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Land Area Eligible for Afforestation and Reforestation within the Clean Development Mechanism: A Global Analysis of the Impact of Forest Definition

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Abstract Within the United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol, countries have significant latitude to define a forest. The most important parameter affecting area designated as forest is the minimum crown cover which can be set between 10 and 30%. The choice will have implications for the amount of land available in a country for afforestation and reforestation activities within the Clean Development Mechanism (CDM-AR). In this paper, we present an analysis of the regional differences in land availability for CDM-AR projects. We then examine how the choice of a high or low threshold value for crown cover will affect the area available for CDM activities and how the limitations imposed by this element of the definition compares to other factors that are likely to limit CDM activities. Results represent a global analysis that included all countries not included in Annex I of the Kyoto Protocol, and examined the effect on land availability of a range of crown cover thresholds ranging from 10–30%. Of the 140 Non-Annex One countries, 107 countries were found to have a potential for CDM-AR projects. Asia had the largest amount of combined area suitable for CDM-AR at the 10% crown cover threshold level. However, at 30%, South America had the greatest amount of land available, and a large change in available land area, which increased by almost five times compared to what was available at the 10% threshold. The area available in Africa increased by a factor of 5.5. Central America showed the largest increase, to almost 10 times more at the 30% threshold. By contrast, within Asia, the area increase was

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comparatively less, but still the area nearly doubled. Globally, a low threshold of 10% crown cover excluded almost 2/3 of the land identified that was eligible at 30%, over 5 million km^2. The spatial analyses showed not only the effects of the choice of the crown cover criterion, but also where the land was available for CDM activities within each country at different thresholds. Protected areas account for 10–20% of the CDM-AR eligible area in most countries.

Keywords Afforestation/Reforestation · Carbon sequestration · Clean development mechanism · CDM-AR · Climate change mitigation · Forest definition · Land use land cover and forestry (LULUCF) · Land suitability modeling · Global spatial analysis

1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol established the Clean Development Mechanism (CDM), with the intention to reduce greenhouse gas emissions while assisting developing countries in achieving sustainable development, with the multiple goals of poverty reduction, environmental benefits and cost-effective emission reductions (Madlener et al. 2006). There is significant concern that the CDM will not live up to its promise to deliver development benefits while contributing to climate change mitigation. So far, only a few countries have benefited, but in large part the countries that are most vulnerable to climate change, in particular the Least Developed Countries (LDCs), are not seeing significant development benefits as a result of participation in the CDM (Cosbey et al. 2005). Recognizing that rural populations that depend upon subsistence agriculture are most vulnerable to climate change, land-use, land-use change and forestry (LULUCF) projects are gaining in acceptability as a means for reorienting the CDM to deliver development benefits to vulnerable populations (Robledo and Forner 2005).

During the first commitment period (2008–2012), the CDM allows for a small percentage of emission reduction credits to come from LULUCF projects, with only two types of LULUCF activities currently allowed: afforestation, which is the establishment of trees on land that has not had forest on it for more than 50 years; and reforestation, which is the establishment of trees on land that has had forest on it within the last 50 years, but is not currently forested (UNFCCC 2002a, b). In order to qualify as a CDM Afforestation/Reforestation (CDM-AR) eligible activity, reforestation is limited to ‘‘those lands that did not contain forest on 31 December 1989’’ (UNFCCC/CP/2001/13/Add.1) Since it is anticipated that most projects will involve reforestation (Dutschke 2002), proving that forest land was converted to non-forest land use before 1990 is an essential prerequisite.

Developing (or Non-Annex I) countries must provide a country-specific forest definition before they can host CDM-AR projects. Country-specific values for crown cover, minimum area, and tree height, must be decided upon from a range provided in the forest definition given in the Marrakech Accords (UNFCCC 2002a,b) of the Kyoto Protocol.

> ‘‘‘Forest’ is a minimum area of land of 0.05–1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10–30% with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist either of closed

> forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown cover of 10–30% or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.''

The selection of the forest definition is binding only for the first commitment period (2008–2012). However, only one set of parameters may be chosen, even for countries with very diverse ecosystems and biomes. Twenty-two Non-Annex I countries had reported their forest definitions as of February 1, 2007. The remaining countries should be anxious to report their definitions as soon as possible, if they wish to encourage CDM-AR projects, and to gain competitive advantage, as projects are now able to start at anytime.

Although at first sight the definition of forest may seem obvious, there are in fact many definitions of the term ''forest'' in use throughout the world (Lund 2002; Helms 2002). Because of the wide geographic distribution of forests, and the diversity in composition and structure of vegetation, forests are not always easily distinguished from other land cover types. In addition to the great diversity amongst the world's forests—from dry and sparse to moist and dense—definitions also vary because of differences in culture, forest use, societal dependence on forest products, and the stage of societal development (Helms 2002). In a number of fora, the definition of forest has become both a political as well as a technical issue (FAO 2004, 2005). Current existing national forest definitions, as reported to FAO (2000), were not found to be adequate for complying with CDM-AR rules (Neeff et al. 2006). For example, out of a 122 Non-Annex I countries which reported their definitions, forty-four used functional definitions only, referring to ecological zones, forest types and land use (Neeff et al. 2006). Only forty countries use at least one quantitative threshold in their national definition, while seventeen did not have a national forest definition.

The CDM-AR provisions acknowledge that forests are variable and permit national participation by allowing each country to set its own nationally relevant threshold values for the definition of forest. The CDM-AR provisions provide for significant latitude in the choice of these parameters. This flexibility allows countries to choose a definition that furthers national policy objectives, and to maximize, or to minimize, their potential for CDM-AR. It can determine to a large extent how much land is available, what kinds of projects may qualify, as well as significantly affect the estimate of currently forested area. Global forest area increased by 300 million ha, or approximately 10%, when FAO redefined forest between the 1990 and 2000 Forest Resource Assessments (Neeff et al. 2006). The choice of minimum crown cover is generally the major determinant, and is especially sensitive and problematic, with various tradeoffs for high and low choices. For example, many agricultural landscapes have a tree cover that exceeds 10%, and these could be eliminated from consideration with the choice of a low minimum threshold. For example, currently, the FAO uses a crown cover threshold of 10% for its definition. For the CDM, if the tree cover threshold is high, however, there is a risk of the CDM providing perverse incentives to convert natural ecosystems with relatively low tree cover to other forest-type land-use, e.g., plantations (Dutchke, 2002). Globally, there are over 290 Million ha land having a crown cover between 10% and 40% (FAO 2000).

In this paper, we present an analysis of the regional differences in land availability for CDM-AR projects worldwide. We examine how the choice of a higher or lower threshold value for crown cover will affect the area available for CDM activities and how the

limitations imposed by this element of the definition is likely to impact CDM activities regionally and nationally. Results represent a global analysis that included all Non-Annex One countries, and examine the effect on land availability of a range of minimum crown cover thresholds, ranging from 10 to 30%.

2 Methods and materials

2.1 Land suitability analysis

A geospatial analysis evaluated the effect of a range of minimum crown cover thresholds on the availability of land for CDM-AR, globally, regionally, and on a per country basis. The analysis is based on available global datasets and was performed using a spatial modeling procedure implemented in ArcGIS (ESRI Inc.) using ArcAML programming language. The following criteria were used to identify areas considered in this analysis as not suitable for CDM-AR:

- High elevation areas, above 3500 m and/or treeline (see Sect. 2.2)
- Dry areas with Aridity Index (AI) lower than the specified threshold AI < 0.65 (see Sect. 2.3)
- Areas classified as urban, water bodies, or various types of tundra.
- Areas classified as irrigated or under other intensive agricultural production, assuming that these areas are already in high value production, or their conversion may impact on food security.
- Recently deforested areas, that is, areas that are identified as forest in the USGS Ecosystem Land Characteristics Database (USGS 1993), as per guidelines that exclude recently deforested areas from being eligible.

Environmental and other global geospatial datasets used for the global analysis (spatial resolution: 500 m–1 km/15–30 arc-seconds) include:

- VMAP 1—Country Boundaries (NIMA 1997)
- Global Ecosystem Land Cover Characterization Database v. 2.0 (USGS 1993)
- MODIS Vegetation Continuous Field—Tree Cover (Hansen et al. 2003)
- SRTM Digital Elevation Model—Topography (USGS 2004)
- World Database on Protected Areas (WDPA Consortium 2004)
- WorldClim (Hijmans et al. 2004)
- MODIS12 v2—2001(Strahler et al. 1999)

A sinusoidal projection was used to calculate zonal statistics and carry out areal computations, as it represents area extent accurately across latitudes (i.e. equal-area projection). The cell size for analyses in sinusoidal projection is 500 m. For map display purposes, the dataset is presented in geographic coordinates. Areas meeting the various exclusion criteria were merged into one raster layer to produce a map delineating the areas that are unsuitable for CDM-AR, based upon biophysical condition, or due to its status as forest or recently deforested area. Water-bodies, urban areas and wetlands exclusion criteria were identified and extracted from the USGS Landuse Characteristics Database (USGS, 1993), as was the analysis of historical forest cover used to estimate the 1990 forest cover baseline, as per the eligibility criterion. In addition, the potential for CDM-AR within protected areas was evaluated based upon the IUCN/UNEP World Database of Protected Areas (WDPA Consortium 2004).

2.2 Upper elevation limits for CDM-AR

Areas approaching treeline were considered not likely to be suitable for most CDM-AR activities. There is wide variation in the elevation at which treelines are found, both within the tropics and as the distance from the equator increases. Korner and Paulsen (2004) found that climatic treelines are associated with soil temperatures during the growing period equal to about 6.7 ± 0.8 SD degrees C. A global climatic treeline was calculated, excluding as unsuitable all areas with average temperature in the growing season below 6.5°C. The length of the growing season was calculated as the number of months where the average monthly temperature is above 0°C. Spatially distributed monthly average temperature values were derived from the WorldClim dataset (Hijmans et al. 2004). Although treeline can surpass 4000 m in certain parts of the world (e.g. the eastern Himalaya), viable CDM-AR projects were assumed unrealistic at elevations above 3500 m. Even at this elevation, it is more likely that ecological restoration will be the purpose, rather than commercial forestry plantations.

2.3 Aridity Index for CDM-AR land suitability

Potential evapotranspiration (*PET*) was estimated on a global scale (Zomer et al. 2006) and used to calculate a Aridity Index (*AI*) in order to exclude areas too dry for tree growth (i.e., plantations) from the land suitability analysis. *PET* is a measure of the ability of the atmosphere to remove water through evapotranspiration *(ET)* processes (Allen et al. 1998). Five different methods of calculating *PET* were evaluated for use in the land suitability analysis (Zomer et al. 2006). The method of Hargreaves (1994) was used to model *PET* globally for this study, and is based on mean monthly temperature (T*mean*), mean monthly temperature range (*TD*) and extraterrestrial radiation (*RA*, radiation on top of atmosphere) to calculate *PET*, as shown below:

$$PET = 0.0023 \cdot RA \cdot (Tmean + 17.8) \cdot TD^{0.5} (\text{mm/d}) \quad (1)$$

Aridity is commonly expressed as a function of precipitation and potential evapotranspiration (*PET)*. In a classification of climatic zones proposed by UNEP (1997), an Aridity Index (*AI*) was used to quantify precipitation deficit over atmospheric water demand as:

$$\text{Aridity Index } (AI) = MAP/MAE \quad (2)$$

where:

MAP = mean annual precipitation
MAE = mean annual evapotranspiration.

Monthly values for precipitation and temperature were obtained from WORLDClim (Hijmans et al. 2004) for years 1960–1990.

To understand the relationship of aridity to tree and forest cover, we compared *AI* to the land use classes in the Global Ecosystems Land Characteristics Database (USGS 1993), MOD12 2001 (Strahler et al. 1999), and the MODIS VCF Tree Cover estimates (Hanson et al. 2003). Optimal climatic zones for tree plantations were empirically determined to

have $AI > 0.65$ (Zomer et al. 2006). This minimum threshold for suitability represents a moisture range generally observed in semi-arid zones (UNEP 1997) that can support rain-fed agriculture with more or less sustained levels of production.

2.4 Estimating impacts of crown cover

Crown cover is defined as the percentage of ground covered by the vertical projection of the outermost perimeter of the natural spread of the foliage of plants, which cannot exceed 100%. This is synonymous with canopy cover (IPCC 2003). Five minimum crown cover threshold values were used to exclude areas with existing ''forest'' from the remaining land considered suitable for CDM-AR. Forested area was estimated, based on crown cover at 5% increments from 10% to 30%. Tree cover and canopy cover estimates were obtained from the MODIS VCF—Tree Cover Dataset (Hansen et al. 2003). Five scenarios illustrating the global implications of crown cover threshold were combined with the other CDM-AR exclusion criteria. The results of this analysis were delineated by administrative boundaries, and tabulated globally, regionally, and nationally. Countries were sorted into impact classes based upon the increase in available land resulting from a change in crown cover threshold from 10% to 30%. The impact level on national land availability has been classified on a country-by-country basis, both as increase in total area, and as a relative percent of the total area of that country.

2.5 Encofor on-line analysis tool

The land suitability and forest definition analysis was mapped and tabulated for all Non-Annex I countries. Country maps can be interactively retrieved on-line using the ENCOFOR CDM-AR Online Analysis Tool (Zomer et al. 2005), available at http://csi.cgiar.org/encofor/forest/. Spatial query is available on a country-by-country basis, with maps, tables, and graphs of the delineated area. In addition, socio-ecological characteristics of the suitable areas are presented, such as current landuse and population density. The tool allows the user to specify the crown cover threshold to be used as 'forest definition', and to choose to include protected areas within the area deemed suitable for CDM-AR.

3 Results

3.1 Crown cover threshold—regional impacts

The importance of the exclusion criteria categories varied among continents, regions, and countries. Of the 140 Non-Annex I countries, 107 countries were found to have a potential for CDM-AR projects (Fig. 1). As expected, the area excluded by the crown cover criterion decreased substantially with the threshold set at 30%, This had a significant impact on the area available within most Non-Annex I countries (Table 1). Asia had the largest amount of combined area suitable at the 10% threshold level. However, at the 30% threshold level, South America had by far the greatest amount of land available, which increased by almost five times of that which was available at the 10% threshold. Likewise, the area available in Africa increased by 5.5 times when the threshold was set at 30%. Central America showed

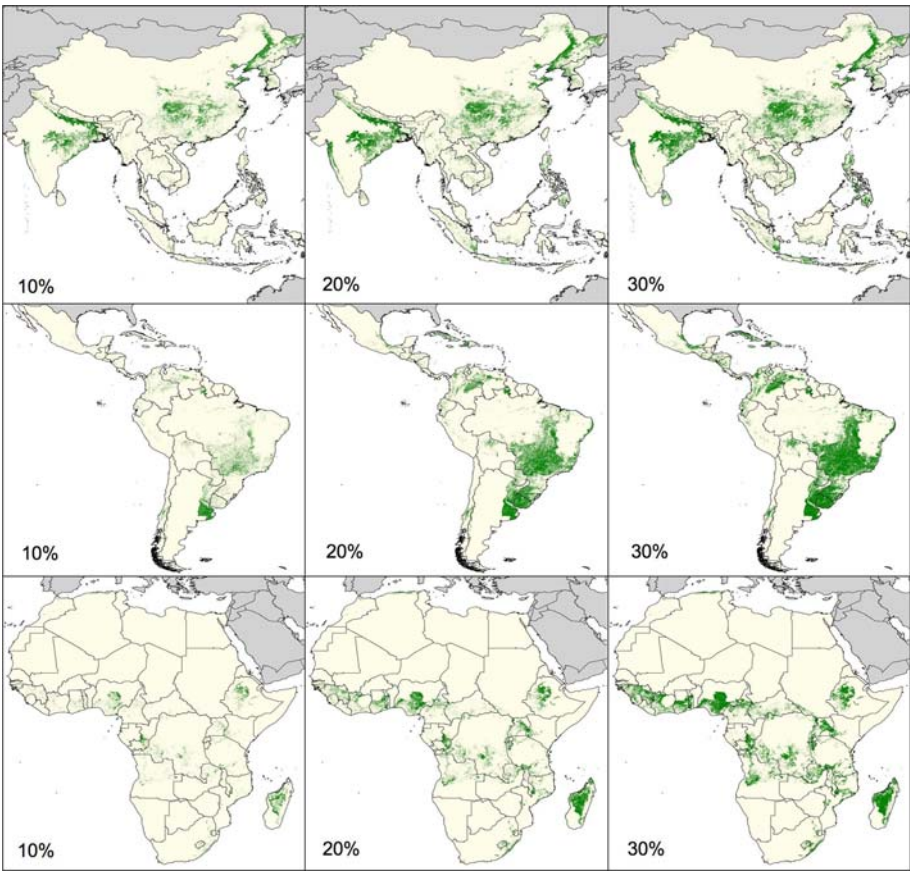

Fig. 1 Areas identified as eligible for CDM-AR (shown in green), illustrating the impact of choice of crown cover density threshold on forest definition. Impact on eligibility is shown below at three crown cover thresholds (10, 20, 30%) for Asia, the Americas, and Africa. Annex I countries are shown in grey, with Non-Annex I countries shown in light yellow

the largest increase, with area increased to almost 10 times more at 30% threshold level. By contrast, within Asia, the area increase was comparatively much less, but still the area nearly doubled.

Regionally, South America is shown to have a large potential area deemed suitable at all threshold levels. Large areas are delineated as suitable in southeastern Brazil and northeastern Argentina, Uraguay, and Paraguay, as well as significant areas in Colombia, Venezuela, Ecuador, Bolivia and Chile. Most of the Amazon is excluded at all crown cover levels. Northeastern Brazil is also noticeably excluded, mostly due to dry conditions. Much of the Altiplano (and of course the high cordillera) is excluded due to elevation, as well as in some cases very arid conditions. The increase in area at the 30% threshold in South America was more than 2 million km^2 (Table 2).

Relatively little area is suitable within North Africa, due to dry conditions. However, in Sub-Saharan Africa, both the West and Central Africa region and the East and Southern Africa region are shown to have large areas suitable for CDM-AR. The choice of crown cover threshold is particularly significant in the West and Central Africa region, with

Table 1 Total CDM-AR suitable area (km^2) and percentage of the total continental land area suitable for CDM-AR (%), showing effect of crown cover threshold within the forest definition on land eligibility

Continent	Crown cover density threshold					Increase (sq km)
	10%	15%	20%	25%	30%	
Total CDM-AR suitable area (sq km)						
Africa	359,540	708,448	1,111,289	1,539,153	1,961,010	1,601,470
Asia	1,147,140	1,465,255	1,714,683	1,914,312	2,105,277	958,137
Central America	24,231	55,117	112,399	179,189	239,635	215,405
Europe	42,157	60,359	70,597	77,505	82,276	40,119
Oceana	4,166	6,122	8,616	11,957	15,822	11,656
South America	703,980	1,475,085	2,296,590	2,897,199	3,331,106	2,627,126
Global	2,281,213	3,770,386	5,314,172	6,619,314	7,735,125	5,453,912
Percent of total continental area suitable for CDM-AR(%)						
Continent	Crown cover density threshold					Increase (%)
	10%	15%	20%	25%	30%	
Africa	1.6	3.2	5.0	6.9	8.7	7.1
Asia	4.4	5.6	6.5	7.3	8.0	3.7
Central America	0.9	2.1	4.2	6.7	8.9	8.0
Europe	17.5	25.1	29.4	32.2	34.2	16.7
Oceana	0.9	1.2	1.8	2.4	3.2	2.4
South America	4.0	8.3	13.0	16.4	18.9	14.9

The increase in suitable area resulting from shifting the crown cover threshold from 10% to 30% is given in both total area (km^2) and as a percent of the total continental land area

increase of more than 7 times, when 30% is used, corresponding to an increase of more than 800,000 km^2. Likewise the East and Southern Africa region showed an increase of almost five times, accounting for more than 700,000 km^2 difference. Within South Asia, the area available nearly doubled from 350,000 km^2 at 10% crown cover to 630,000 km^2 at 30%. Results for all Non-Annex I countries, at all crown cover thresholds is given in Appendix 1.

3.2 Crown cover threshold—national impacts

The magnitude of increase in national land availability resulting from the choice of a 30% threshold (compared to the 10% threshold) has been classified, on a country by country basis, into seven classes and mapped (Fig. 2). Thirteen countries are in the highest class, showing an increase of greater than 100,000 km^2 (Table 3). Brazil has the largest increase with over 1.8 million km^2 becoming additionally available, representing more than a five-fold increase in absolute area. Other countries demonstrating a large impact include China (350,000 km^2, 64% increase), India (244,000 km^2, 78% increase), Nigeria (195,000 km^2, 446% increase), and the Democratic Republic of Congo (190,000 km^2, 554% increase). Twenty-six countries increased their eligible land by more than 50,000 km^2, 50 by more than 10,0000 km^2, and altogether, 89 countries were found to have increases of more 1000 km^2.

Table 2 Total CDM-AR suitable area (km^2) and percentage of the total regional land area suitable for CDM-AR (%), showing effect of crown cover threshold within the forest definition on land eligibility

Sub-Continent	Crown cover density threshold					Increase (sq km)
	10%	15%	20%	25%	30%	
Total CDM-AR suitable area (sq km)						
Central America	24,231	55,117	112,399	179,189	239,635	215,405
East Asia	571,759	704,920	792,410	859,261	932,940	361,182
Eastern / Southern Africa	213,354	397,358	607,157	797,961	960,457	747,103
Europe	42,157	60,359	70,597	77,505	82,276	40,119
North Africa	9,049	11,382	12,451	13,515	15,234	6,185
Northern and Central Asia	59,866	62,247	63,670	64,973	66,458	6,592
Oceana	4,166	6,122	8,616	11,957	15,822	11,656
South America	703,980	1,475,085	2,296,590	2,897,199	3,331,106	2,627,126
South Asia	357,134	469,029	546,234	592,069	633,445	276,311
SouthEast Asia	94,394	156,441	236,333	320,015	392,145	297,751
West and Central Africa	137,138	299,708	491,682	727,677	985,319	848,181
Western Asia	63,987	72,619	76,037	77,995	80,289	16,302
Percent of total regional area (%)						
Sub-Continent	Crown cover density threshold					Increase (%)
	10%	15%	20%	25%	30%	
Central America	0.9	2.1	4.2	6.7	8.9	8.0
East Asia	6.0	7.4	8.3	9.0	9.7	3.8
Eastern and Southern Africa	2.6	4.9	7.5	9.8	11.8	9.2
Europe	17.5	25.1	29.4	32.2	34.2	16.7
North Africa	0.3	0.4	0.4	0.5	0.5	0.2
Northern and Central Asia	1.2	1.2	1.3	1.3	1.3	0.1
Oceana	0.9	1.2	1.8	2.4	3.2	2.4
South America	4.0	8.3	13.0	16.4	18.9	14.9
South Asia	10.1	13.2	15.4	16.7	17.9	7.8
SouthEast Asia	2.1	3.5	5.3	7.2	8.8	6.7
West and Central Africa	1.2	2.6	4.3	6.4	8.6	7.4
Western Asia	1.8	2.0	2.1	2.2	2.3	0.5

The increase in suitable area resulting from shifting the crown cover threshold from 10% to 30% is given in both total area (km^2) and as a percent of the total regional land area

The importance of the increase in area in respect to the size of the country was ascertained by normalizing the increase by the total area of each respective country. This measure, which divides the total area increase by the total area of the entire country is a measure of the relative importance of the area change to the individual country. By this measure, many of the smaller countries, which reported relatively small increases in CDM-AR eligible area, showed that this amount of land was significant and substantial at the national level (Fig. 3). However, in Brazil, which is a large country and which had the largest increase in total area, this increase was still a large proportion (20%) of the total country area (Table 4). Altogether, for more than 40 countries the increased amount of land which became eligible at the 30% level was more than 10% of the total country area.

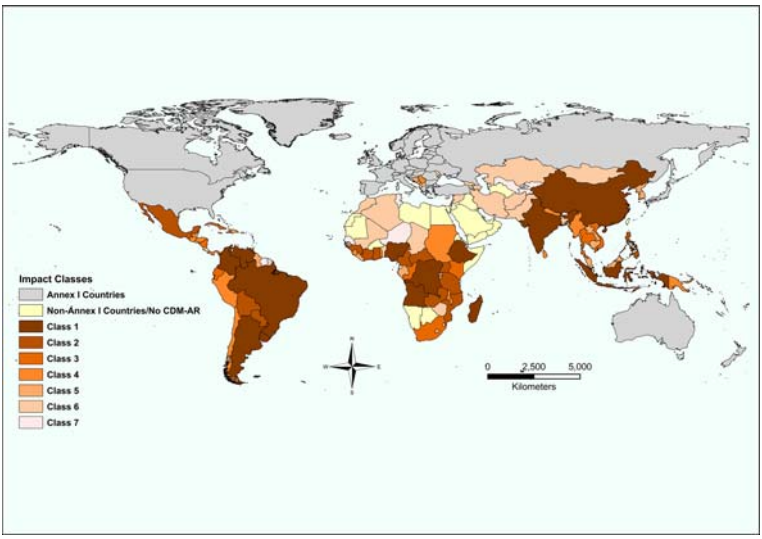

Fig. 2 The impact on area available resulting from an increase in the crown cover threshold from a 10% to 30% is displayed by classes which reflect the absolute magnitude of the increase in area (km^2)

Table 3 Non-Annex I countries shown by the total area increase (km^2) in areas when using 30% crown cover as the forest specification threshold, as compared to using 10%

Country	Percentage increase (%)	Area increase (sq km)	Country	Percentage increase (%)	Area increase (sq km)
Class One			*Class Five*		
Brazil	463	1,857,436	Gabon	137	9,272
China	64	347,739	Laos	913	9,036
India	78	244,143	Bosnia Herzegovina	185	8,836
Nigeria	446	195,449	Albania	79	8,563
Congo (DRC)	554	190,906	North Korea	41	8,410
Colombia	657	186,419	Rwanda	753	7,765
Madagascar	193	162,271	Cambodia	166	7,330
Argentina	91	161,158	Dominican Republic	803	7,282
Uruguay	1481	147,190	Guinea-Bissau	407	6,818
Indonesia	302	116,623	Guyana	105	6,560
Angola	805	111,233	Malaysia	265	6,509
Venezuela	348	106,145	Liberia	2319	5,995
Ethiopia	201	101,041	El Salvador	1218	5,601
Class Two			Lesotho	244	5,587
Guinea	1645	82,626	South Korea	52	5,033
Cote D'Ivoire	1583	77,969	*Class Six*		
Mexico	953	77,763	Pakistan	70	4,908
Tanzania	539	69,549	Algeria	76	4,544
Mozambique	878	68,599	Costa Rica	1112	4,527
Ghana	1063	67,897	Bangladesh	17	4,223

Table 3 continued

Country	Percentage increase (%)	Area increase (sq km)	Country	Percentage increase (%)	Area increase (sq km)
Philippines	387	67,286	Moldova	38	4,204
Cameroon	1017	65,799	Georgia	42	3,629
Zambia	649	63,802	Zimbabwe	601	3,425
Uganda	935	62,571	Benin	290	3,248
Bolivia	357	59,978	Kazakhstan	17	2,768
Paraguay	603	54,057	Montenegro	152	2,671
Central African Rep.	3563	53,813	Mongolia	157	2,356
Class Three			Swaziland	341	2,352
Cuba	769	41,407	Mali	1014	1,826
Thailand	405	38,640	Macedonia	139	1,703
Congo	187	36,199	Syria	45	1,659
South Africa	270	33,490	Belize	580	1,382
Vietnam	256	32,844	Lebanon	30	1,382
Kenya	553	28,163	Jamaica	716	1,326
Nicaragua	1070	21,193	Chad	1311	1,242
Ecuador	470	20,181	Morocco	46	1,138
Class Four			Azerbaijan	26	1,126
Burma	240	19,483	Iran	43	1,121
Togo	605	18,020	Armenia	16	1,047
Sudan	2470	16,949	Afghanistan	4	1,045
Chile	112	16,313	*Class Seven*		
Nepal	105	16,029	Suriname	291	893
Honduras	1318	15,276	Kyrgyzstan	5	870
Serbia	114	14,143	Solomon Is.	266	644
Malawi	261	13,923	Senegal	248	589
Guatemala	1139	13,721	Trinidad & Tobago	189	581
Panama	1938	13,103	The Bahamas	85	562
Burundi	1894	13,035	Tajikistan	3	556
Sierra Leone	1362	12,875	Tunisia	88	503
Haiti	456	11,942	Niger	227	455
Sri Lanka	415	11,653	Cyprus	115	304
Papua New Guinea	281	11,012	Comoros	577	299
Peru	220	10,214	Bhutan	497	264
			Equatorial Guinea	780	238
			Barbados	124	165
			Antigua & Barbuda	262	133

3.3 Suitable land within protected areas

Protected areas and national parks were excluded from our results a priori. Protected areas are usually protected for their unique ecosystems and it is unlikely that a land use change in these areas would be desirable. However, the Kyoto Protocol does not proscribe CDM-AR

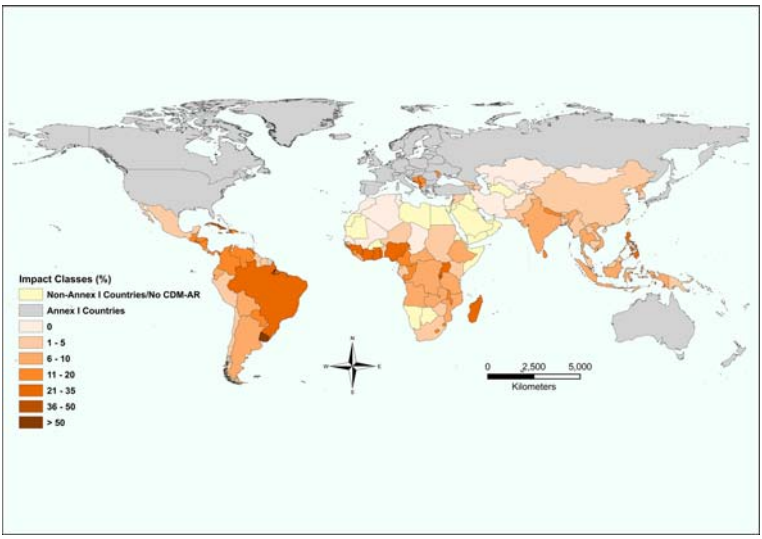

Fig. 3 The impact on area available resulting from an increase in the crown cover threshold from a 10% to 30% is displayed by classes which reflect the relative change in respect to the total area of the country (% of total country area). The total area increase within each country has been divided by the total area of that country, to reflect the importance of this impact from the national perspective

in these areas. We recognize that there may be ecosystem restoration in protected areas that would qualify for CDM finance, and that some degraded areas now designated as protected offer optimal opportunities for reforestation and CDM-AR. A relevant example is the Mt. Elgon Reforestation Project (FACE 1998) in eastern Uganda. The government of Uganda worked with the FACE (Forests Absorbing Carbon Emissions) Foundation and IUCN to fund reforestation, based on the carbon sequestration component of the improved ecosystem services provided by ecological restoration. The legal commitment to permance provided by the national park status provides an ideal opportunity for carbon sequestration.

Considering protected areas as unsuitable for CDM projects excluded between 10 and 20% of the CDM-AR eligible area in each country (at the 30% minimum crown cover threshold). China had the largest amount of CDM-AR eligible land within protected areas (Table 5), however Venzuela, Tanzania, Congo (DRC), India, Angola, Ethiopia, and Brazil all had more than 10,000 km^2 of eligible land within protected reserves. Altogether, 36 countries have more than 1,000 km^2 of eligible land with protected areas.

4 Discussion

Whereas increasing the share of LULUCF projects is being considered as a means of addressing the equity issue in the distribution of CDM benefits, it must be recognized that countries and regions offer different CDM-AR opportunities. Trees grow more rapidly in warm, humid environments and regions with clay soils retain higher soil carbon than regions with sandy soils. A global analysis of land suitability (Zomer et al. 2006) showed that availability of biophysically suitable land that met the CDM-AR eligibility criteria was far in excess of the amount of land required to satisfy the current cap on CDM-AR (i.e. 1% of total emission reduction credits). While land availability is not currently a constraint to

Table 4 Non-Annex I countries shown by the relative increase (%) in area, in relation to the total country area, when using 30% crown cover as the forest specification threshold, as compared to using 10%

Non-Annex I Country	Increase as % of Total Country Area	Non-Annex I Country	Increase as % of Total Country Area
Uruguay	83	Macedonia	7
Burundi	48	Belize	6
Haiti	44	Liberia	6
Cuba	38	Liberia	6
Guinea	34	Indonesia	6
Togo	31	Argentina	6
Rwanda	31	Bolivia	6
Albania	30	Georgia	5
Ghana	28	South Korea	5
El Salvador	27	Kenya	5
Madagascar	27	The Bahamas	5
Uganda	26	Cambodia	4
Cote D'Ivoire	24	Mexico	4
Philippines	23	Laos	4
Brazil	22	Niger	4
Nigeria	21	China	4
Guinea-Bissau	20	Armenia	4
Montenegro	19	Gabon	3
Lesotho	18	Cyprus	3
Sierra Leone	18	Guyana	3
Panama	18	Bangladesh	3
Sri Lanka	18	Burma	3
Bosnia & Herzegovina	17	Benin	3
Nicaragua	17	South Africa	3
Colombia	16	Papua New Guinea	2
Serbia	16	Solomon Is.	2
Dominican Republic	15	Chile	2
Cameroon	14	Malaysia	2
Lebanon	14	Azerbaijan	1
Honduras	14	Syria	1
Swaziland	14	Equatorial Guinea	1
Paraguay	14	Zimbabwe	1
Guatemala	13	Peru	1
Moldova	12	Sudan	1
Jamaica	12	Bhutan	1
Malawi	12	Suriname	1
Venezuela	12	Pakistan	1
Nepal	11	Kyrgyzstan	0
Congo	11	Tajikistan	0
Vietnam	10	Tunisia	0
Ethiopia	9	Senegal	0
Costa Rica	9	Israel	0

Table 4 continued

Non-Annex I Country	Increase as % of Total Country Area	Non-Annex I Country	Increase as % of Total Country Area
Angola	9	Morocco	0
Mozambique	9	Algeria	0
Central African Rep.	9	Afghanistan	0
Zambia	8	Mongolia	0
Congo (DRC)	8	Mali	0
Ecuador	8	Kazakhstan	0
India	8	Chad	0
Thailand	7	Iran	0
Tanzania	7	Uzbekistan	0
North Korea	7		

Table 5 Percentage increase (%), and increase in area (km^2), when protected areas are included as eligible with the criteria for CDM-AR eligible lands

Country	Percentage increase (%)	Area increase (sq km)	Country	Percentage increase (%)	Area increase (sq km)
China	3.66	32593	Malawi	3.77	726
Venezuela	22.15	30263	Peru	4.11	611
Tanzania	26.17	21577	Tajikistan	2.80	571
Congo (DRC)	8.53	19236	Kenya	1.72	571
India	2.87	16023	Azerbaijan	8.63	468
Angola	11.31	14147	Laos	4.41	442
Ethiopia	8.39	12682	Paraguay	0.64	406
Brazil	0.47	10590	Honduras	2.40	394
Zambia	13.33	9815	Morocco	9.21	335
Indonesia	4.21	6535	Costa Rica	6.30	311
Philippines	7.36	6230	Sudan	1.53	269
Colombia	2.80	6025	Belize	15.46	251
Mexico	5.31	4561	Rwanda	2.69	237
Cameroon	5.82	4203	Panama	1.35	186
Congo	6.43	3577	Algeria	1.68	177
Uzbekistan	73.29	3567	Macedonia	5.82	171
Uganda	4.91	3403	Zimbabwe	4.25	170
Central African Rep.	5.54	3064	Burundi	1.22	167
Mozambique	3.96	3028	Jamaica	11.04	167
Kazakhstan	15.49	2951	Dominican Rep.	1.98	162
Ghana	3.94	2924	Pakistan	1.22	146
Chile	9.46	2924	South Korea	0.90	132
South Africa	6.06	2783	Iran	3.16	118
Cambodia	18.07	2125	Sierra Leone	0.79	109

Table 5 continued

Country	Percentage increase (%)	Area increase (sq km)	Country	Percentage increase (%)	Area increase (sq km)
Nigeria	0.85	2035	Swaziland	3.58	109
Bolivia	2.49	1911	Bangladesh	0.37	109
Thailand	3.96	1909	Malaysia	1.08	97
Mongolia	48.90	1887	Equatorial Guinea	35.51	95
Madagascar	0.73	1807	Georgia	0.72	88
Cuba	3.79	1772	Lesotho	0.93	74
Togo	7.94	1667	Armenia	0.94	73
Kyrgyzstan	8.50	1557	Liberia	0.69	43
Ecuador	5.45	1334	Haiti	0.14	21
Guatemala	8.88	1325	Guinea	0.02	19
Cote D'Ivoire	1.45	1202	Antigua & Barbuda	8.57	16
Nepal	3.31	1038	Guyana	0.09	12
Vietnam	1.95	891	El Salvador	0.18	11
Sri Lanka	5.92	857	Senegal	1.00	8
Nicaragua	3.64	844	Bhutan	1.26	4
Gabon	5.17	829	Trinidad & Tobago	0.25	2
Papua New Guinea	5.48	819	Singapore	1.65	2
Suriname	61.08	733	Niger	0.27	2

meet allowances of the CDM, relative differences in available land have been shown to have an effect on the distribution of projects nationally (Verchot et al. 2007). This study, along with the in-depth case studies presented in Verchot et al. (2007), and the guide presented by Neeff et al (2006) demonstrate that countries can enhance their ability to provide land for CDM-AR projects though careful selection of forest definition criteria and thresholds.

Earlier forest policy analysts argued that a forest definition should not include any reference to human function, land use or destination in a zoning plan, because they are not essential characteristics of a forest (Tromp 1976; Van Miegroet 1976). In accordance to these, the UNFCCC, and consequently the CDM, defines forest land strictly by crown cover, tree height, and minimum area size. In contrast to the FAO definition (FAO 2004), which has set the crown cover threshold at 10%, the UNFCCC definition ignores the primary function of the land. The consequence of this is that it potentially can lead to the exclusion from CDM-AR of many rural landscapes where tree cover is considerable, yet the primary function of the land is agriculture. For example, this can easily be the case where smallholder mixed farming systems incorporate boundary plantings and other multipurpose trees into a primarily agricultural landscape. The lack of an element regarding the primary function of the land in the Kyoto definition creates a situation where, if countries set a low canopy cover threshold, many small-holder agroforestry projects will potentially be excluded from eligibility for carbon finance because these lands would be considered as existing forest. In both East Africa and Southeast Asia, it is not unusual to

find large numbers of trees on farms (Kindt et al. 2004, 2005). These issues are further complicated in agricultural systems that incorporate recurring forest fallows, such as found in the Amazon, or in landscapes with swidden type farming systems.

A simple interpretation of the results of our analysis suggest that if countries wish to use carbon finance for rural development, promote agroforestry, or otherwise maximize the availability of land for CDM-AR projects, the maximum threshold of 30% crown cover should be chosen. However, countries may have incentives for choosing other threshold levels, having to do with biophysical conditions, types of forests, or intended project types. For example, of the 22 countries which have so far reported their definition to the UNFCCC, three have chosen a threshold of 20%. Most of the reporting countries, with the exception of China, Dominican Republic, and Nicaragua, have sought to eliminate the risk of prior vegetation being considered as forests by choosing the 30% threshold.

Selection of an optimum country-specific crown cover threshold is a consequence of both prior land cover characteristics and anticipated crown cover of desired project types. Neeff et al. (2006) present a comparative analysis integrating prior site conditions with project types to identify feasible threshold values. Countries with large areas of territory in biomes with primarily low crown cover vegetation types, such as dry forests and open woodlands, may have several reasons to choose lower values. Choosing a high minimum crown cover threshold would classify large areas of low-cover forest as non-forest, allowing for their conversion to higher cover plantations, with potentially significant loss of biodiversity, habitat, and perhaps local livelihoods. Likewise, if there was an interest to restore low covers open forest on degraded or marginal areas, a low threshold might be chosen. In more humid countries, choosing a higher threshold may allow for inclusion of degraded forest areas with low forest cover, and which may provide incentives for restoration through the CDM.

Countries interested in promoting agroforestry and productive plantations will want to choose a high threshold (Kant 2005), whereas if protective plantations or ecological restoration of marginal areas are to be encouraged, a lower threshold would provide more feasible opportunities. Some countries might be interested in promoting urban forestry, perhaps for example Singapore, and in this case will want to choose a low minimum threshold. Physical structure of specific crops and management systems should also be considered if permanent tree crops or energy plantations are going to be encouraged, e.g. oil producing tree species are often cut back severely in order to increase yields and to facilitate harvesting of the fruits.

Tradeoffs may also exist with other climate change mitigation efforts or international treaties. The proposal to include Reduced Emissions from Deforestation and Degradation (REDD) now on the UNFCCC negotiating agenda (Trines et al. 2006) is one such case in point. If a 30% crown cover is selected as the threshold for CDM-AR, then when land goes below 30% cover, it becomes non-forest and hence is deforested; if 10% is selected, then degradation and carbon emissions can occur all the way down to 10% without triggering ‘‘deforestation’’.

5 Conclusion

The importance of the choice of a crown cover threshold used in setting the forest definition has been highlighted and quantified by the results of this study. This choice has a significant impact on land availability for CDM-AR in almost all the Non-Annex I countries, as well as on the types of CDM-AR projects that can be pursued. In general,

results demonstrate that in order to maximize the area available for hosting CDM-AR projects, and/or to promote small-holder agroforestry activities in agricultural areas, countries should select the higher minimum threshold of 30% crown cover. However, there are various other, and country-specific, reasons to choose lower thresholds. The analysis that we present here allows countries that are considering using CDM finance for rural development to explore the implications of selecting various levels for the crown cover threshold, and to quantify and spatially delineate the impact on land availability. Choosing an optimal crown cover threshold will allow countries to maximize their participation and flexibility within the CDM of the Kyoto Protocol. It has been shown that this choice has significant implications for the Non-Annex 1 countries, regardless of size, geographic location, or biome. The choice of a crown cover threshold, in particular, and forest definition in general, has significant implications for that country in terms of its ability to reap the full potential of opportunities offered within the CDM-AR provisions.

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Appendix 1: Total area for CDM-AR at specified crown cover density threshold (sq. km.)

Continent	Sub-Continent	Country	Crown cover density threshold				
			10%	15%	20%	25%	30%
Africa	Eastern / Southern Africa	Angola	13813	31591	55371	89295	125045
		Burundi	688	2369	6109	10292	13724
		Comoros	52	97	162	248	350
		Ethiopia	50182	79845	105013	130252	151222
		Kenya	5096	13096	22698	28904	33260
		Lesotho	2286	4445	5796	7296	7872
		Madagascar	83971	135492	197981	232449	246241
		Malawi	5328	10293	14810	17578	19251
		Mozambique	7813	19471	36068	55574	76412
		Rwanda	1031	2499	4979	7224	8795
		South Africa	12402	26233	33537	40692	45892
		Swaziland	689	1722	2245	2676	3041
		Tanzania	12904	30909	50600	67870	82453
		Uganda	6695	17686	35983	53862	69266
		Zambia	9836	20253	33347	50326	73639
		Zimbabwe	570	1360	2458	3425	3995

Appendix 1 continued

Continent	Sub-Continent	Country	Crown cover density threshold				
			10%	15%	20%	25%	30%
	North Africa	Algeria	5979	7621	8397	9171	10522
		Morocco	2501	3041	3233	3423	3639
		Tunisia	569	720	821	922	1072
	West / Central Africa	Benin	1121	2352	3456	4095	4368
		Cameroon	6472	17406	30225	47900	72271
		Central African Rep.	1510	5419	12521	28734	55324
		Chad	95	310	643	944	1337
		Congo	19407	29480	39024	48823	55606
		Congo (DRC)	34467	67210	110625	169556	225373
		Cote D'Ivoire	4925	16337	32002	54798	82893
		Equatorial Guinea	31	55	99	170	268
		Gabon	6745	9326	11684	14041	16017
		Ghana	6387	18462	35146	56913	74284
		Guinea	5024	18854	37195	55767	87650
		Guinea-Bissau	1675	2731	4234	5826	8493
		Liberia	259	845	2057	3800	6254
		Mali	180	561	952	1325	2006
		Niger	201	366	444	544	656
		Nigeria	43792	96541	147687	197345	239241
		Senegal	238	370	496	643	827
		Sierra Leone	946	2658	5350	8368	13820
		Sudan	686	1981	3827	9877	17636
		Togo	2979	8447	14017	18208	20998
Americas	Central America	Antigua & Barbuda	51	93	131	154	184
		Barbados	133	196	238	280	298
		Belize	239	450	809	1200	1621
		Costa Rica	407	874	1784	3353	4935
		Cuba	5387	14892	29448	40195	46794
		Dominica	10	16	23	27	32
		Dominican Rep.	907	2237	4169	6317	8189
		El Salvador	460	858	1759	3841	6061
		Guatemala	1205	2735	6153	10536	14926
		Haiti	2619	5938	9669	12563	14561
		Honduras	1159	2616	5658	10573	16435
		Jamaica	185	405	794	1174	1511
		Mexico	8157	16758	37749	62901	85919
		Nicaragua	1980	4356	8392	15582	23173
		Panama	676	1888	4679	9409	13779
		The Bahamas	659	806	946	1084	1221

Appendix 1 continued

Continent	Sub-Continent	Country	Crown cover density threshold				
			10%	15%	20%	25%	30%
	South America	Argentina	177729	237016	280902	312411	338887
		Bolivia	16807	25416	38847	57049	76785
		Brazil	401334	940067	1535620	1965450	2258770
		Chile	14580	20209	24662	28000	30893
		Colombia	28360	67732	125709	177679	214779
		Ecuador	4295	8672	14197	19702	24476
		Guyana	6231	9017	10628	11757	12791
		Paraguay	8958	18954	34473	48919	63015
		Peru	4640	7070	9797	12418	14854
		Suriname	307	483	734	986	1200
		Trinidad & Tobago	307	449	604	766	887
		Uruguay	9937	82188	133681	148896	157127
		Venezuela	30498	57813	86738	113168	136643
Asia	East Asia	China	541884	669125	752451	817680	889622
		North Korea	20267	24014	26867	27791	28677
		South Korea	9608	11781	13092	13790	14641
	Northern / Central Asia	Kazakhstan	16282	17425	18012	18520	19049
		Kyrgyzstan	17453	17773	17969	18138	18323
		Mongolia	1502	2070	2608	3174	3858
		Tajikistan	19806	20128	20221	20279	20362
		Uzbekistan	4824	4851	4860	4863	4866
	South Asia	Bangladesh	24875	27047	28121	28689	29098
		Bhutan	53	155	220	271	317
		India	314084	416864	486411	525111	558227
		Nepal	15314	20762	24896	27939	31343
		Sri Lanka	2808	4202	6586	10059	14462
	SouthEast Asia	Burma	8122	13110	18555	23621	27605
		Cambodia	4429	5680	7294	9147	11759
		Indonesia	38649	63746	94896	127811	155272
		Laos	990	2420	4768	7177	10027
		Malaysia	2453	3692	5282	7231	8961
		Philippines	17370	29041	46649	67285	84656
		Thailand	9531	18488	29258	39478	48171
		Vietnam	12852	20265	29632	38264	45696
	Western Asia	Afghanistan	26204	26890	27026	27100	27249
		Armenia	6653	7252	7495	7612	7700
		Azerbaijan	4293	4871	5143	5312	5419
		Cyprus	264	380	425	492	568
		Georgia	8551	10282	11211	11716	12180
		Iran	2620	3111	3306	3506	3741
		Israel	122	168	186	194	203
		Lebanon	4613	5312	5611	5809	5995

Appendix 1 continued

Continent	Sub-Continent	Country	Crown cover density threshold				
			10%	15%	20%	25%	30%
		Pakistan	7018	9734	10636	11071	11926
		Syria	3650	4619	5001	5184	5308
Europe	Europe	Albania	10821	15176	17068	18288	19384
		Bosnia & Herzegovina	4782	8504	10800	12381	13618
		Macedonia	1229	2088	2476	2749	2931
		Moldova	11154	13069	14093	15103	15358
		Montenegro	1757	2843	3567	4048	4428
		Serbia	12415	18680	22594	24935	26557
Oceana	Oceana	Papua New Guinea	3924	5621	7976	11197	14935
		Solomon Is.	242	501	640	761	887

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