored (LN_FORESTCOVER):[30]

(1) E(LN_COST) = 4.73 + 0.48 * LN_FORESTCOVER.

In this estimation, R^2 is 0.57, the p-value[31] of the intercept is 0.023 and of the slope 0.007. The estimated coefficient of 0.48 implies that a 1 per cent increase in forested area to be monitored increases the cost of high-resolution data purchases by 0.48 percent on average.

Predicted costs for lower capacity countries.

As of 2015, nearly one third of REDD countries with 10.8 percent of total forested area in REDD countries have low[32] reporting capacity *and* low[33] forest area change monitoring and remote sensing capacities, and therefore have to build up all these capacities from scratch. These are the countries that are defined as *lower capacity*

[30] Two observations in the dataset may be considered *outliers* (cost outliers): United Republic of Tanzania and Ecuador. If these observations are included, a 1% increase in forested area to be monitored increases the cost of data by 0.47%, but the fit becomes much poorer (Based on a regression of the natural log of cost on the natural log of forest cover we found: LN_COST = 5.06 + 0.47 * LN_FORESTCOVER. R-squared is 0.41 and the p-value of the intercept is 0.0353 and of the slope 0.0185). Without Ecuador and the United Republic of Tanzania in the dataset, we find the relationship LN_COST = 4.73 + 0.48 * LN_FORESTCOVER. TR-squared increases to 0.57, the p-value of the intercept is 0.023 and of the slope 0.007. We choose to use this latter result.

[31] A p-value is the probability of rejecting the zero hypothesis of no effect when the zero hypothesis is actually true.

[32] Defined as low" or "very low" in Romijn et al (2015).

[33] Not having the capacity to produce their own forest map (Romijn et al 2015).

countries in Table 5.1. Here we first use equation (1) to predict the *costs of purchasing high-resolution data*, based on the forest coverage in these countries, working under the assumption that the data collection in the 13 pilot SEPAL countries was deemed sufficient by FAO to meet the REDD requirements. Second, since these countries lack capacities, the SEPAL budget distribution (see Figure 6.1) is used as the basis for predicting the *total costs of building up capacity*.

Based on the estimated relationship between forested area in a country and the cost of purchasing data (see Equation 1), the predicted cost of purchasing the necessary coverage of high-resolution data for the total forest area in all the “lower capacity countries” is approximately USD 403,546 annually (see Table 6.1 for the predicted cost by country for the lower capacity countries, and Table 6.3 for the higher capacity countries). In Table 6.1, this cost is disaggregated by REDD countries’ capacity level for forested area change monitoring and remote sensing (as of 2015). In Table 6.1 it is striking how little capacity there is for monitoring some of the forested area in REDD countries, and how little it would cost to purchase sufficient data (by approximated SEPAL standards) to *monitor* these forests. For example, in 2015 no forest cover map existed for 6.2 per cent of REDD country forests, and experience from the SEPAL countries indicates that it would cost only USD 218,500 to purchase one year of data for these forests USD (see Table 6.1).

Table 6.1 Cost of purchasing high-resolution data for the 19 lowest capacity REDD countries (see Table 5.1)

State of forest area change monitoring and remote sensing capacity in 2015	REDD countries	REDD country forests	Total predicted annual cost high-resolution data, USD
No forest cover map exists	Fiji, Togo, Honduras, Central African Republic, Nigeria, Guinea, Solomon Islands, Chad, Equatorial Guinea, Gabon	6.2%	218,483
One forest cover map (external)	Vanuatu, Pakistan, Burkina Faso	0.6%	40,181
Multiple forest cover maps exist (external)	Cameroon, Liberia, Benin, Guinea-Bissau, Malawi, Zimbabwe	4.0%	144,882
TOTAL: Low capacity country as of 2015	19 countries of 64 REDD countries altogether	Of REDD forests 10.8%	Average annual cost for these 19 countries: USD 403,456

In the SEPAL project, the cost of purchasing data is 31-32% of the total annual budget on average (see Figure 6.1). If we use the SEPAL distribution of budget expenses to add the predicted *costs of building up capacity* for the countries listed in Table 6.1, it suggests that it would cost approximately USD 4 million to purchase commercial data *and* build up capacity over a period of three years to monitor the 10.8 % of forests in REDD countries. Note that this estimated cost is a nominal value.

Predicted costs for higher capacity countries

Now we consider the costs of purchasing high-resolution data for the higher capacity countries (see upper right-hand quadrant of Table 5.1), which have 63 per cent of REDD forests. We assume that these countries do not need to build up forest area monitoring and remote sensing capacity. It appears that the majority of these countries lack the capacity to report on their carbon pools. One reason may be that the countries base their REDD MRV systems on freely available low and medium resolution data. If these countries were to replace the freely available low/medium resolution data with commercial high-resolution data, they could reduce the uncertainty of their REDD estimates. Based on the estimated relationship in Equation (1), the predicted total annual cost of purchasing high-resolution data for REDD countries with a "high capacity" for forest area monitoring and remote sensing capacity but low carbon pool reporting capacity is USD 1.1 million.

Table 6.2 Forested area and predicted annual costs of purchasing high-resolution data for the 29 higher capacity countries (see Table 5.1)

REDD country	Forested area (km^2)	Predicted cost of high resolution data (USD/year)
El Salvador	2 650	5,116
Paraguay	153 230	36,459
Samoa	1 710	4,139
Laos	187 610	40,212
Papua New Guinea	335 590	53,283
Bhutan	27 550	15,890
Cambodia	94 570	28,865
Congo	223 340	43,752
Côte d'Ivoire	104 010	30,225
Dominican Republic	19 830	13,552
Ethiopia	124 990	33,036
Madagascar	124 730	33,003
Sudan	192 100	40,675
Uganda	20 770	13,860
United Republic of Tanzania	460 600	62,108
Colombia	585 020	69,728
Indonesia	910 100	86,357
Malaysia	221 950	43,620
Panama	46 170	20,401
Sri Lanka	20 700	13,837
Argentina	271 120	48,056
Bangladesh	14 290	11,565
Bolivia	547 640	67,535
Democratic Republic of the Congo	1 525 780	110,893
Kenya	44 130	19,960
Peru	739 730	78,114
Philippines	80 400	26,684
Suriname	153 320	36,470
Vietnam	147 730	35,820
TOTAL	7381 360	1,123,215

For reference purposes, we also predict the cost of purchasing commercial high-resolution satellite data for *all* REDD countries using equation (1) (see Table 6.3). Note that these figures only include data purchases and do not include the cost of building up capacity in the lower capacity countries. In addition, these figures include data purchases for countries that are in the highest capacity category in Table 5.1, such as Costa Rica.

Table 6.3 Predicted cost of purchasing commercial high-resolution data by REDD country. The discount rate is 4% in the present value calculations

	"Very good" forest area change monitoring and remote sensing capacity in 2015 =equals 1, otherwise equals 0 (Romijn et al 2015)	"Very good" carbon pool reporting capacity 2015	Forest cover (km^2) (2015)	Predicted annual cost data, USD	Predicted value of data costs 2017-2030
Argentina	1	0	271 120	48,056	405,368
Bangladesh	1	0	14 290	11,565	97,555
Benin	0	0	43 110	19,735	166,471
Bhutan	0	0	27 550	15,890	134,037
Bolivia	1	0	547 640	67,535	569,680
Burkina Faso	0	0	53 500	21,909	184,810
Cambodia	0	0	94 570	28,865	243,486
Cameroon	0	0	188 160	40,269	339,682
Central African Republic	0	0	221 700	43,597	367,755
Chad	0	0	48 750	20,945	176,678
Chile*	--	--	177 350	39,132	330,091
Colombia	1	0	585 020	69,728	588,179
Congo	0	0	223 340	43,752	369,063
Costa Rica	0	1	27 560	15,893	134,063
Côte d'Ivoire	0	0	104 010	30,225	254,958
Democratic Republic of the Congo	1	0	1 525 780	110,893	935,419
Dominican Republic	0	0	19 830	13,552	114,316
Ecuador	1	1	125 480	33,099	95,527
El Salvador	0	0	2 650	5,116	43,155
Equatorial Guinea	0	0	15 680	12,096	102,034
Ethiopia	0	0	124 990	33,036	278,670
Fiji	0	0	10 170	9,810	82,751
Gabon	0	0	230 000	44,379	374,352
Ghana	0	1	93 370	28,687	241,984
Guatemala	1	1	35 400	17,940	151,330
Guinea	0	0	63 640	23,829	201,006
Guinea-Bissau	0	0	19 720	13,516	114,012
Guyana	1	1	165 260	37,818	319,007
Honduras	0	0	45 920	20,348	171,642
India	1	1	706 820	76,412	644,561
Indonesia	1	0	910 100	86,357	728,450
Jamaica	0	1	3 350	5,731	48,343
Kenya	1	0	44 130	19,960	168,369
Laos	0	0	187 610	40,212	339,202
Liberia	0	0	41 790	19,440	163,983
Madagascar	0	0	124 730	33,003	278,391
Malawi	0	0	31 470	16,947	142,954
Malaysia	1	0	221 950	43,620	367,949
Mexico	1	1	660 400	73,941	623,717
Mongolia*	--	--	125 520	33,104	279,243
Morocco*	--	--	56 320	22,461	189,466
Myanmar	1	0	290 410	49,682	419,084
Nepal	0	1	36 360	18,174	153,304
Nigeria	0	0	69 930	24,942	210,394
Pakistan	0	0	14 720	11,732	98,963
Panama	1	0	46 170	20,401	172,089
Papua New Guinea	0	0	335 590	53,283	449,460
Paraguay	0	0	153 230	36,459	307,544
Peru	1	0	739 730	78,114	658,917
Philippines	1	0	80 400	26,684	225,088
Samoa	0	0	1 710	41,39	34,914
Solomon Islands	0	0	21 850	14,204	119,815
South Sudan*	--	--	71 570	25,223	212,764
Sri Lanka	1	0	20 700	13,837	116,720
Sudan	0	0	192 100	40,675	343,107
Suriname	1	0	153 320	36,470	307,637
Togo	0	0	1 880	4,333	36,550
Tunisia*	--	--	10 410	9,921	83,687
Uganda	0	0	20 770	13,860	116,914
United Republic of Tanzania	0	0	460600	62,108	523,902
Vanuatu	0	0	4400	6,540	55,167
Vietnam	1	0	147730	35,820	302,154
Zambia	0	1	486350	63,765	537,879
Zimbabwe	0	0	140620	34,975	295,026
TOTAL				2,077,744	22,825,365

*REDD country not included in Romijn et al. (2015) dataset.

Table 6.3 shows the predicted costs of purchasing commercial high-resolution data for one year and for the period 2017-2030 for all REDD countries. Mongolia, Morocco, Tunisia and South Sudan were not included in the study by Romijn et al. (2015) so the table does not contain information about the capacity levels of these countries. Predicted expenditure on high-resolution data, if all REDD countries were to purchase high-resolution data (assuming that the nominal price of the data remains constant and a discount rate of 4%[34]), is:

- USD 2 million in annual costs
- USD 22.8 million as the total cost for the period 2017-2030.

6.2. A cost comparison

Although the data used in this analysis are less than perfect, the analysis sheds some light on the costs of increased use of high-resolution satellite data to monitor forests in the same way and extent as the SEPAL pilot countries. These predicted costs indicate that there is a potential for cutting costs by using more high-resolution data than have typically been used for forest area change monitoring. However, ground observations will always provide the most complete source of information for national forest monitoring and with respect to REDD+ are regarded as a critical component for certain information needs.

Estimates of the exact time and costs associated with a National Forest Monitoring System (NFMS) are not available from FAO (Pekkarinen, 2016), but are substantial. As a rule-of-thumb, FAO estimates that a traditional NFMS for REDD, using ground observations as the main source of reference data, costs USD 1 million per year per country, and that establishing a self-sustaining NFMS takes 6-10 years (Pekkarinen, 2016). In the following, we refer to this type of NMFS as a "rule-of-thumb NFMS". Furthermore, national circumstances have major effects on time used, the use of different data sources and costs. FAO does not have time-cost estimates for analysis of different data sources, as this is very dependent on national circumstances (Pekkarinen, 2016). Thus, in our cost comparison, we use the rule-of-thumb costs for building a NFMS.[35] The costs of Guyana's efforts and the budget of the FAO SEPAL project (discussed in section 6.1) are used in the cost comparisons in this chapter to analyse the costs and time associated with using a higher share of high-resolution satellite data as reference data.

First, we compare the time and costs associated with developing a rule-of-thumb NFMS with the cost of building up capacity and monitoring with high-resolution data for the *19 lower capacity countries* in (upper left-hand quadrant of Table 5.1). If these lower capacity countries were to adopt FAO's rule-of-thumb NMFS to monitor deforestation and forest degradation, they would be able to report on their carbon pool by 2023-2027 if work started in 2017, and it would cost USD 114-190 million[36] to bring the countries in Table 5.1 up to the level of being able to report. On the other hand, deforestation and forest degradation could largely be monitored using high-resolution data, which can replace some of the ground observations used in a rule-of-thumb NFMS. If the example of Guyana could be followed for other REDD countries when it comes to reporting, these countries should be able to report on their carbon pools about two years later: in 2019, if monitoring starts in 2017. The time saving of using a large degree of high-resolution data compared to the rule-of-thumb NFMS approach is between 4 and 8 years. In terms of costs, if

[34] The rate required by the Ministry of Finance for government projects in Norway.

[35] It is important to note here that the costs of a rule-of-thumb NFMS are not directly comparable with the costs of monitoring deforestation and degradation using a mix of ground observations and high-resolution satellite data, because a rule-of-thumb NFMS would produce more detailed information. However, once completed, both approaches would permit a country to report their carbon pools at a higher level than Tier 1.

these 19 lower capacity countries were to use high-resolution data at the level of the SEPAL countries, they would need to purchase commercial data at an annual cost of USD 403,546. If the SEPAL budget distribution is used (where data costs account for about *one third of the budget*), data (400K) and capacity build-up (USD 800K) would amount to about USD 1,2 million in year one (USD 400,000 times 3). Assuming that countries would need three years of data and capacity build-up of to be able to report, the total cost for reporting by all of the 19 lower capacity countries would be USD 3.6 million.

Using the FAO rule-of-thumb numbers and the SEPAL budget, it thus appears that it is possible for a country to start reporting 4-6 years earlier if high-resolution data is used rather than the rule-of-thumb NFMS approach. For the 19 lower-capacity countries, it appears that high-resolution satellite monitoring at the same level and extent as for the SEPAL pilot countries may be achieved at about 3%[37] of the costs of the rule-of-thumb NFMS approach.

These estimates indicate that if high-resolution data were to be acquired annually from commercial sources for all REDD countries in the time period 2017-2030, the present value of the predicted purchasing costs would be approximately USD 22.8 million. This number indicates the cost savings for REDD countries if they decided to monitor forests using high-resolution data to the same extent as the SEPAL pilot countries and could use these data at no cost.

[37] USD 1.2 million in annual cost times three years 3*USD 1.2 million = USD 3.6 million which is approximately 3 per cent of USD 114 million.

7. Conclusions

This report discusses barriers to the progress of REDD countries' Readiness preparations. For a REDD country to monitor emission reductions attributable to forest management and conservation policy measures, the country must build reporting capacities. To cost-effectively organize the capacity building in the Readiness stage, it is important to consider all aspects of the country's decision-making process. This includes all economic factors, reporting requirements imposed by the financing parties, potential synergy effects and, finally, the effects of uncertainties with respect to the verification process and future payment schemes. Such uncertainty reduces the value of the benefits the REDD country expects from their Readiness preparation. If there is substantial uncertainty and/or risk aversion, REDD countries have incentives to build less reporting capacity than if there was no such uncertainty. Uncertainty delays the progress of a REDD country's Readiness preparations and may even causes forest-developing countries not to participate in REDD activities at all.

Around 60 percent of eligible countries participate in REDD efforts. Of these countries, many are relatively inactive and have not yet commenced building MRV capacities. Countries that are currently building readiness receive financing for their efforts from several different sources. Some, but far from all countries, have made good progress in their capacity building in the REDD Readiness stage. A few are in the process of implementing REDD policies that reduce emissions from deforestation and forest degradation. Only three countries have received payments from their sponsors for reduced emissions, and in all cases these payments were a result of bilateral projects with the Norwegian government (see also NORAD, 2013, for an assessment of the Norwegian forest initiative and its progress).

To understand the main reasons for the slow progress in the REDD countries' Readiness preparations, in particular with regard to building carbon pool reporting capacity, it is necessary to understand the complexity of the decisions on Readiness preparations a REDD country must make. To achieve cost-effective building of capacities for REDD+, forest countries must (see the discussion in chapter 3 or Appendix B for a more detailed description):

- have complete information about the prices of all usable data sources to optimally use data for analysing and estimating forest reserves and changes;
- take into consideration the nature and state of their national forest resources (type of forests, damage levels, economic activities utilizing the current resource, biodiversity and possible endangered species, etc.);
- take into consideration the country's previously built reporting capacities;
- evaluate the impact of uncertainty regarding the reporting requirements necessary for the verification process and the payment schemes in the final stages of the REDD process;
- take into consideration co-financers' reporting requirements for the REDD efforts if these requirements diverge from the reporting requirements for REDD (e.g. with respect to the welfare of indigenous people, preservation of endangered species);
- consider the value of using forest resources for other purposes, e.g. logging or industry;
- consider political constraints, etc.

All the points in the above list must be taken into account if a forest country is to cost-effectively produce the capacities required for active participation REDD+.

Building the capacities necessary to report on REDD efforts requires private/country specific information regarding marginal costs and benefits, wages, time use, qualifications and other aspects relevant to building capacities, funds, etc. It also requires the project to be integrated into the overall capacity building and maintaining of capacities reporting to the UN with respect to a country's forest reserves and policies for managing these resources. In some countries, there may be restrictions on the possibilities for policy making, due to international treaties and commitments, other government policies, lack of infrastructure or other public and/or private conflicts of interests. These additional restrictions may play an important role when countries organize their capacity-building for REDD. The additional restrictions also increase countries' capacity-building costs and may ultimately jeopardize a country's ability to participate.

As discussed by NORAD (2013), a general UN framework for actual payments and verification requirements did not exist at the time of the evaluation. Since then, an overarching international framework for payments and verification requirements has been adopted, but details are left to donors like the Carbon Fund and/or bilateral funders. This implies that these incentives are not in place until the agreements are signed, and that the incentives for the forest countries to build carbon pool reporting capacities are still weak because of the great uncertainty regarding the requirements for reports to pass the verification process. Uncertainty with respect to the reporting requirements and payment vehicle increases the expected costs and reduces the expected benefits of building REDD Readiness, and thus reduces the likelihood that a forest country will make good progress on their Readiness preparations (as pointed out by NORAD 2013). The data in Romijn et al (2015) indicate that synergies in building different capacities are not exploited to the fullest extent, and this may be due to uncertainties in the payment and verification system (see the discussions in chapter 4 and Appendix D). The data indicate that the countries that have come farthest in the REDD process have built monitoring capacities in addition to their national forest inventory, even if this has still not increased their carbon pool reporting capacities.

To increase participation in REDD and improve the progress of participating countries, it is important that the bilateral and UN-supported efforts are as cost-effective as possible. This implies using the cheapest data alternatives possible while achieving adequate reporting quality. If REDD countries could use high-resolution satellite data (the data may have to be subsidised to lower the cost) where possible as reference data, it may reduce REDD countries' uncertainties with respect to verification requirements and payments. This may be a means of maintaining progress in the Readiness preparations even before the parties have reached an agreement on verification requirements and the payment scheme. This may also increase participation and ultimately the efficiency of the REDD programme in reducing carbon emissions from forest deforestation and degradation.

Time series of high-resolution satellite data could be used in determining a country's reference level and in monitoring deforestation and forest degradation. The use of high-resolution satellite data is probably one of the reasons that Guyana was able to report just one year after collecting the data and receive payments within three years. High-resolution data could help countries that currently have low remote sensing capacity and low reporting capacity with their monitoring (see the cost example in chapter 5).

Several methods can be used to find the forest reference level. In this report, we compare FAO's rule-of-thumb estimate of costs for an NMFS with the use of high-resolution satellite data as exemplified by FAO's SEPAL project. According to

FAO, building a NFMS of sufficient quality to meet the REDD requirement takes as a rule-of-thumb between 6 and 10 years, while experience from Guyana indicates that time to reporting using high-resolution satellite data may be between 1 and 2 years. The use of high-resolution satellite data could therefore speed up the process for some of the REDD reporting requirements. Currently, all satellite data with a resolution higher than 10m is only available commercially, and the fact that such data must be purchased limits the monitoring of tropical forests (Reiche et al., 2016). As discussed in section 6.2, the cost of using high-resolution satellite data to bring a country up to reporting capacity for some of the REDD requirements may be as low as 3% of the costs of performing a rule-of-thumb NFMS. If high-resolution data for monitoring were to be purchased for all REDD countries for the years 2017-2030, the total cost would be an estimated USD 22.8 million.

To sum up, our analysis indicates that one main barrier to the progress of REDD countries in their Readiness preparations is uncertainty about the payment schemes and verification criteria. Close follow-up of the forest country, as well as well-defined reporting requirements and payment vehicles, appear to be very important to the progress of REDD preparations. Uncertainty with respect to payment schemes and verification criteria make the expected alternative cost/benefit-ratios of preserving forest resources too low for forest countries to spend resources on REDD+ preparations instead of continuing the current policy regime. If this is the case, one of the most important actions to take in order to accelerate REDD Readiness preparations is to reduce this uncertainty. Agreeing on common criteria for reporting, verification and payments is one option. This may prove difficult, however, as different donors have different agendas and there may be country-specific conditions that need to be taken into consideration.[38] Thus, imposing a common structure for the REDD efforts may come into conflict with other, related policy aims.

Alternatively, the cost of these uncertainties for the REDD countries could be reduced by subsidising the use of high quality satellite data to increase the flexibility of producing reports ex post without having to adjust the data acquisition after the uncertainty about reporting and verification requirements is revealed. The empirical cost analysis presented in this report indicates that both time and money could be saved by using high-resolution data rather than the current NFMS approach based mainly on ground observations. Currently, low-resolution data can be obtained for free, while purchasing high-resolution data for all REDD countries would cost approximately USD 2 mill annually and USD 22 for the period 2017-2030. One option would be to make these data freely available, as suggested by Reiche et al. (2016). Freely available high-resolution data would without doubt lower the cost barrier for reporting for REDD countries. However, we do not know if this will be either a necessary or a sufficient condition for increasing the progress of REDD Readiness preparations.

It is important to note that this analysis does not discuss whether it is socially optimal to subsidise the use of high-resolution satellite data in building Readiness, nor does it provide an empirical illustration of the optimal solution. It only illustrates the potential for time and cost reductions when more high-resolution satellite data are added to the data mix as compared to a more traditional approach using a combination of extensive ground observations and low-resolution satellite data. Performing a complete cost-benefit analysis of the two options would require, *inter alia*, country-specific information on many variables, including benefits, which are not available to us in this analysis. It would also entail taking account of

[38] Examples of such issues may be the opportunity to have synergies effects between managing emissions from the forest and other issues of importance, such as distributional issues, the economic foundation of indigenous peoples, preservation of endangered spices, etc.

the expected value of all future reporting requirements. The cost figures used in this empirical illustration are also uncertain, especially the data on ground observation costs. The cost differences between high-resolution satellite data and ground observations do, appear to be quite large, however. Even if there is time and money to be saved by using high-resolution data, they may be too expensive for many countries. Making these data freely available should help improve the monitoring of tropical forests and lower the cost barrier for actively participating in REDD activities.

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Vedlegg A: Tables

Table A 1 Non-Annex I UNFCCC member countries, UN REDD member countries and FCPF member countries. 2016

Country	Non-Annex 1 UNFCCC-member	REDD member	FCPF member
Afghanistan	1	0	0
Albania	1	0	0
Algeria	1	0	0
Angola	1	0	0
Antigua and Barbuda	1	0	0
Argentina	1	1	1
Armenia	1	0	0
Azerbaijan	1	0	0
Bahamas	1	0	0
Bahrain	1	0	0
Bangladesh	1	1	0
Barbados	1	0	0
Belize	1	0	1
Benin	1	1	0
Bhutan	1	1	1
Bolivia	1	1	1
Bosnia and Herzegovina	1	0	0
Botswana	1	0	0
Brazil	1	0	0
Brunei	1	0	0
Burkina Faso	1	1	1
Burundi	1	0	0
Cambodia	1	1	1
Cameroon	1	1	1
Cabo Verde	1	0	0
Central African Republic	1	1	1
Chad	1	1	0
Chile	1	1	1
China	1	0	0
Colombia	1	1	1
Comoros	1	0	0
Congo	1	1	1
Cook Island	1	0	0
Costa Rica	1	1	1
Cyprus	1	0	0
Côte d'Ivoire	1	1	1
Cuba	1	0	0
Democratic People's Republic of Korea	1	0	0
Democratic Republic of the Congo	1	1	1
Dominica	1	0	0
Dominican Republic	1	1	1
Ecuador	1	1	0
Egypt	1	0	0
El Salvador	1	1	1
Equatorial Guinea	1	1	0
Eritrea	1	0	0
Ethiopia	1	1	1
Fiji	1	1	1
Gabon	1	1	1
Gambia	1	0	0
Georgia	1	0	0
Ghana	1	1	1
Grenada	1	0	0
Guatemala	1	1	1
Guinea	1	1	0
Guinea-Bissau	1	1	0
Guyana	1	1	1
Haiti	1	0	0
Honduras	1	0	1
India	1	1	0
Indonesia	1	1	1
Iran	1	0	0
Iraq	1	0	0
Israel	1	0	0
Jamaica	1	1	0
Jordan	1	0	0

Country	Non-Annex 1 UNFCCC-member	REDD member	FCPF member
Kazakhstan	1	0	0
Kenya	1	1	1
Kiribati	1	0	0
Kuwait	1	0	0
Kyrgyzstan	1	0	0
Laos	1	1	1
Lebanon	1	0	0
Lesotho	1	0	0
Liberia	1	1	1
Libya	1	0	0
Madagascar	1	1	1
Malawi	1	1	0
Malaysia	1	1	0
Maldives	1	0	0
Mali	1	0	0
Malta	1	0	0
Marshall Islands	1	0	0
Mauritania	1	0	0
Mauritius	1	0	0
Mexico	1	1	1
Micronesia	1	0	0
Mongolia	1	1	0
Montenegro	1	0	0
Morocco	1	1	0
Mozambique	1	0	0
Myanmar	1	1	0
Namibia	1	0	0
Nauru	1	0	0
Nepal	1	1	1
Nicaragua	1	0	1
Niger	1	0	0
Nigeria	1	1	1
Nieue	1	0	0
Oman	1	0	0
Pakistan	1	1	1
Palau	1	0	0
Panama	1	1	1
Papua New Guinea	1	1	1
Paraguay	1	1	1
Peru	1	1	1
Philippines	1	1	0
Qatar	1	0	0
Republic of Korea	1	0	0
Republic of Moldova	1	0	0
Rwanda	1	0	0
Saint Kitts and Nevis	1	0	0
Saint Lucia	1	0	0
Saint Vincent and the Grenadines	1	0	0
Samoa	1	1	0
San Marino	1	0	0
São Tomé and Príncipe	1	0	0
Senegal	1	0	0
Saudi Arabia	1	0	0
Serbia	1	0	0
Seychelles	1	0	0
Sierra Leone	1	0	0
Singapore	1	0	0
Solomon Islands	1	1	0
South Sudan	0	1	0
Somalia	1	0	0
South Africa	1	0	0
Sri Lanka	1	1	0
Sudan	1	1	1
Suriname	1	1	1
Swaziland	1	0	0
Syria	1	0	0
Tanzania	0	1	1
Tajikistan	1	0	0
Thailand	1	0	0
Macedonia	1	0	0
Timor-Leste	1	0	0
Togo	1	1	1
Tonga	1	0	0
Trinidad and Tobago	1	0	0
Tunisia	1	1	0

Country	Non-Annex 1 UNFCCC-member	REDD member	FCPF member
Turkmenistan	1	0	0
Tuvalu	1	0	0
Uganda	1	1	1
United Arab Emirates	1	0	0
United Republic of Tanzania	1	0	0
Uruguay	1	0	1
Uzbekistan	1	0	0
Vanuatu	1	1	1
Venezuela	1	0	0
Vietnam	1	1	1
Yemen	1	0	0
Zambia	1	1	0
Zimbabwe	1	1	0
Sum	152	64	45

Table A 2 Commercial data prices

Sensor	Spatial Resolution	Resolution	Spectral Bands	Temporal Repeat (days)	Area (km)	Year Since	Price (USD/km^2)
IRC-P6 LISS 3	23.5	23.5	4 (A,V,R,IRC)	24	141*141	2003	0.04
DMC Archive	22	22	5 (V,R,IRC)	1	160*160	2004	0.04
DEIMOS-1 archive*	22	22	3 (V,R,IRC)	3	160*160	2008	0.08
DMC New	22	22	6 (V,R,IRC)	1	160*160	2004	0.18
DEIMOS-1 new*	22	22	4 (V,R,IRC)	3	160*160	2008	0.19
SPOT 4/5	20	20	4 (V,R,Irc, Irm)	3	60*60	1998	0.71
TerraSAR-X scansar	18	18	Banda x (HH)	5	150*100	2007	0.08
SPOT 5	10	10	3 (V,R,Irc)	3	60*60	2002	1
SPOT6 HR	6/1.5	6	5 (VNIR, Pancro)	1	60*60	2012	-
SPOT6 Archive	6	6	4 (VNIR)	1	60*60	2012	2.05
SPOT6 New	6	6	4 (VNIR)	1	60*60	2012	2.67
IRC-P6 Liss 4	5.8	5.8	3 (VNIR)	5	70*70	2004	0.22
DMC Pancro	5	5	1	2	20*20	2004	?
RapidEye	5	5	4 (A,V,R,IRC)	1	75*25	2009	1.28
SPOT 5	5	5	1 (Pancro)	3	60*60	2002	2
TerraSAR-X stripmap	3	3	Banda x (HH)		20*20	2007	1.32
Formosat	8/2 (pancro)	2	(VNIR)	1	24*24	2004	4.5
Ikonos Archive	4/ 1 (pancro)	1	3 (VNIR)	5	11*11	1999	10
IRC-P6 Liss 4	1	1	1 (Pancro)	5	23*23	2003	2.02
Ikonos New	4/ 1 (pancro)	1	4 (VNIR)	5	11*11	1999	20
QuickBird archive	2.4/ 0.6 (pancro)	0.6	4 (V,R,Irc, Irm)	3.5	16*16	2001	16
QuickBird new	2.4/ 0.6 (pancro)	0.6	5 (V,R,Irc, Irm)	3.5	16*16	2001	25
Pleiades archive	2/ 0.5(pancro)	0.5	5 (A,V1,V2,5,IRC)	1	20*20	2011	13
WorldView-2	2/ 0.5(pancro)	0.5	8	5	16*16	2009	16
Pleiades new	2/ 0.5 (pancro)	0.5	6 (A,V1,V2,5,IRC)	1	20*20	2011	23
WorldView-2 new	2/ 0.5(pancro)	0.5	8	5	16*16	2009	25
GeoEye-1 archive	1.6/ 0.4 (pancro)	0.4	6 (V,R,Irc, Irm)	3	15*15	2008	16
GeoEye-1 new	1.6/ 0.4 (pancro)	0.4	7 (V,R,Irc, Irm)	3	15*15	2008	25

Source: Sepal draft budget.

Table A 3 SEPAL budget

#	Category	Output	Activity	Item	Unit cost USD	Type unit	# units	Total USD 2014	2015	2016
1	SDMS set-up	1	1	Negotiating and finalizing project proposal w/ partners and donors	774	Days	15	11 605		
2		1	1	Project budget, work-plan, management structure developed	774	Days	15	11 610		
4		1	1	Preparing and realizing kick-off to launch mechanism	774	Days	30	23 220		
6		1	1	Introducing the processing system to REDD-country at relevant REDD-events	675	Days	10	6 750		
		1	1	Total travel for coordination	4200	Travel	10	42 000		
				SUBTOTAL				95 185	-	-
7	Computing servic	1	1	Cloud service (data transfer)	0.12	GB	148932	17 872		
8		1	1	Cloud service (startup)	1592	Instance	3	4 776		
		1	1	Cloud service (processing)	0.664	Hours		-		
9		1	1	Cloud service (storage)	0.065	GB	88664	5 763		
10		1	1	Cloud service (storage requests)	0.00005	Request	1000000	50		
14		1	2	Programming SDMS query, retrieval and interface	1	Contractor	100000	100 000	100 000	
15		1	1	Preparation of processing chain	823	Day	30	24 690		
16		1	1	Installing applications to server	823	Day	5	4 115		
17		1	1	Download and storage of critical public data (necessary for processing)	0	GB		-		
18		1	3	Dedicated high-speed internet connection for selected user countries	2800	Connection	5	14 000	9 000	9 000
				SUBTOTAL				171 266	109 000	9 000
20	Data services and	3	2	Pre-processing of core data	1.18E-06	Km2	5044460	6	6	6
21		3	1	Purchase of commercial raw data		Km2		702 549	1 039 189	1 255 202
23		3	2	Pre-processing of commercial data	0.00106	Km2	5044460	5 340	5 340	5 340
24		1,3	1,2	Example processing chain - composite, mosaic, classification	1.1763E-05	Km2	5044460	59		
25		1,3	1,2	Upload of medium resolution data to processing system	0	GB		-		
26		3	1	Upload of national, high spatial resolution data to processing system	0	GB		-		
				SUBTOTAL				707 955	1 044 535	1 260 548
27	Capacity Building	2	1	Developing training module	417	Day	20	8 340	8 340	8 340
28		2	2	Capacity building on site in using the services provided	823	Day	10	8 230	8 230	8 230
29		2	2	Capacity Building Field visit (travel + DSA)	5000	Travel	30	150 000	150 000	150 000
30		2	2	Capacity Building Field visit (travel + DSA)	2500	Travel	20	50 000	50 000	50 000
31		2	2	Capacity Building Field visit (logistics)	500	Day	50	25 000	25 000	25 000
32		2	3	Technical help desk - ongoing technical support	41	Day	240	9 840	9 840	9 840
				ICRU professional salaries				2 113	2 113	2 113
				SUBTOTAL				253 523	253 523	253 523
33	Management and coordination	all	all	FAO - One full time person P-4	16467	Month	12	200 220	200 220	200 220
		all	all	FAO - One full time person P-3	13773	Month	12	159 828	159 828	159 828
		all	all	FAO - One full time person G-4	8031	Month	12	102 468	102 468	102 468
34		all	all	Partner organisation - half-time dedicated person	16467	Month	6	98 802	98 802	98 802
35		all	all	External consultants	30000	Month	3	90 000	90 000	90 000
36		all	all	Executive coordination mechanism	700	Person Day	20	14 000	14 000	14 000
				Terminal Report Costs				-	-	8 000
				Evaluation				70 000	-	-
				ICRU professional salaries				37 828	37 828	37 828
				ICRU GS salaries				8 197	8 197	8 197
				ICRU consultants salaries				7 200	7 200	7 200
				SUBTOTAL				773 146	703 146	711 146
				Project Total (USD)				2 001 074	2 110 204	2 234 217
				Overhead (13%) (USD)				260140	274327	290448
				Grand Total (yearly) (USD)				2261214	2384531	2524665
				Grand Total (USD)				7170410		

Source: Sepal draft budget.

Vedlegg B: The cost model

In this appendix, we give the mathematical optimization problem faced by forest countries wanting to build their reporting capacities in the Readiness stage of REDD+ in a cost-effective way. This optimization problem gives an overview of the theoretical discussions relating to cost-effective building of reporting capacities discussed in chapter 3.

B.1 The optimization problem

In this model, we focus on the REDD countries' building of reporting capacities at the Readiness stage. The aim is to optimize the quality of REDD-related reports on emission reductions from deforestation and forest degradation, taking into account economic factors (grants, costs, etc.), that the reporting capacities built may be utilized to produce additional reports to other national and/or international entities (e.g. UNFCCC, the Carbon Fund, FAO FRA) or bilateral partner countries (synergy effects), quality requirements from donors (countries or private funds) and the uncertainty that exists with respect to future UN quality requirements and payment schemes.

We focus on the ability of REDD countries to build capacities on three major areas (coordinating with the reporting capacities discussed in Romijn et al., 2015), all necessary to be able to participate in the REDD+ mechanism:

- Forest inventory reporting capacity (Y_1),
- Remote sensing and monitoring capacity (Y_2) and
- Carbon pool reporting capacity (Y_3).

In order to obtain a reliable estimate of the amount of carbon stored in biomass, the REDD countries need to build forest inventory accounts with respect to forest cover, type of forest and biomass in various types of forest. They also need to have monitoring capacity to observe changes in forest cover and/or degradation of the forests' biomass in existing forests. The countries also need to build emissions accounts to report on emissions due to changes in forest covers. This is needed both historically, to obtain an estimate of historical changes over time for the reference deforestation and degradation level, and for future changes in the deforestation and/or degradation level, in order to determine changes in the deforestation and/or degradation rate as a result of preservation measures put forward by the forest countries' government.

Most forest countries finance their REDD+ efforts from many different sources; various UN organization, donor countries and private funds. In the agreements for receiving these funds, the different donor entities have quality requirements, restrictions and considerations that the REDD country needs to fulfill. These requirements and restrictions may vary and are individual for each case. Some are already agreed upon, and thus known. However, the details of quality requirements for the UNs REDD+ initiative are not yet finalized. In this model, we mainly (but not only) focus on the quality requirements of the Carbon Fund, since these are relatively well defined, and we expect the UN REDD requirements to be similar. However, where they are not finalized, we look at the REDD countries' expectations concerning these requirements. We assume that the quality of the reporting on activity $i = 1, 2, 3$ to donor entity k reflects reporting capacities, ranging from no reporting capacity at all ($Y_i^k = 0$) to full reporting capacity ($Y_i^k = \tilde{Y}_i^k$).

Countries may use data from different sources to build their reporting capacity:[39]

- field observations (on-ground observations or air-borne Lidar) (X_1),
- freely available coarse- or medium-resolution satellite data (X_2)
- fine-resolution commercial satellite data (X_3).
-

Currently (autumn of 2016), the freely available satellite data are of either medium or low-resolution quality. All finer optical and thermal/SAR data are commercial.

We assume that all three data sources may be used to build a *Forest inventory capacity*:

$Y_1^k = Y_1^k(X_1^1,\ X_2^1,\ X_3^1)$.

It is possible to create a forest inventory with medium or low-resolution optical satellite data only (i.e. $X_1^1 = 0$ and/or $X_3^1 = 0$) , but in order to achieve the expected reporting quality required by a particular entity *k* ($Y_1^k > \breve{Y_1^k}$), e.g. the Carbon Fund, or most bilateral agreements, one needs fine-resolution optical, thermal/SAR satellite data or field observations ($i.e. X_1^1 > 0 \frac{\text{and}}{\text{or}} X_2^1 > 0$, depending on the requirements).[40] It is further assumed that all capacities increase with increased data input but at a decreasing rate.

To build *remote sensing and monitoring capacity*, we assume that satellite data are needed ($X_2^2 > 0$ and/or $X_3^2 > 0$), but additional in-field observations may be supplied if desired:

$Y_2^k = Y_2^k(X_1^2, X_2^2,\ X_3^2)$.

Also, remote sensing and monitoring capacity may be built on the basis of medium or low-resolution satellite data alone ($X_3^2 = 0$), but to achieve sufficient quality in reporting to entity *k* ($Y_2^k > \breve{Y_2^k}$), fine resolution satellite data ($X_3^2 > 0$) may be needed. It is further assumed that all capacities increase with increased input of data at a decreasing rate, so that the larger the number of maps already produced, the smaller the quality increase due to adding yet another map.

Furthermore, we assume that *carbon pool reporting capacity* is a function of forest inventory and remote sensing and monitoring capacities that have already been built for reporting to entity *k* (Y_1^k, Y_2^k), both as a part of the REDD+ reporting to these entities and for reporting to FAO FRA or UNFCCC, as well as additional input from any of the three main data sources:
$Y_3^k = Y_3^k\left(Y_1^k, Y_2^k, X_1^3,\ X_2^3,\ X_3^3\right)$.

It is possible to build carbon pool reporting capacity on remote sensing and monitoring capacities (Y_2^k=0) using IPPC Tier 1 only, or on capacities built on medium to low-resolution optical/thermal satellite data only ($X_1^3 = 0$ and/or $X_3^3 = 0$), but either in-field observations or fine resolution satellite data must be used in order to use IPPC Tier 2 and Tier 3 and thus give a full report on all capacities, in order for a country's reports to fulfil the expected requirements of the REDD+ mechanism ($Y_3^k > \breve{Y_3^k}$).

39 There are many types of data, but for the purpose of this analysis, we categories them into these three groups.

40 For the Carbon Fund, this demand is expressed in Account element 1, FMT Note 2012-8: Recommendations of the working group on the methodological and pricing approach for the Carbon Fund of the FCPC (2012).

When it comes to financing their REDD+ efforts, we assume that the REDD countries may receive Readiness grants from an international organization g (IG^g), as well as national founding over governmental budges and/or through national organisations o (NG^o). The country's budget for building REDD reporting capacity will be the sum of all international grants and domestic founding: $I = \sum IG^g + \sum NG^o$.

This may be used to build any number of capacities to report to any entity k to any desired level.

Furthermore, we assume that there is a cost associated with transforming input into the capacity to report, where p_j^i is the cost per unit of using input data X_j^i (j=1, 2, 3) in the production of capacity Y_i^k (i = 1, 2, 3). This implies that the same type of data may have different costs in different applications, as the time cost is likely to vary across applications, even if the unit costs are not assumed to vary according to which entity the country is reporting to. These costs include all aspects of using these kinds of data, including data purchases and the costs of the labour used to analyse and report the data. Thus, these costs will probably also vary across EDD countries, both because of variations in wages, but also because of differences in operating costs, as some countries have already invested in infrastructure and reporting capacity using particular data sources (e.g. in connection with national parks and other conservation projects). We also assume that there will be a cost associated with using already built forest inventory (q_1) and remote sensing and monitoring reporting capacity (q_2) to build the carbon pool reporting capacity (Y_3^k).

The forest countries are assumed to receive benefits from these reporting capacities ($\beta_i^k, i = 1, 2, 3$) in the form of payment for reduced emissions reported to various entities and partner countries k through the REDD+ mechanism.[41] Since the payment schemes are not yet agreed upon in most cases, these benefits are expressed in expected terms. The expected benefit received is assumed to increase with the quality of the emission reduction estimates reported:

$$\beta_i^k = \beta_i^k\left(Y_i^k\right), i = 1, 2, 3.$$

As a minimum quality requirement, many entities demand the use of reference data ($X_j^i > 0 \; for \; i = 1, 2 \; and \; j = 1, 3$) and that the quality of the emission reduction estimates be verified by a third party to exceed the required level ($Y_i^k > \widetilde{Y_i^k}, i = 1, 2, 3$). For many entities, both restrictions are needed to receive expected payments over the REDD+ mechanism. If not fulfilled, the expected payments are zero: $\beta_i^k\left(Y_i^k \leq \widetilde{Y_i^k} \; and/or \; X_1^i = 0 \; and/or \; X_3^i = 0\right) = 0$. We also assume that a reduction of the uncertainty related to the payment scheme will increase the expected value of the benefits, in particular if the REDD country is risk averse.

REDD countries are assumed to maximize the sum of the benefits ensuing from producing these reporting capacities with respect to their input of different data sources, given their budget.

[41] They may also receive benefits in the form of net benefits from better management of their own forest resources, but in this model, we assume these benefits to be zero for the sake of simplicity. An alternative interpretation is that these benefits are normalized against the value of the benefits attributable to better management of own forest reserves.

$$\max_{X_j^i} \sum_k \left\{ \begin{array}{c} \beta_1^k(Y_1^k)Y_1^k(X_1^1,\ X_2^1,\ X_3^1) + \beta_2^k(Y_2^k)\quad Y_2^k(X_1^2,\ X_2^2,\ X_3^2) \\ +\beta_3^k(Y_3^k)\quad Y_3^k(Y_1^k(X_1^1,\ X_2^1,\ X_3^1), Y_2^k(X_1^2, X_2^2,\ X_3^2), X_1^3,\ X_2^3,\ X_3^3) \end{array} \right\}$$

$$given \begin{bmatrix} \sum IG^g + \sum NG^o \ \le q_1 \sum Y_1^k(X_1^1,\ X_2^1,\ X_3^1) + q_2 \sum Y_2^k(X_1^2, X_2^2,\ X_3^2) + \sum_{i=1}^3 \sum_{j=1}^3 p_j^i X_j^i \\ X_j^i > 0\ for\ i = 1,2\ and\ j = 1,3 \\ Y_i^k > \widetilde{Y_i^k}, i = \ 1,2,3 \end{bmatrix}$$

,

denoting the Lagrange multiplier for the budget condition μ (representing the forest countries' marginal cost of funds), the Lagrange multiplier for the reference data requirement ρ, and the Lagrange multiplier for the quality requirement φ.

This optimization problem gives the following six sets of first order conditions:

$$\beta_1^k \frac{\partial Y_1^k}{\partial X_j^1} + \frac{\partial \beta_1^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} Y_1^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} Y_3^k - \mu\left(q_1 \frac{\partial Y_1^k}{\partial X_j^1} + p_j^1\right) \le 0 \ \ for\ all\ \ j = 1,2,3 \text{ and k}$$

$$\beta_2^k \frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_2^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} Y_2^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} Y_3^k - \mu\left(q_2 \frac{\partial Y_2^k}{\partial X_j^2} + p_j^2\right) \le 0 \ \ for\ all\ \ j = 1,2,3 \text{ and k}$$

$$\beta_3^k \frac{\partial Y_3^k}{\partial X_j^3} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial X_j^3} Y_3^k - \mu p_j^3 \le 0 \quad for\ all\ j = 1,2,3 \text{ and k}$$

$$\sum IG^g + \sum NG^o - \left(q_1 \sum Y_1^k + q_2 \sum Y_2^k + \sum_{i=1}^{3}\sum_{j=1}^{3} p_j^i X_j^i\right) \le 0$$

$$X_j^i > 0\ for\ i = 1,2\ and\ j = 1,3$$

$$Y_i^k - \widetilde{Y_i^k} \le 0, i = \ 1,2,3 \text{ and k}$$

Solving these first order conditions with respect to all X_j^i, where *i = 1, 2, 3* and *j = 1, 2, 3*, gives the demand for the three different data sources for building the three different reporting capacities, all together nine different demand functions. These demand functions for different data sources for use in building various reporting capacities will determine the countries' level of reporting to different entities.

B.2 Determinants of the cost-effective solution

$$\beta_i^k \frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_i^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_i^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_3^k = \mu\left(q_i \frac{\partial Y_i^k}{\partial X_j^i} + p_j^i\right) \ \ \wedge j = 1,2,3\ ,\ \ i = 1,2\ \ and\ k$$

$$\beta_3^k \frac{\partial Y_3^k}{\partial X_j^3} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3}{\partial X_j^3} Y_3^k = \mu p_j^3 \quad \wedge j = 1,2,3\ and\ k$$

We also see from these equation that we should include the marginal benefits from building capacity *i=1, 2* on the building of carbon pool reporting capacity ($\frac{\partial Y_3^k}{\partial Y_i}$) when evaluating how much to use of data type *j=1, 2, 3* to produce reporting capacity *i=1, 2*. This means that we take into account the synergy effects between the reporting of forest inventory and remote sensing and monitoring capacity and the building of carbon pool reporting capacity when deciding how much to build the different capacities and which data to use. Finally, we see that the country needs to take into consideration that the quality of the reports affects the benefits accruing to them through the REDD++ payment system.

Solving this for the marginal cost of funds, we arrive at a principle for how to use different types of data to balance the building of forest inventory and remote sensing and monitoring capacity relative to the building of carbon pool reporting capacity, given by:

$$\frac{\beta_1^k \frac{\partial Y_1^k}{\partial X_j^1} + \frac{\partial \beta_1^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} Y_1^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_1^k}\frac{\partial Y_1^k}{\partial X_j^1} Y_3^k}{q_1 \frac{\partial Y_1^k}{\partial X_j^1} + p_j^1} = \frac{\beta_2^k \frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_2^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} Y_2^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_2^k}\frac{\partial Y_2^k}{\partial X_j^2} Y_3^k}{q_2 \frac{\partial Y_2^k}{\partial X_j^2} + p_j^2} \quad \bigwedge j = 1, 2, 3 \; and \; k$$

$$\frac{\beta_i^k \frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_i^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_i^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_3^k}{q_i \frac{\partial Y_i^k}{\partial X_j^i} + p_j^i} = \frac{\beta_3^k \frac{\partial Y_3^k}{\partial X_j^3} + \frac{\partial \beta_3^k}{\partial Y_3}\frac{\partial Y_3^k}{\partial X_j^3} Y_3^k}{p_j^3} \quad \bigwedge j = 1, 2, 3 \; and \; i = 1, 2 \; and \; k$$

These relationships indicate that it is not enough to weigh the cost of producing one reporting capacity against the benefits, including the synergy and pay-off effects. We also need to weigh the cost-benefit ratio of one reporting capacity against all others with respect to the use of input *j*. The reason for this is that countries are limited by the amount of funds available for this type of activity, and the benefits relative to costs of using a particular type of data (say in-field observations) may be higher for other uses. If these cost-benefit ratios are not the same, a country may increase its output and/or reduce costs by moving the use of the data source to an application with a more favourable cost-benefit ratio. They thus have to weigh different activities against each other with regard to the use of all data sources as well.

Finally, the first order conditions also lay guidelines for how to weigh the costs and benefits of using different types of data *j* to build a particular reporting capacity:

$$\frac{\beta_i^k \frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_i^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_i^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_j^i} Y_3^k}{q_i \frac{\partial Y_i^k}{\partial X_j^i} + p_j^i} = \frac{\beta_i^k \frac{\partial Y_i^k}{\partial X_r^i} + \frac{\partial \beta_i^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_r^i} Y_i^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_r^i} + \frac{\partial \beta_3^k}{\partial Y_3^k}\frac{\partial Y_3^k}{\partial Y_i^k}\frac{\partial Y_i^k}{\partial X_r^i} Y_3^k}{q_i \frac{\partial Y_i^k}{\partial X_r^i} + p_r^i} \quad \bigwedge j, r = 1, 2, 3 \; where \; j \neq r, and \; i = 1, 2 \; and \; k$$

$$\frac{\beta_3^k \frac{\partial Y_3^k}{\partial X_j^3} + \frac{\partial \beta_3^k}{\partial Y_3^k} \frac{\partial Y_3^k}{\partial X_j^3} Y_3^k}{p_j^3} = \frac{\beta_3^k \frac{\partial Y_3^k}{\partial X_r^3} + \frac{\partial \beta_3^k}{\partial Y_3^k} \frac{\partial Y_3^k}{\partial X_r^3} Y_3^k}{p_r^3} \quad \bigwedge j, r = 1, 2, 3 \; where \; j \neq r$$

These equations tell us that, optimally, the benefits relative to costs should be the same for the use of all data sources. If these cost-benefit ratios are not the same, a country may increase its output and/or reduce costs by using more of the data source in the application where it has the highest cost-benefit ratio.

B.3 Corner solutions

In some cases, the REDD country may decide to not use a particular data source *j* to build a particular reporting capacity *i*. This will occur when the marginal cost of using this data source to build this particular capacity always exceeds the benefits. This is the case when the first order condition for this data use is negative for all quantities, and is referred to as a corner solution.

One case where we expect to see this quite often is when in-field data is used to build remote sensing and monitoring capacity:

$$\beta_2^k \frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_2^k}{\partial Y_2^k} \frac{\partial Y_2^k}{\partial X_j^2} Y_2^k + \beta_3^k \frac{\partial Y_3^k}{\partial Y_2^k} \frac{\partial Y_2^k}{\partial X_j^2} + \frac{\partial \beta_3^k}{\partial Y_3^k} \frac{\partial Y_3^k}{\partial Y_2^k} \frac{\partial Y_2^k}{\partial X_j^2} Y_3^k < \mu \left(q_2 \frac{\partial Y_2^k}{\partial X_j^2} + p_j^2 \right) \; \wedge j = 1, 2, 3 \; and \; k$$

However, we may see it for all the demand functions, especially if the marginal cost of funds (μ) is high, as we would expect it to be in poorer countries, and when the price of data is high (as it is for in-field observations).

Also important is the expected benefits of producing this reporting capacity (β_i^k). If they are expected to be low, either because the country does not expect to produce sufficient quality reports to receive funds from the REDD+ mechanism on the resources available to the country, or because it does not expect to be able to use this information to gain benefits through other activities, this will also increase the probability of observing zero consumption of the more expensive types of data for building a particular reporting capacity.

This may also explain the apparently contradictory observation that a country may not build carbon pool reporting capacity even though it has a relatively good forest inventory and/or remote sensing and monitoring capacity. This will occur if $\beta_3^k \frac{\partial Y_3^k}{\partial X_j^3} < \mu p_j^3$ and the costs of using the already built capacity are higher than the perceived benefits. There may also be other reasons for this observation, which are not included in this economic analysis, such as political or juridical reasons. These reasons will not be discussed in more detail here.

Vedlegg C: Satellite and remote sensing data in REDD+[42]

Remote sensing can help to provide information on the type and intensity of land changes and the shape and pattern of deforestation and degradation, and it can track forest disturbances and dynamics using time series. Mapping land use change is more challenging than mapping land cover. However, good results can be obtained by using dense, long time series to assess changes in the rate, pattern and shape of deforestation. Forest activity data acquired by community-based monitoring can also be a valuable source of information. In this appendix, we give a brief account of how satellite data may be used in building capacities for REDD+ Readiness. For more information about specific satellites and their strengths and weaknesses in relation to Readiness preparations, see De Sy et al. (2012).

The high-resolution satellites are commercial, while the low-resolution satellites are public and the data they provide are mainly free. For reference measurements, the high-resolution satellites are needed. Low-resolution satellite data can then be used to check changes in the reference scenario. De Sy et al. sum up their discussion in a table De sy et al. (2012). They conclude that a combination of medium and fine resolution optical/thermal sensors will guarantee the best remote sensing capacity for all activities to be reported to REDD+. No other combination gives as good a result as this.

Monitoring of forest area change

A remote sensing-based national system for monitoring forest area change should measure gains and losses in forest area using the IPCC general practice guidelines (GPG). The use of time series of observations in a continuous, consistent manner to obtain accurate results and compare changes in the longer term isessential. To date, the primary tool for monitoring forest area change in the tropics on a national scale is optical medium spatial resolution (10–30 m) data. Landsat TM and ETM+ satellite data are most commonly used, owing to their observation continuity from the 1980s onwards and their global free data access policy, although recent problems with Landsat 5 and 7 are creating uncertainty about future use. Other relevant data sources are the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Système Pour l'Observation de la Terre (SPOT), Indian Remote Sensing Satellite (IRS), Disaster Monitoring Constellation (DMC) and the Chinese-Brazilian Earth Resources Satellite (CBERS) which are free for developing countries. Methodologies are well established, and limitations are more related to the long-term continuity of these systems and to data availability (wall-to-wall or full coverage, persistent cloudiness and seasonality), country capacities and processing and analysis costs. Alternatives to wall-to-wall mapping are systematic sampling and hotspot analysis.

Using multiple sensors in synergy with different spectral, spatial and temporal resolutions can increase cost efficiency and can resolve the issues of limited optical coverage, cloudiness and seasonality. The suitability of the methods depends on national circumstances such as cost of data and technical capabilities, clearing size and patterns of deforestation, forest phenology and the overall size of the country and forest area. Coarser resolution (250–1000 m) optical data (MODIS, MERIS) are generally not suitable for determining forest area change in the minimum mapping units (<1 ha) required for REDD+. However, owing to their higher temporal resolution (daily) and large coverage they have a function in sampling and stratification strategies, hotspot detection and pan-tropical monitoring for consistency among national efforts.

[42] The main source for the information given in this appendix is De sy et al. (2012).

Space-borne SAR sensors (e.g. ERS1/2 SAR, JERS-1, ENVISAT-ASAR, ALOS PALSAR, Cosmo Skymed SAR) are ideal for complimenting optical sensors because of all-weather availability and can provide multi-temporal datasets suitable for tropical forest monitoring at local to regional scales and for early detection of deforestation. Combined processing or fusion of SAR and optical data for forest monitoring and land cover assessment has been used in case studies with promising and accurate results.

The use of commercial space-borne (RapidEye, IKONOS, Quickbird) and airborne fine resolution optical sensors and air-borne LiDAR for monitoring forest area change at national scale is limited owing to relatively high costs and limited coverage, but it can be useful in subnational hotspot monitoring (see section 'Subnational hotspot monitoring').

Near real-time deforestation detection

The detection of active forest change (hotspots) is important for REDD+ for tracking forest area change that requires immediate response or intervention. Low-resolution optical sensors (MODIS, MERIS) currently take consistent and frequent measurements over large areas, which makes them ideal for identifying locations of rapid change for further analysis with finer spatial resolution data or as an alert system for controlling deforestation. Other near real-time change detection methods utilizing coarse optical satellite data, including both optical and SAR data, are available in the research domain. However, further work is needed to evaluate and validate these methods for detecting near real-time forest disturbance detection.

Forest degradation monitoring

Robust approaches to the use of remote sensing data in degradation mapping are not yet available. The use of remote sensing data for monitoring forest degradation is more complicated and less efficient than for deforestation and not all types of degradation can be monitored with high certainty. Commercial extraction is usually associated with substantial canopy damage and changes in infrastructure (roads, log landings), which makes it easier to observe with remote sensing. Wood extraction for local use is often more difficult to monitor with remote sensing as canopy changes tend to be subtle and gradual, and there is less infrastructural change. Local forest inventories and community-based monitoring are therefore valuable tools for monitoring this type of degradation in terms of activity data and emission factors.

Activity data on forest degradation can be assessed using direct or indirect remote sensing approaches. Medium to fine spatial resolution optical, SAR or LiDAR sensors are needed to directly observe canopy damage, small clearings and structural forest changes. As forest degradation is often a more gradual process than deforestation, it requires longer, dense observation time series. Frequent monitoring (annual to inter-annual) is necessary because the optical signature of degradation (closing of canopy gaps) often disappears within 1–2 years. The indirect approach focuses on observing human infrastructures associated with extraction of forest products. It has been successful in identifying degraded forest areas over longer periods with less frequent observations but lower quality than the direct approach.

Emission factors or changes in forest carbon stocks owing to degradation are usually measured through forest field sampling and forest inventories but repeated in situ measurements of degradation emission factors are scarce. There is increasing evidence that space-borne SAR and particularly airborne LiDAR can measure changes in forest carbon resulting from forest degradation. Although progress has been made, currently existing remote sensing methodologies are not considered mature enough for operational implementation at national scale.

Monitoring of wildfires and burnt areas

Monitoring of carbon emissions from biomass burning comprises 3 activities: detection of active fires, mapping of post-fire burnt areas (fire scars and regeneration) and fire characterization (e.g. fire severity, energy released. Active fire products are available in near real-time, and multi-year global active fire data are generated using thermal infrared bands from coarse spatial resolution sensors such as AVHRR, Along Track Scanning Radiometer (ATSR), MODIS or the Geostationary Satellite system (GOES). Several satellite-derived multi-year global burnt area datasets have been produced from low-resolution optical sensors such as AVHRR, MODIS, ATSR-2 and SPOT-VGT. The current burnt area products may not provide enough spatial resolution for the compiling of detailed emission inventories at national level, but they can be integrated with finer resolution data. An alternative to using burnt area models (indirect approach) is to measure directly the energy released by actively burning fires (fire characterization), using mid-infrared and thermal wavelengths, from which the total biomass consumed can be derived. However, this approach requires fine spatial and temporal resolution for accurate results. Consequently, the method is still in the research phase and not yet operationally viable for REDD+ monitoring.

Biomass mapping

Forest carbon densities are traditionally assessed using field-based inventories, which are valuable but expensive, time-consuming and inherently limited in geographic representativeness. Many developing countries do not have forest inventories of adequate quality (se discussion in section 4). Recent studies have developed wall-to-wall pan-tropical benchmark maps from satellite data of forest carbon density at 500 m and 1 km resolution. These low-resolution data are an important step, but cannot estimate the carbon stocks of tropical forests for specific countries with the certainty required for REDD+.

Airborne, very fine-resolution optical sensors can measure forest carbon stocks with higher certainty, however. Airborne LiDAR sensor approaches have been successful in providing fine resolution estimates of forest carbon density for small areas, and are thus gaining acceptance among government agencies willing and able to invest in airborne LiDAR systems. A satellite-based LiDAR system would provide more global coverage and would greatly extend capabilities for estimating carbon stocks for all forest types, but there is no satellite with vegetation LiDAR sensors operational at present. Until there is, fine resolution, cost-effective mapping of carbon stocks for project-scale and national-scale assessments will rely on integration of optical satellite imagery and airborne LiDAR samples of forest carbon density. SAR sensors on board several satellites (ERS-1, JERS-1, Envisat, ALOS PALSAR) have been used to quantify forest carbon stocks in relatively young or degraded forests, but will be less useful for mature, higher biomass forests because of signal saturation. However, integration with optical satellite data and selected field measurements produces good results.

There are currently no standard practices or methods for measuring above-ground forest biomass through remote sensing or field inventory networks at national scale in REDD+ countries. The Forest Inventory and Analysis (FIA) programme of the USDA Forest Service enables national-scale biomass estimation in accordance with UNFCCC requirements and could be used as a model for implementation of standardized practices in tropical REDD+ countries. Furthermore, multi-sensor synergies among optical, radar and LiDAR technologies are rapidly overcoming the limitations of individual sensors, and the range of spatial, thematic and temporal information thus achieved can be used to augment and enhance plot-scale estimates of forest biomass and carbon stocks. Moreover, new developments in compliant REDD+ MRV at the lower jurisdictional scales of states, provinces, and departments show that a combination of tactical field plots and remote sensing can be implemented in a cost-effective manner to make carbon emissions monitoring a reality.

Subnational hot-spot monitoring

The intensity of forest changes and REDD+ implementation activities or projects varies within countries and not all areas need to be monitored at the same level of detail and accuracy. In fact, specific areas of active change or dedicated REDD+ implementation activities should be monitored with more precision. For example, the constraints on finer spatial resolution sensors are the high costs, technical complexity and relatively limited coverage. Especially in countries with low monitoring capacities, it may be more efficient and pragmatic to dedicate major monitoring efforts to subnational hotspots, with a particular view to covering more challenging issues such as GHG emissions due to forest degradation or GHG removals due to sustainable management of forests. A national stratification based on human activities that affect forest carbon could integrate the subnational monitoring into the national system, but a clear understanding of the drivers and processes that affect a country’s carbon stock is necessary. Stratification can be carried out by identifying locations of rapid, major deforestation by means of national monitoring of forest and land use change using low to medium resolution optical sensors, satellite sensors (e.g. IKONOS, QUICKBIRD, TerraSAR-X, Cosmo Skymed) or airborne fine resolution optical sensors (SAR or LiDAR). Furthermore, fine resolution sensors and subnational hotspot analysis can provide verification and accuracy assessment of coarser resolution analysis, training data to calibrate algorithms and a link to ground-based measurements (e.g. forest inventories) and national estimation approaches.

Forest type mapping

Forest type maps provide spatially explicit information on native primary and secondary forests, plantations, and tree species that may be useful for stratification purposes, estimating biomass, forest planning and biodiversity monitoring. The spectral and spatial resolution of most space-borne optical sensors is not sufficient for differentiating consistently between forest types. However, fine resolution optical imagery can distinguish forest types on the basis of spectral response or textural measures (e.g. regular spacing of plantation trees). Accuracy can be enhanced by using inter-annual multi-temporal data (seasonal dynamics) or longer time series (plantation cycles). Fine spatial resolution radar and LiDAR sensors can identify forest types based on vegetation structure. Airborne hyperspectral sensors and the synergy of LiDAR and optical data, where structural and spectral information is combined, show most promise. The heterogeneity of forest types in the tropics makes mapping more difficult by comparison with temperate regions. So far, there are no standardized methods or classification schemes for tropical forest types.

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