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Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+

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ABSTRACT

Countries participating in REDD+ need to prepare to report on their forest carbon stocks changes. Remote sensing and forest inventories are key tools and data sources for monitoring but the capacities within non-Annex I countries needed for reporting to the UN Framework Convention on Climate Change (UNFCCC) vary considerably. The purpose of this study was to assess the status and development of national monitoring capacities between 2005 and 2010 in tropical non-Annex I countries. Different global data sources were integrated for the comparative analysis of 99 countries. Indicators were derived for four main categories: national engagement in the REDD+ process, existing monitoring capacities, challenges with respect to REDD+ monitoring under particular national circumstances and technical challenges for the use of remote sensing. Very large capacity gaps were observed in forty nine countries, mostly in Africa, while only four countries had a very small capacity gap. These four countries show a net increase in forest area with 2513 ha × 1000 ha, while all other countries together have a forest loss of 8299 ha × 1000 ha in total. Modest improvements were observed over the last five years, especially with regard to carbon pool reporting. Based on the different circumstances and current capacities of each country, general recommendations are made for the design and planning of a national REDD+ forest monitoring system and for capacity development investments. The four countries with good capacities for both monitoring of forest area change and for performing regular forest inventories could have an important role in South-South capacity development.

1. Introduction

At the 16th session of the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP16), held in Cancún in December 2010, agreements were made to confront climate change including a decision on '*Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forest and enhancement of forest carbon stocks in developing countries*', also known as REDD+. The agreement states that Parties should collectively aim to slow, halt and reverse forest cover and carbon loss, thereby addressing the five above mentioned activities of REDD+. To achieve these goals, countries are requested to develop a national strategy or action plan and to determine a national forest reference emission level. For monitoring, reporting and verification (MRV) of REDD+ activities countries need to set up a robust and transparent national forest monitoring system which is appropriate for their national circumstances (UNFCCC, 2010). In this paper we further use the term non-Annex I

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countries, as recognized by the UNFCCC, to indicate developing countries.

Methodological approaches for REDD+ monitoring were outlined at the COP15 in December 2009 (Decision 4/CP.15) and emphasized that the national monitoring system should use a combination of remote sensing and ground based forest carbon inventory approaches for measuring forest area changes and forest carbon stocks and changes (UNFCCC, 2009a). Furthermore, countries may adopt a step-wise approach to implement REDD in three phases. Phase I involves development of national strategies or action plans, policies and measures, and capacity-building. For Phase II countries have to demonstrate that through their monitoring system their demonstration activities are result based, while for Phase III countries are requested to address all requirements of MRV as stated in Decision 1/CP.16 (UNFCCC, 2010). MRV of greenhouse gas (GHG) emissions should be done in accordance with requirements from the Intergovernmental Panel on Climate Change (IPCC) guidance and guidelines and the five reporting principles of consistency, comparability, transparency, accuracy and completeness (UNFCCC, 2009b). According to the IPCC (2006) guidelines estimations of changes in carbon stocks need to be reported for five carbon pools in forests: above-ground biomass, belowground biomass, dead wood, litter, and soil organic matter (IPCC, 2006).

A common approach for calculating carbon emissions is as follows (Maniatis and Mollicone, 2010; IPCC, 2006):

$$\text{Emissions} = \text{AD} \times \text{EF} \quad (1)$$

AD means activity data, which refers to the area of forest change (in hectare), e.g., forest converted to grassland or forest converted to cropland, etc. and EF means emission factor which relates to the carbon stock change estimations per unit of activity (in carbon per hectare).

The IPCC provides three Tiers for reporting with different level of detail and accuracy. For Tier 1 emission factors are based on global default values, for Tier 2 on country specific data and for Tier 3 more detailed methods, including process-based models are used for carbon stock change estimation and reporting (IPCC, 2003, 2006). The IPCC recommends using higher Tiers for the measurement of significant sources and sinks. For this Tier 2 or 3 methods would provide the desired level of accuracy for important components of the GHG inventory. However, higher Tier methods require more data and are more expensive, because they involve monitoring of local variables (Streck et al., 2008). For less important carbon pools, the Tier 1 approach using default values for carbon estimates will be sufficient (GOFC-GOLD, 2010).

When the idea of REDD+ became formal as stipulated in the Bali Action Plan (UNFCCC, 2008b), governments started to elaborate their national strategies. A challenge is to develop and implement efficient approaches to monitor forest area and carbon stock changes, which is in accordance with the IPCC GPG and guidelines for national GHG inventories (Corbera and Schroeder, 2011; DeFries et al., 2007). The main difficulty is to develop carbon emission estimates for all five activities of REDD+ (deforestation, forest degradation, conservation, sustainable management of forest and enhancement of forest carbon stocks) in such a way, that the estimates comply with the land use categories as determined by the IPCC. To do so, Maniatis and Mollicone (2010) proposed a stratification of forest land into managed and un-managed land and a further subdivision into forest management practices and forest types to operationalize and implement national forest inventories for REDD+. Another approach of regrouping the five activities of REDD+ under the land use categories used by the IPCC GPG to set up systems for MRV for REDD+ is proposed by Herold and Skutch (2011). Satellite remote sensing is seen as a key tool for measuring and monitoring deforestation, because it is the only practical means to cover the large area of forest for national level monitoring in developing countries (DeFries et al., 2007; Böttcher et al., 2009; Goetz et al., 2009). Since an agreement on REDD+ has been reached, there is the need to develop recommendations for non-Annex I countries and to help the international community in setting investment priorities for implementing national forest monitoring systems for MRV of GHG emissions (FAO, 2011).

Developed countries are encouraged to help strengthen the capacities of non-Annex I countries for estimating their emissions (UNFCCC, 2009a). Most non-Annex I countries have limited experience in implementing national forest monitoring systems and the particularities of the REDD+ mechanism create additional requirements that are beyond the experience of national forest services. Capacity is lacking at technical, political and institutional levels to provide a complete and accurate estimation of forest area change and to attribute GHG emissions to these changes (Forest Carbon Partnership Facility, 2008, 2010). This shortage in capacity can be due to a number of factors including: limited engagement in the UNFCCC REDD process, lack of experience in application of the IPCC guidelines, shortage or lack of access to available useful data and limited estimation and reporting of national inventories (Hardcastle et al., 2008; Herold, 2009; Wertz-Kanounnikoff et al., 2008). Therefore, capacity building is a key necessity for non-Annex I countries to participate in the REDD+ mechanism, but the nature of the capacity building need is country specific since the types and size of the existing capacity gaps vary as do the REDD+ implementation priorities. To efficiently allocate resources to these activities, it is essential to investigate where and to what extent capacity building is needed and how the needs vary regionally.

This paper presents the current status and recent changes in non-Annex I countries' capacities for monitoring forest area change and carbon stock change with respect to MRV for REDD+, in accordance with REDD+ implementation Phase III. While all REDD+ countries start with Phase I based on their current (varying) monitoring capacities, it is assumed that the MRV system will be fully operational for Phase III. We perform a global comparative assessment of forest monitoring capacities and challenges given REDD+ monitoring requirements for 99 tropical non-Annex I countries by integrating different global data sources. Furthermore, we assess the recent changes in capacities for monitoring forest area and carbon stock changes based on FAO/FRA country reports from 2005 to 2010. Special emphasis is on remote sensing capacities that are required for regular monitoring of activity data.

2. Methodology

2.1. Data

Focus of this study was on all non-Annex I countries that are located in the dry tropical or humid tropical regions according to the WWF classification (WWF, 2011), which is a total of 99 countries. Data were assembled from global data sources primarily and were integrated into a single database. In addition, some harmonized national data sources, which generally have a higher accuracy but often lack comparability, were used for the 99 countries. Altogether, these datasets allowed us to make systematic global comparisons and to observe relative differences between all 99 non-Annex I countries.

The main data sources to assess the monitoring capacities were the FAO Forest Resources assessment (FRA) (FAO, 2006, 2010), the National Communications to UNFCCC (UNFCCC, 2008a) and the ‘‘Readiness Project Idea Notes’’ (R-PIN’s) which countries have submitted to the FCPF (http://www.forestcarbonpartnership.org/fcp/). The FAO FRA produces global tables and country reports on a regular basis which include information on the forest resources of a country, such as measurements and estimations of forest area, biomass and carbon stocks. The National Communications include a national inventory of anthropogenic GHG emissions which countries submit to the UNFCCC. The R-PINs contain initial plans for a national REDD+ strategy, information on the current status of the monitoring system and GHG estimation as well as a description of the current country situation with respect to its forests. The R-PINs also address potential challenges for implementing a REDD+ strategy and the constraints of the current monitoring system. From these three reports it appears that some countries use remote sensing data (e.g., medium resolution data such as Landsat, CBERS and SPOT) as primary source to deliver information on forest types and extent and forest time series, but many countries lack resources and expertise to do so. Additional information on forests, forest observation data, carbon stocks and forest disturbances was derived from a variety of global datasets (Table 1).

2.2. Methods

A methodology was developed to attribute a value to the capacity that is lacking in each country to establish a national REDD+ monitoring system (IPCC, 2006; GOFC-GOLD, 2010). We call this the ‘‘capacity gap’’. The capacity gap can be defined as the difference between what is required for REDD+ monitoring under national circumstances and the current monitoring capacity of a country.

The capacity gap was calculated by summarizing different performance indicators for four assessment categories. Indicators were developed for two different assessment categories which represent the current capacities of a country and also for two assessment categories which represent specific challenges for a country: (1) national engagement of a country in the REDD+ processes, (2) existing monitoring capacities for monitoring of forest cover and carbon stock changes, (3) challenges that countries face in the REDD+ process and (4) remote sensing technical challenges. The first category focuses on the level of engagement in the UNFCCC REDD+ process and the experience that countries have in applying the IPCC GPG for estimation and reporting of national GHG inventories. The second category examines the current national monitoring capacities for measuring and reporting forest area and carbon stock. This includes human resources, institutions for (remote sensing) data collection and processing, etc. The third category addresses the specific challenges that countries face for REDD+ implementation. This varies for each country and can be occurrence of deforestation hotspots, forest area affected by fire or a high proportion of carbon in the vegetation or soil. The fourth category focuses on particular technical challenges for applying remote sensing monitoring in a country, such as high cloud cover and seasonality (variations in cloud cover) or rough terrain with extreme slopes, which can cause difficulties for the use of satellite data, because advanced data processing techniques are required. Also, data access (internet speed) and the availability of satellite data may be a constraint for monitoring.

For each of these assessment categories, criteria were formulated to address the specific requirements of a national REDD+ monitoring system and indicators were developed to assess the current capacities and specific challenges with respect to REDD+ monitoring (UNFCCC, 2009a, 2010; IPCC, 2006; GOFC-GOLD, 2010). The analysis was performed in a transparent and consistent way. Table 1 lists the four categories and indicators in relation to the criteria, and the data sources that were used to gather information for each indicator. The indicators were evaluated for each country according to specific characteristics and subsequently each indicator received a score. The table in Appendix A contains the indicator scores for all countries. Different indicators could receive a different highest score, depending on the importance of the indicator for this study. The ‘monitoring capacities’ for example, have a highest value of 4, because this is the basis of the monitoring system, while the indicator ‘topography’ has a highest value of 0.5, because this is of less relevance.

Main focus is on addressing the capacities to monitor deforestation. The issue of degradation is partially covered by variables such as ‘‘forest area affected by fire’’, ‘‘cloud coverage’’ and data coming from the FAO FRA. However, due to lack of global datasets addressing degradation, it was not possible to include it as separate factor in the global comparison.

The capacity gap was determined by adding up the indicator values of assessment categories ‘‘national engagement of a country in the REDD+ process’’ and ‘‘existing monitoring capacities for measurement of forest cover and carbon stock changes’’ and thereby subtracting the indicator values of assessment categories ‘‘challenges that countries face in the REDD+ process’’ and ‘‘remote sensing technical challenges’’, as indicated in Fig. 1. Assessment categories 1 and 2 received a positive score, because they represent the current capacities in place; assessment categories 3 and 4 received a negative score, because the challenges create extra obstacles for having a full monitoring system in place which is appropriate under their national circumstances. For this analysis both qualitative and quantitative data sources were

Table 1 – Overview of assessment categories and indicators in relation to the criteria for developing a robust national REDD+ monitoring system, the data sources that were used to gather information for each indicator and the scoring system used for valuing the indicators.

Assessment category	Criteria	Indicator	Data sources	Characteristic	Indicator value	Score
National engagement	Understanding of international UNFCCC negotiations and REDD process	Level of engagement in UNFCCC REDD process	UNFCCC Country Submissions for REDD; UNFCCC Country National Communications; FCPF R-PIN	No documented interaction or only a National Communication (NC)	Low	0
				NC and/or at least one REDD submission	Medium	0.5
				NC and at least one REDD submission and R-PIN/R-PP available	High	1
	Understanding of IPCC guidelines for reporting	Completeness of national UNFCCC reporting on GHG inventory	Note by UNFCCC Secretariat on financial support provided by the Global Environment Facility for the preparation of national communications (UNFCCC, 2008a)	<50%	Low	0
				50–99%	Medium	0.5
				100%	High	1
Existing monitoring capacities	Forest area change monitoring capacity	Forest area change time series and remote sensing capacities	Country Reports for FAO FRA 2005 and 2010	No forest cover map	Low	0
				One forest cover map (external)	Limited	1
				Multiple forest cover maps (external)	Intermediate	2
				One or more forest cover maps (in-country), most recent before 2000 for the 2005 assessment/most recent before 2005 for the 2010 assessment	Good	3
				Multiple forest cover maps (in-country), most recent after 2000 for the 2005 assessment/most recent after 2005 for the 2010 assessment	Very good	4
	Carbon stock assessment	Forest inventory capacity on growing stock and/or biomass	Country Reports for FAO FRA 2005 and 2010	No forest inventory	Low	0
				One forest inventory (external)	Limited	1
				Multiple forest inventories (external)	Intermediate	2

				One or more forest inventories (in-country), most recent before 2000 for the 2005 assessment/ most recent before 2005 for the 2010 assessment	Good	3
				Multiple forest inventories (in-country), most recent after 2000 for the 2005 assessment/ most recent after 2005 for the 2010 assessment	Very good	4
		Reporting on carbon for different pools	Country Reports for FAO FRA 2005 and 2010	No reported carbon stocks	Low	0
				Aboveground biomass (AGB) reported (using Tier 1)	Limited	1
				Minimum AGB and soil reported (using Tier 1)	Intermediate	2
				AGB reported (using Tier 2)	Good	3
				Various carbon pools reported (using Tier 2)	Very good	4
REDD challenges	Addressing challenges for national REDD actions and monitoring	Area affected by fire (in forests) on annual average 2000–2008	GLOBCARBON Burnt Area Estimates (Plummer et al., 2008)	Probability of fire in the country = 0%	Low	0
				Probability of fire in the country >0% and/or probability of forest fire = 1–10%	Medium	0.5
				Probability of forest fire >10%	High	1
		Proportion of forest area with tree canopy cover >40% with high soil carbon content (>15 $kg/m^2/m$)	Organic carbon pool ($kg/m^2/m$) – Subsoil (FAO, 2007)	0%	Low	0
				1–20%	Medium	0.5
				>20%	High	1
		Proportion of forest area with tree canopy cover >40% with high (above- and belowground) carbon stock (>125 t/ha)	IPCC Tier-1 above ground and below ground Global Biomass Carbon Map for the year 2000 (Ruesch and Gibbs, 2008)	0%	Low	0
				1–50%	Medium	0.5
				>50%	High	1
		Deforestation hotspots	MODIS Vegetation Continuous Field (VCF) Product 2001 (Hansen et al., 2006); MODIS VCF Hot-Spots, 2000–2005 (Hansen et al., 2008)	Proportion of forest area <1%	Low	0
				Proportion of forest area >1%	High	1
Remote sensing technical challenges	Addressing remote sensing technical challenges for annual monitoring	Annual cloud coverage probability	MODIS M3 Product (Cloud Fraction Mean) and EECRA (Extended Edited Cloud Report Archive)	0%	Low	0
				1–50%	Medium	0.5

Table 1 (*Continued*)

Assessment category	Criteria	Indicator	Data sources	Characteristic	Indicator value	Score
		Seasonality: average dynamic of cloud cover (variations) within a year	MODIS M3 Product (Cloud Fraction Mean) and EECRA (Extended Edited Cloud Report Archive)	>50%	High	1
				<10%	Low	0
		Topography: percentage of country with slope >10°	SRTM (Shuttle Radar Topography Mission) and FAO Elevation Product	>10%	High	0.5
				<10%	Low	0
		Data access: average internet download speed	Broadband internet speed (http://www.speedtest.net)	>10%	High	0.5
				<500 kb/s	Low	1
				500–2000 kb/s	Medium	0.5
				>2000 kb/s	High	0
		Data availability: percentage of country covered by Landsat 5	Coverage of Landsat 5 and CBERS receiving stations	<80%	Low	1
				>80%	High	0

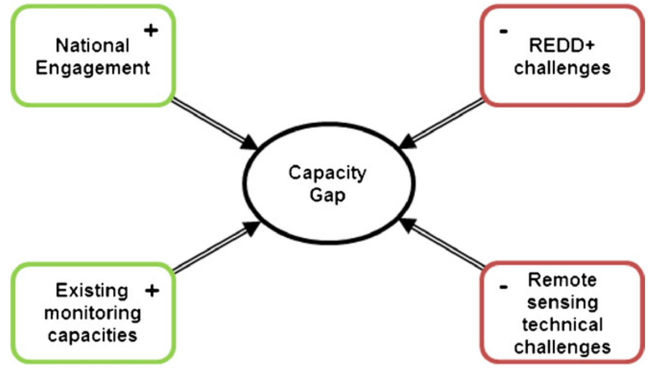

Fig. 1 – Conceptual figure for determining the capacity gap for countries to develop a national REDD+ monitoring system. Indicators used for assessment categories 1 and 2 (national engagement and existing monitoring capacities) contribute positively and indicators used for assessment categories 3 and 4 (REDD+ and RS technical challenges) contribute negatively to the final score.

used, therefore the outcomes were determined on an ordinal scale and in this way it was possible to compare the 99 countries in terms of gap in current monitoring capacities under specific country circumstances. If a country has large capacity and no challenges, this results in a very small capacity gap. When capacities are low, this increases the gap in capacities and if a country has additional challenges for monitoring, this increases the capacity gap even more.

The capacity gap was calculated using the following formula:

$$\begin{aligned}\text{Capacity gap} = {} & \left(\sum(\text{indicator scores of category 1})\right.\\ & \left.+\sum(\text{indicator scores of category 2})\right)\\ & -\left(\sum(\text{indicator scores of category 3})\right.\\ & \left.+\sum(\text{indicator scores of category 4})\right) \qquad (2)\end{aligned}$$

The highest possible score that could be obtained by a country is 14, the lowest possible score is −8. Countries were assigned to one of five categories based on the final score: <1 very large gap; 1–3 large gap; 3–5 medium gap; 5–7 small gap; >7 very small gap.

Additionally, a separate analysis was made for the changes in monitoring capacities (assessment category 2) between 2005 and 2010 based on the information from the FAO/FRA country reports (FAO, 2006, 2010). Information on forest area change monitoring capacity, on forest inventory capacity and on carbon reporting capacity was extracted from different sections in the reports. The same criteria were used to assess the capacities for the years 2005 and 2010 (see Table 1), which makes the results for both years comparable. The change in capacities was calculated as the difference in indicator scores between 2010 and 2005. One note has to be made that countries can have a different point of departure, so countries which already have very good monitoring capacities in 2005 may not show improvements in 2010. But countries which have very weak monitoring capacities in 2005 may show improvements if they established some basic capacities.

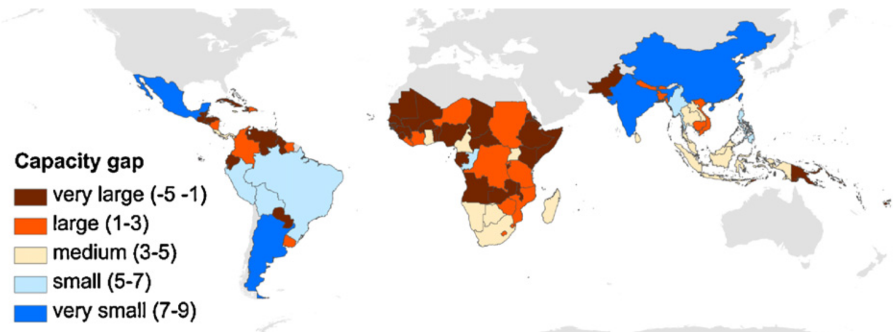

Fig. 2 – Spatial distribution of the capacity gap for 99 tropical non-Annex I countries. The outcomes have been derived by adding up the indicator scores for the assessment categories 1 and 2 (national engagement and existing monitoring capacities) and then subtracting the scores for the assessment categories 3 and 4 (REDD+ and remote sensing technical challenges).

3. Results

3.1. *Capacity for implementing a national forest monitoring system for REDD+*

This study highlights that the majority of countries lack capacity to implement a complete and accurate national monitoring system to measure the success of REDD+ implementation using the IPCC GPG for national GHGs inventories, based on REDD+ implementation Phase III. The characteristics as well as the size of the capacity gap varies for each country. Fig. 2 shows the spatial distribution of the capacity gap for the 99 tropical non-Annex I countries. Forty nine countries have a very large capacity gap, twenty three countries a large gap, seventeen countries a medium gap and only six countries a small and four countries a very small capacity gap. All 99 countries have a different deforestation rate and are in a different stage of forest transition. In Fig. 3, the capacity gap is expressed in relation to the net change in forest area for the time period of 2005–2010. Countries with a very small capacity gap show an increase in total forest area with 2513 ha × 1000 ha, while countries with larger capacity gaps have a net loss of total forest area of 8299 ha × 1000 ha.

Some countries like Mexico and India are in an advanced stage and already have good to very good capacities for measuring forest area change and performing a regular national forest inventory on growing stock and forest biomass. In Africa on the contrary, largest capacity gaps are found, because there is limited engagement in the REDD+ process and development of overall monitoring capacities is still in an early stage. Moreover, African countries face considerable REDD+ and remote sensing technical challenges (summarized in Appendix A). Most South American and Asian countries have a small to medium capacity gap. Their engagement in the UNFCCC REDD+ process and experience in GHG reporting is relatively high. Most of these countries also have quite good forest area change monitoring capacities, but for many countries the capacity to estimate changes in carbon pools is still rather limited.

Table 2 summarizes the capacities of the countries to monitor forest area change and to perform forest inventories based on the analysis of FAO FRA 2010 data. Time series of remote sensing data contain repeated measurements on forest area which enables to track changes. Forest inventories provide the data on growing stock and biomass which are necessary for calculating carbon stock and changes in the forest area. For most countries capacities are better developed to monitor forest area change (fifteen countries scored "very good") than to perform forest inventories (only seven countries scored "very good"). Forty eight of the 99 countries have none, limited or some existing capacities for both elements and require the development of basic capacities. Only nineteen countries have good to very good capacities for both indicators and need no or little improvement on their existing monitoring capacities.

3.2. *Recent changes in monitoring capacities*

In Fig. 4, the changes in capacities between FAO FRA 2005 and 2010 reporting for forest area change monitoring (a),

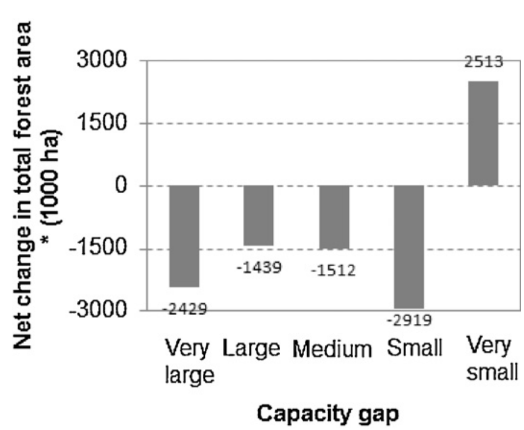

Fig. 3 – Capacity gap in relation to the net change in total forest area between 2005 and 2010 (based on FAO/FRA forest area statistics), summarized for all countries that fall into each capacity gap category.

Table 2 – Country capacities for forest area change monitoring and for performing a forest inventory, summarized for all 99 studied countries, based on the FAO/FRA country reports from 2010. The numbers in table refer to the number of countries in that category.

		Forest area change monitoring (RS) capacities					
		None	Limited	Intermediate	Good	Very good	Sum
Forest inventory capacities	None	10	2	4	8	0	24
	Limited	17	4	3	4	3	31
	Intermediate	4	1	3	3	2	13
	Good	3	6	2	9	5	24
	Very good	0	0	1	1	4	7
	Sum	34	13	13	24	15	99

performing forest inventories (b) and carbon pool reporting (c) are visualized. Most improvements, however modest, can be seen in African countries, where the overall monitoring capacities were not very well developed in 2005. Throughout all tropical countries, improvements can be specifically observed in carbon pool reporting capacity. This usually implies that in 2005 countries had no carbon pool reporting at all, or only reported on carbon in above ground biomass using default (Tier 1) IPCC values and in 2010 reported at least on both above ground biomass and soil (still at Tier 1 level). In African and South and Central American countries there are some improvements in forest inventory capacities. This is because countries perform forest inventories on a more regular basis or they now have a national authority that performs the forest

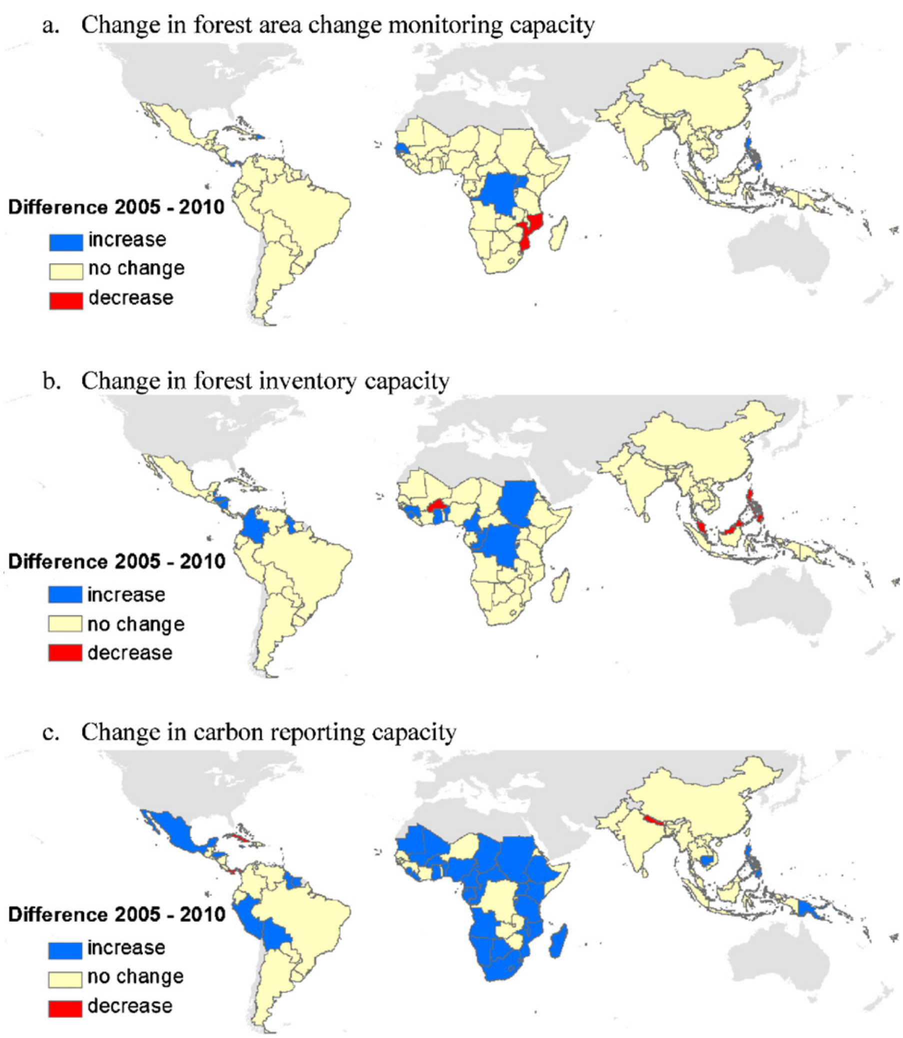

Fig. 4 – Change in capacities based on the difference between FAO/FRA 2005 and 2010 reporting for (a) monitoring forest area change, (b) performing a forest inventory and (c) reporting on the five different forest carbon pools.

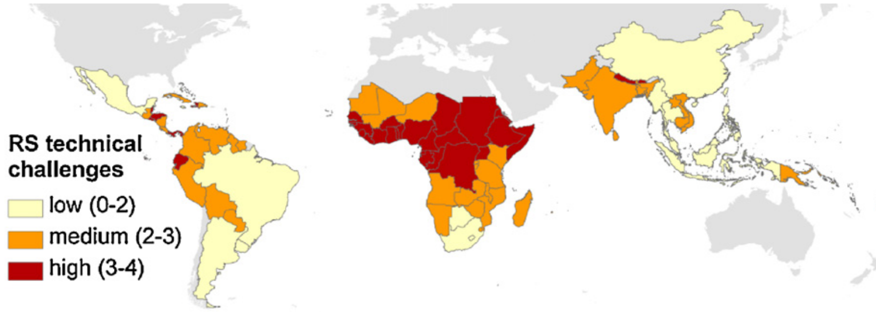

Fig. 5 – Remote sensing technical challenges summarized for each country. The outcomes have been derived by adding up the indicator scores of the 5 RS technical challenges (see Table 1).

inventory instead of external researchers. For forest area change monitoring capacity, not many improvements can be observed. Remote sensing capacities and the intensity of the use of time series data for forest area change have mostly remained the same over the last five years. A decrease in monitoring capacities can be observed in a few countries, which in some cases is due to the internal political situation. Thus, unstable conditions or other factors may actually decrease national monitoring and reporting capacity in the future and may jeopardize REDD+ implementation in some regions.

3.3. *The use of remote sensing for a national REDD+ monitoring system*

Basic technical capacities like a suitable internet connection (to regularly download large images datasets) and the availability of remote sensing data are essential for designing a remote sensing based monitoring system. Many countries however, have technical difficulties with implementing a national monitoring system. The technical challenges are summarized in Fig. 5. Cloud cover and seasonality (variations in cloud cover) form a technical challenge for the use of optical remote sensing instruments throughout all tropical countries. Mountainous countries like Ecuador and Peru have large variations in altitude which also creates a technical challenge for analyzing satellite images. Topographic effects occur in satellite images because of differences in terrain orientation, which causes variation in radiance (Wen et al., 2008), so more advanced data analysis techniques are required to analyze these images. Especially in African countries, internet speed (and access to data) and coverage with Landsat TM data is more limited than elsewhere, which is an obstacle for creating a consistent monitoring system based on remote sensing data. Technical support is needed to set up and improve a remote sensing based monitoring system for REDD+.

Table 3 shows the relation between the countries' current forest area change monitoring capacities and the remote sensing technical challenges, summarized from the indicators that were used for this assessment category. Thirty eight countries have considerable remote sensing technical challenges. The seventeen countries which are located in the upper right corner of table (low capacities and high remote sensing technical challenges) have to improve their monitoring capacities significantly, thereby taking the technical challenges into account when using remote sensing for the monitoring task. There are examples on how to deal with such challenges among the twelve countries with good and the single country with very good forest area change monitoring capacity and large amounts of remote sensing technical challenges and these countries could learn from each other.

Many countries have considerable REDD+ challenges (assessment category 3) and need special attention for monitoring of the specific vulnerable areas. An example of this is the forests that contain high amounts of carbon in the soil, which may potentially emit large quantities of carbon into the atmosphere, when they are deforested. Fig. 6 shows the

Table 3 – Current capacities for countries to monitor forest area change in relation to the remote sensing technical challenges. The score for the remote sensing technical challenges has been derived by adding up the indicator scores for the five RS technical challenges, using the categories low (0–2), medium (2–3), high (3–4). The numbers in table refer to the number of countries in that category.

		Remote sensing technical challenges			
		Low	Medium	High	Sum
Forest area change monitoring capacity	Low	2	14	17	33
	Limited	0	11	3	14
	Intermediate	1	7	5	13
	Good	8	6	12	26
	Very good	6	6	1	13
	Sum	17	44	38	99

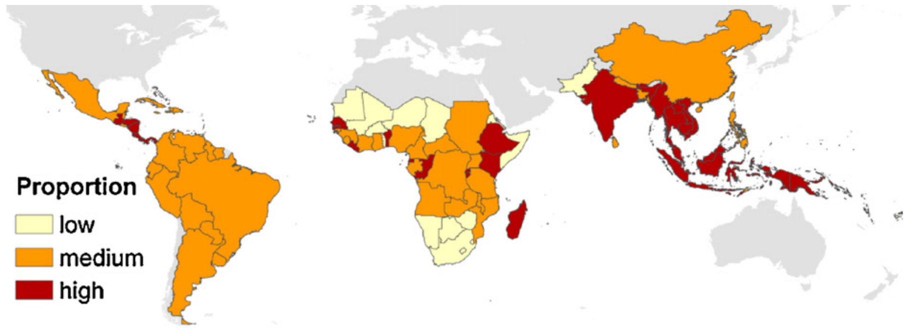

Fig. 6 – Proportion of forest (with VCF tree cover >40%) with high soil carbon content (>15 kg/m^2/m).

forest areas with a percentage of tree canopy cover >40%, derived from the MODIS VCF product (Hansen et al., 2006), that contain a high amount of soil carbon (>15 kg/m^2/m) (FAO, 2007). Large quantities of soil carbon can be found in Southeast Asia, particularly in tropical peat swamps.

4. Discussion

4.1. *Bridging the capacity gap*

Only four countries have a very small capacity gap and likewise four countries have very good capacities for both forest area change monitoring and for performing forest inventories (see Table 2), while forty eight countries have none to intermediate capacities for these two issues. This indicates the need for large capacity building efforts in order to bridge the current gap in capacities if REDD+ is actually going to be a performance based mechanism. Capacity building efforts should result in consistent REDD+ monitoring systems that are able to report on carbon stocks and changes in compliance with the five IPCC principles of consistency, transparency, comparability, completeness and accuracy (IPCC, 2006). The gap in monitoring capacities that becomes apparent from this study can be summarized according to these reporting principles:

- *Consistency*: In many countries, carbon estimations are based either on single-date measurements or on integrating heterogeneous data sources (FAO, 2006, 2010), rather than using a systematic and consistent measurement and monitoring approach;
- *Transparency*: Lack of transparency can be expected because estimates are often based on expert opinions, independent assessments or model estimations without a proper description of the information sources used to produce forest carbon data (FAO, 2006, 2010);
- *Comparability*: Few countries have experience in using the IPCC (2006) Revised National GHG Accounting Guidelines for the land-use sector or at higher Tiers to monitor land use and land use change and estimate GHG emissions (FAO, 2006, 2010; UNFCCC, 2008a). It is necessary to use common methodologies and guidance to produce comparable results;
- *Completeness*: In many countries there is a lack of suitable data for measuring and monitoring forest area change and changes in carbon stocks. Carbon stock data for above ground and below ground biomass are often based on estimations or conversions using IPCC default data (Tier 1) and very few countries are able to provide information on all five carbon pools or estimates from biomass burning (FAO, 2006, 2010; UNFCCC, 2008a). Reporting on other GHGs like N_2O or CH_4 are also often based on Tier 1 defaults or completely ignored;
- *Accuracy*: There is limited information on error sources and levels of uncertainty of the estimates provided by countries, as well as approaches to analyze, reduce, and deal with them in international reporting (FAO, 2006, 2010).

The fact that no large improvements in monitoring capacities could be seen from the FAO FRA 2005–2010 reporting suggests that current REDD+ capacity building efforts have not had major impact on national reporting to the UN-FAO. It should be noted that the data used to report under FRA are usually reflecting the country status of 2–3 years before, i.e., the capacities reported for 2010 are actually representing the country capacities of 2007–2008 and thus do not allow for assessing an actual ‘‘REDD effect’’ for the FRA. The monitoring capacity building activities are essential and the international community needs to commit the human and financial resources to address these gaps if this situation is to change.

In terms of net changes in forest area, the four countries with very good capacities (very small capacity gap) show an increase in total forest area over the years 2005–2010, mainly because of China's large-scale afforestation program. The data reported for these four countries (China, India, Mexico and Argentina) can be perceived as very certain because of the good monitoring capacities. The forest area change data for the countries with large capacity gaps have more uncertainty in the data, because these countries use less accurate data and methods and it is less well known how they monitor their forest area and carbon stock changes.

4.2. *The use of remote sensing under specific country circumstances*

National forest monitoring systems for REDD+ need to be designed in such a way that it is suitable for the national circumstances of each participating country (UNFCCC, 2010). Each country has a different situation with respect to the amount of forest left, the rate of deforestation and the deforestation threats, and therefore needs to design a monitoring system to tackle its particular REDD+ challenges. In this study, various REDD+ challenges were taken into account when defining the capacity gap.

Many tropical countries have the problem of forest fires, which causes a large amount of carbon emissions to the atmosphere. For adequate fire monitoring, combined moderate resolution and high resolution remote sensing imagery, which includes shortwave infrared, mid-infrared and thermal infrared spectral bands is very suitable for mapping active fires and burned areas from space and, combined with ground data on emission factors, should be considered while designing the REDD+ monitoring system (GOFC-GOLD, 2010; Lentile et al., 2006).

Special attention should be paid to monitor the areas that are vulnerable for deforestation and are significant sources of carbon; for these areas, higher Tier levels are required to report on GHG emissions (IPCC, 2006). An important example of this is the tropical peatland ecosystems in Southeast Asia, which are rapidly being converted into oil palm or pulpwood plantations (Murdiyarso et al., 2010). Deforestation and drainage for agriculture or plantations cause large emissions of CO_2 the atmosphere (Hirano et al., 2009; Hergoualc'h and Verchot, 2011). It is important to use higher resolution activity data to be able to report at Tier 2 or 3 levels (Havermann, 2009).

When using remote sensing for monitoring, at a minimum a time series of Landsat images (medium resolution) should be analyzed for national deforestation monitoring (Herold and Johns, 2007). Radar data could be used to complement optical data in environments with persistent cloud cover, because long-wavelength microwaves are able to penetrate the clouds. However, this approach is still in the research and development phase and is not yet operational on a large scale (GOFC-GOLD, 2010). In order to use remote sensing in mountainous areas, the topographic effects in satellite images need to be removed. This can be done by using a model for topographic correction and land surface reflectance estimation for optical remote sensing data, however this is also still in the research and development stage in the remote sensing field (Wen et al., 2008). Therefore, remote sensing is very promising for national level monitoring of forest area change, but under particular national circumstances support for research is still needed to solve technical challenges in order to use remote sensing in an operational way.

4.3. *Recommendations for the international community*

The UNFCCC encourages countries to collectively aim to slow, halt and reverse forest cover and carbon loss, by making efforts on capacity building and technology development and transfer among countries (UNFCCC, 2010). International efforts and activities could improve satellite data coverage through investing in better data access mechanisms in particular in Central Africa and Central America. For small countries, sharing regional capacity for forest area change and carbon stock assessments is an option. There are, however, extra costs involved in establishing regional cooperation, so efforts should build upon existing networks where possible. The cost of accessing, processing and analyzing remote sensing data though, can be reduced through a regional approach. This will ensure efficient use of resources and overcome challenges such as persistent cloud cover, data access limitations and lack of pre-processed data for annual coverage. Some non-Annex I countries (i.e., India, Brazil and Mexico) have suitable capacities and long experience in forest inventories and monitoring and could have an important role in regional cooperation and south-south exchanges to support capacity development. Through South-South cooperation, experts from a non-Annex I country with rich expertise in scientific and other best practices share their experiences with experts from other non-Annex I countries, and train them on how to implement these practices. For example, countries that have similar REDD+ or remote sensing technical challenges (e.g., high occurrence of forest fire or large areas with steep topography), but different monitoring capacities could exchange insights and skills on how to monitor under these particular national circumstances. REDD+ on itself will not provide enough incentives for countries to improve their monitoring systems. Therefore it is important to take into account the co-benefits of REDD+ like ecosystem services and improving livelihood of local people in order to get enough revenues.

As indicated before, capacities are less well established for carbon stock measurement than for forest area change monitoring. Further research and capacity building efforts are required to properly address the issues of measuring carbon stocks and carbon stock changes, in compliance with the UNFCCC and IPCC requirements. Most countries have forest research organizations that could be mobilized with international support to develop better emission factors for improved accounting.

4.4. *Some issues remaining*

In this study we mainly used indicators which address the issue of avoided deforestation (RED). REDD+, however, also comprises avoided degradation, afforestation, forest management and other forestry activities. The study relies on open access global datasets, which are available to address deforestation, but only to a limited extent for the other activities under REDD+. Afforestation and degradation are partially covered by assessment category two, for which the data source is FAO FRA reporting. Data on forest area changes which are net changes include afforestation and deforestation activities and carbon stock assessments include deforested and degraded areas. Challenges remain the same for both deforestation and degradation monitoring, e.g., cloud cover is an issue for remote sensing monitoring of both activities. The indicator "forest area affected by fire" also refers partially to degradation, because forest fire may cause deforestation as well as degradation depending on the strength and scale of the fire. With use of open access global datasets, it was not possible to include monitoring degradation as a separate indicator in the analysis. For this, more detailed information is needed, depending on the type of degradation, on for example availability of high resolution remote sensing data, availability of field data and other indicators (e.g., road networks) that indirectly refer to degraded areas (Herold et al., 2011).

In this paper we argue that low indicator scores may result from lack of data, capacities and access to technologies. However, for some of the indicators used in this study (e.g., completeness of national UNFCCC reporting on GHG inventory, or FAO FRA reporting) political will, governance and functioning institutions are also important factors. Lack of governance and dis-functioning institutions may result in incomplete reporting. This aspect is not covered by this study, because the purpose of our study was to make a descriptive analysis and not to go into details about what exactly causes the gap in capacities. It would be an interesting follow up research to investigate this.

5. Conclusions

The majority of countries have limitations in providing complete and accurate estimates of forest loss and GHG emissions. Forty nine of the 99 countries have a very large capacity gap, while only four countries have a very small capacity gap and have sufficient means to monitor their forest cover and carbon stock changes according to REDD+ implementing Phase III. The existing capacity gap differs in size and characteristics between the 99 studied tropical non-Annex I countries. In general, capacities are less well established for carbon stock measurement (seven countries scored "very good") than for measuring forest area change (fifteen countries scored "very good"). Further research and capacity building efforts are required to properly address the issues of measuring carbon stocks and carbon stock changes. Very little forest carbon monitoring capacity improvements were reported in for FAO/FRA reporting, but there is some sign of progress in African countries.

The four countries with a small capacity gap and very good monitoring capabilities show a net increase in forest area with a total of 2513 ha × 1000 ha. Their monitoring systems are well established and the data are reliable. The countries with larger capacity gaps have a net loss of forest area (total of 8299 ha × 1000 ha). This number is more uncertain, because their monitoring capacities are lower. Capacity building will result in reporting of better quality data.

Considering REDD+ monitoring requirements and existing capacities of the eighty nine out of 99 countries with a very large to medium capacity gap, there is need to take immediate action. Countries that are providing support for REDD+ as a performance based mechanism need to have realistic expectations of what developing countries can reasonably do in this area and they need to consider monitoring capacity building as part of their investment commitments. Capacity building activities should be designed taking into account the different starting points and national circumstances of the countries and work towards a minimum level of monitoring capacity to be able to report on forest carbon stocks and emissions to the UNFCCC.

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Appendix A. Indicator scores for all 99 tropical non-Annex I countries

This table contains all individual indicator scores for national engagement (category 1) and monitoring capacities (category 2), the scores for REDD+ challenges (category 3) "Forest area affected by fire" and "proportion of forest area with high soil carbon content" and the summarized scores for the RS technical challenges (category 4).

Country	Engagement in the UNFCCC REDD process	Completeness of GHG inventory	Forest area change monitoring capacity	Forest inventory capacity	Carbon pool reporting capacity	Forest area affected by fire	Proportion of forest area with high soil carbon content	RS technical challenges (summarized)
Angola	Low	Low	Low	Limited	Intermediate	Medium	Medium	Medium
Antigua and Barbuda	Low	Low	Low	Low	Low	Low	High	Medium
Argentina	High	High	Good	Good	Intermediate	Medium	Medium	Low
Bahamas	Low	Medium	Low	Limited	Low	Low	Medium	Low
Bangladesh	Low	Low	Limited	Very good	Limited	Low	Medium	Medium
Belize	Medium	High	Good	Limited	Limited	Low	Medium	High
Benin	Low	Low	Limited	Intermediate	Intermediate	Medium	High	High
Bhutan	Low	Low	Intermediate	Good	Intermediate	Medium	High	High
Bolivia	High	Medium	Very good	Good	Intermediate	Medium	Medium	Medium
Botswana	Low	Medium	Good	Limited	Intermediate	High	Low	Low
Brazil	Medium	Medium	Very good	Intermediate	Very good	Medium	Medium	Low
Burkina Faso	Low	Medium	Low	Limited	Intermediate	Medium	Low	High
Burundi	Low	High	Low	Intermediate	Intermediate	Medium	High	Medium

Cambodia	High	Medium	Very good	Limited	Intermediate	Medium	High	Medium
Cameroon	High	Low	Intermediate	Very good	Intermediate	Medium	Medium	High
Cape Verde	Low	Low	Low	Limited	Intermediate	Low	Low	High
Central African Republic	High	Low	Low	Limited	Intermediate	High	Medium	High
Chad	Medium	Low	Low	Limited	Intermediate	High	Low	High
China	Low	Low	Very good	Very good	Limited	Medium	Medium	Low
Colombia	High	Medium	Very good	Limited	Limited	Medium	Medium	Medium
Comoros	Low	Low	Limited	Good	Intermediate	Low	Medium	Medium
Congo	High	High	Good	Very good	Intermediate	Medium	High	High
Costa Rica	High	High	Very good	Limited	Limited	Low	High	Medium
Côte d'Ivoire	Low	High	Good	Intermediate	Intermediate	Medium	Medium	High
Cuba	Low	Low	Low	Good	Limited	Low	Medium	Medium
Democratic Republic of the Congo	High	Medium	Good	Intermediate	Intermediate	Medium	Medium	High
Dominica	Low	Medium	Low	Low	Low	Low	High	High
Dominican Republic	Medium	High	Good	Low	Limited	Low	Medium	Medium
Ecuador	Medium	Medium	Good	Low	Low	Medium	Medium	High
El Salvador	High	Low	Good	Low	Low	Low	Medium	High
Equatorial Guinea	High	Low	Low	Limited	Intermediate	Low	High	High
Eritrea	Low	Medium	Low	Low	Low	Medium	Low	High
Ethiopia	High	Low	Good	Low	Intermediate	High	High	High
Fiji	Medium	Low	Low	Low	Low	Low	Low	High
Gabon	High	Low	Low	Limited	Intermediate	Medium	Medium	High
Gambia	Low	High	Limited	Limited	Intermediate	Medium	High	Medium
Ghana	High	Medium	Good	Intermediate	Intermediate	Medium	Medium	High
Guatemala	High	Low	Very good	Limited	Limited	Medium	High	Medium
Guinea	Low	Low	Low	Intermediate	Limited	Medium	Medium	High
Guinea-Bissau	Low	High	Intermediate	Low	Limited	Medium	Medium	High
Guyana	High	Low	Low	Limited	Intermediate	Low	Medium	Medium
Haiti	Low	Medium	Low	Low	Intermediate	Low	Medium	High
Honduras	High	High	Low	Limited	Limited	Low	High	High
India	Medium	Low	Very good	Very good	Very good	Medium	High	Medium
Indonesia	High	Medium	Very good	Good	Limited	Medium	High	Low
Jamaica	Low	High	Good	Limited	Intermediate	Low	Medium	Low
Kenya	High	Medium	Low	Limited	Intermediate	Medium	High	Medium
Lao People's Democratic Republic	High	Low	Good	Good	Limited	Low	High	Medium
Lesotho	Medium	Medium	Intermediate	Low	Intermediate	High	Low	Low
Liberia	High	High	Intermediate	Limited	Intermediate	Low	High	High
Madagascar	High	High	Intermediate	Good	Intermediate	Medium	High	Medium
Malawi	Low	Low	Limited	Limited	Intermediate	Medium	Medium	Medium
Malaysia	Medium	Medium	Very good	Good	Limited	Medium	High	Low
Mali	Low	Low	Low	Intermediate	Intermediate	High	Low	Medium
Mauritania	Low	High	Low	Limited	Intermediate	Medium	Low	Medium
Mauritius	Low	Low	Low	Limited	Intermediate	Low	Low	Medium
Mexico	High	High	Very good	Very good	Intermediate	Medium	Medium	Low
Micronesia	Low	Low	Good	Intermediate	Limited	Low	Low	High
Mozambique	High	Medium	Limited	Limited	Intermediate	Medium	Medium	Medium
Myanmar	Low	Low	Very good	Very good	Limited	Medium	High	Low

Appendix A (*Continued*)

Namibia	Low	Medium	Limited	Good	Intermediate	Medium	Low	Medium
Nepal	High	Low	Good	Good	Limited	High	Medium	High
Nicaragua	High	High	Good	Good	Limited	Medium	High	Medium
Niger	Low	Medium	Low	Intermediate	Intermediate	Medium	Low	Medium
Nigeria	Low	Low	Low	Limited	Intermediate	Medium	Medium	High
Pakistan	Low	Low	Low	Limited	Limited	Medium	Low	Medium
Palau	Low	Medium	Intermediate	Intermediate	Limited	Low	Low	Medium
Panama	High	Medium	Very good	Good	Limited	Low	High	High
Papua New Guinea	High	Low	Intermediate	Intermediate	Limited	Medium	High	Medium
Paraguay	High	Medium	Intermediate	Low	Low	Medium	Medium	Medium
Peru	High	Medium	Very good	Good	Intermediate	Medium	Medium	Medium
Philippines	Low	Low	Good	Good	Intermediate	Medium	Medium	Low
Rwanda	Low	Medium	Low	Good	Intermediate	Medium	High	Medium
Saint Lucia	Low	High	Intermediate	Low	Low	Low	Low	Medium
Saint Vincent and the Grenadines	Low	Low	Limited	Low	Low	Low	Low	Medium
Samoa	Medium	High	Good	Low	Low	Low	Low	High
Sao Tome and Principe	Low	Low	Low	Low	Intermediate	Low	Low	High
Senegal	Low	Medium	Limited	Good	Limited	Medium	High	High
Sierra Leone	Medium	Low	Low	Limited	Intermediate	Medium	Medium	High
Singapore	Low	Low	Low	Low	Low	Low	Low	Low
Solomon Islands	Medium	Low	Low	Limited	Limited	Low	Low	Medium
Somalia	Low	Low	Low	Low	Limited	Medium	Low	High
South Africa	Medium	Medium	Good	Low	Intermediate	Medium	Low	Low
Sri Lanka	Medium	Low	Good	Good	Limited	Low	Medium	Medium
Sudan	Low	Low	Intermediate	Intermediate	Intermediate	Medium	Medium	High
Suriname	High	Low	Limited	Good	Intermediate	Medium	Medium	Medium
Swaziland	Low	Low	Limited	Good	Intermediate	Medium	Low	Medium
Thailand	High	Low	Good	Good	Limited	Medium	High	Low
Timor-Leste	Low	Low	Good	Low	Low	Low	Medium	Low
Togo	Low	Low	Low	Low	Low	Medium	Low	High
Trinidad and Tobago	Low	Medium	Good	Good	Intermediate	Low	Low	Medium
Uganda	High	Low	Good	Good	Intermediate	High	Medium	High
United Republic of Tanzania	High	Medium	Intermediate	Limited	Intermediate	High	Medium	Medium
Uruguay	Medium	Medium	Good	Low	Low	Low	Medium	Low
Vanuatu	High	Low	Limited	Low	Low	Low	High	High
Venezuela	Low	Low	Low	Low	Low	Medium	Medium	Medium
Viet Nam	High	Medium	Limited	Good	Intermediate	Medium	High	Medium
Zambia	Low	Low	Limited	Limited	Limited	High	Medium	Medium
Zimbabwe	Low	Medium	Intermediate	Limited	Limited	Medium	Low	Medium

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