Climatic Change (2013) 119:261–267
DOI 10.1007/s10584-012-0662-7

SPRINGBOARD COMMENTARY

Uncertainties and REDD+: Implications of applying the conservativeness principle to carbon stock estimates

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Received: 12 August 2012 / Accepted: 30 November 2012 / Published online: 23 January 2013

Relatively small periodic carbon (C) stock changes at national levels through forest loss and forest degradation contribute, in sum, a substantial 12–15 % to worldwide C emissions (van der Werf et al. 2009). However, a reliable quantification of C stock changes remains difficult. Existing C stocks are fortunately still large; this means that even small relative survey errors can lead to substantial absolute errors in C stock estimates, which may even exceed their periodic changes. This fact makes reporting achieved emission reductions on a credible basis difficult. In this issue, Plugge et al. draw our attention to this important problem through elaborating the effects which uncertainties may have on REDD+ C accounting.

REDD+, a mechanism for reducing emissions from deforestation and forest degradation, which has now been extended to include conservation, management, and enhancement of forest carbon stocks (thus REDD+), is intended to reward developing countries for the mitigation of greenhouse gas emissions (UNFCC 2010). The implementation of effective REDD+ mechanisms requires credibility of the emission reductions achieved. To accomplish the necessary credibility Plugge et al. (this issue) propose using the principle of conservativeness to guarantee emission reductions. Inspired by their paper, I will develop some considerations of my own in an attempt to broaden the discussion on possible implications of an implementation of the conservativeness approach.

1 The principle of conservativeness

The principle of conservativeness is derived from the precautionary approach, which is widely accepted as the best method when making decisions which will have long-term consequences, and particularly where sustainability issues are concerned (Hahn and Knoke 2010). In a situation characterized by uncertainty about past, current and future states it is advisable to utilize safety-first rules, which means assuming worst-case scenarios rather than

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average or optimistic estimates. Following this logic, and drawing on Grassi et al. (2008), Plugge et al. (this issue) apply a variant of the conservativeness principle - the "Reliable Minimum Estimate" (RME) (explained in detail in their paper) - to the issue of monitoring terrestrial C stocks. In applying this approach, which is one of several approaches discussed in Grassi et al. (2008), they assume a total error in estimating the actual C stock which covers at least the radius of a 95%-confidence limit (it will most likely be bigger due to barely quantifiable non-sampling errors). Following the RME approach, the estimated actual C stock less the total error would qualify for REDD+ accounting, only if the resulting conservative estimate is still greater than the expected C stock under a reference emission level (Fig. 1). This reference emission level reflects the C stock which could be expected without any effort being made to avoid deforestation and forest degradation.

Plugge et al. (this issue) show convincingly that applying the conservativeness principle through the RME approach, while intended to guarantee emission reduction for every single participating nation, allows for financial benefits from C accounting only if high levels of deforestation and forest degradation activities are included in setting the reference emission level.

2 Implications of applying the conservativeness principle

Please note that the following considerations are not meant to be absolutely correct and empirically valid. They should be regarded only conceptually, as my aim here is merely to demonstrate the importance of the perspective which is taken - whether a national or a global view is applied - when considering uncertainties. In order to illustrate some of the implications of applying the principle of conservativeness, I will first consider possible uncertainties in monitoring C stocks individually for 25 selected countries which have undergone deforestation and forest degradation in the past. For my analyses, I will use information reported by the FAO (2010) in their recent Forest Resource Assessment. Although the selection of countries is certainly far from complete, I will then use the aggregated figures for the 25 selected countries to analyze the uncertainty from a "global view". As a rough starting point, I further refer to information provided by the German Federal Forest Inventory on obtainable relative standard errors (*r.s.e.*) depending on the area of forest under survey (Table 1).

The standard error (*s.e.*) quantifies the uncertainty of a sample's estimates. In our case, we will use this measure as the standard deviation of total carbon stocks, as estimated by

Fig. 1 Schematic illustration of the principle of conservativeness when a reduction of deforestation and forest degradation activities by 75 % and a total error of 2 % is assumed (data for Cameroon, FAO 2010)

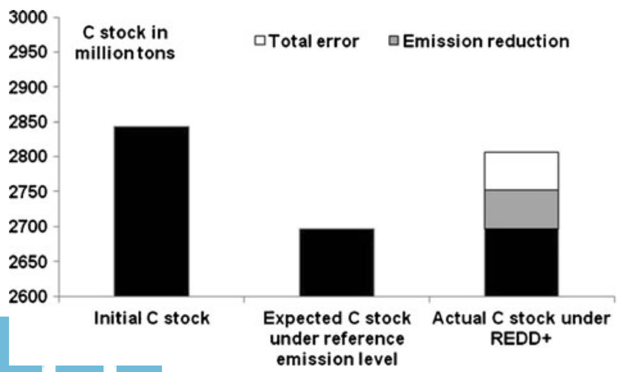

Table 1 Possible relative standard error in German national forest surveying (GNFI 2012)

Forest area (hectares)	Achievable relative standard error, *r.s.e.* (%)
100,000	~ 10
1,000,000	~ 3
11,100,000 (area of German forests)	0.7

sampling[1]; *s.e.* includes both sampling error and random, non-sampling errors (e.g. unsystematic measurement error). Commonly, *s.e.* is used to compute the 95%-confidence limits, using a multiplier of 1.96 to obtain the radius of the confidence interval. For simplicity, I use this radius as a proxy for the total error, although total error might be even greater (Plugge et al. this issue). I consider the uncertainty in estimating both initial and (current) actual C stocks and combine the two uncertainties, while providing a correlation ($k_{initial,actual}$) of 0.7 between successively recorded C stocks on permanent sampling units. Correlation of uncertainties in successive measurements is an important consideration (see Grassi et al. 2008) not explicitly covered by Plugge et al. (this issue). Based on survey experience in estimating standing timber volumes in Central Europe, a correlation of this order can be derived by means of continuous forest inventories (CFI), where sampling is always carried out on the same (permanent) sample plots which are marked in such a way so that they can be found in the course of successive surveys.

Plugge et al. (this issue) refer to a tier-2 or a tier-3 approach for C stock change estimates involving country-specific factors for carbon stock changes. Tier-3 includes developed national-level surveys repeated over time, and thus applies CFI methodology. CFI concepts are so far not overly common in countries preparing for REDD, but should be considered to obtain reliable estimates in C stock changes. For such a survey, the *s.e.* of carbon stock (*C*) changes can be computed as follows, if *r.s.e.* is the relative standard error:

$$s.e._{\Delta C} = \sqrt{s.e._{initial\ C}^2 + s.e._{actual\ C}^2 - 2 \cdot k_{initial,actual} \cdot s.e._{initial} \cdot s.e._{actual}} \quad (1)$$
$$s.e._{initial/actual\ C} = r.s.e. \cdot C_{initial/actual\ Stock}$$

For example, in the case of Cameroon (Table 2) this would mean:

$$s.e._{initial\ C} = 2844 \cdot 0.01 = 28.44 \quad s.e._{actual\ C} = 2807 \cdot 0.01 = 28.07$$
$$s.e._{\Delta C} = \sqrt{28.44^2 + 28.07^2 - 2 \cdot 0.7 \cdot 28.44 \cdot 28.07} = 21.89 \approx 22$$

The "guaranteed" emission reduction (achieved with a probability of 0.975) for Cameroon - with $\overline{e_{red}}$ as the best estimate for the expected emission reduction - would then follow as:

$$guarantee\ e_{red} = \overline{e_{red}} - 1.96 \cdot s.e._{\Delta c} = 111 - 1.96 \cdot 22 \approx 68 \quad (2)$$

Although the principle of conservativeness applied through the RME approach certainly has appeal - particularly for the buyers of emission reductions - given our results, it could obviously be discouraging for developing countries in many cases, when applied at the country level. Indeed, in our analyses, the lower confidence limit used to estimate guaranteed emission

[1] In theory *s.e.* is the standard deviation of sample means or totals, which would be obtained when repeating sampling often, so that a set of various means (or totals) would be obtained. In sampling practice *s.e.* is estimated as the quotient formed by the standard deviation among sampling units (enumerator) and the square root of the number of sampling units (denominator).

Table 2 Assumed errors in monitoring C stocks (FAO 2010, C stocks in living biomass) for a selection of countries (initial C stock obtained from reported 2005 C stock, baseline C stock is the value reported for 2010, while for the estimated current actual C stock, a reduction in deforestation and forest degradation by 75% is assumed)

Country	C stocks and avoided C losses in million tons							
	C stocks (million tons)				Standard error (s.e.)			Guaranteed emission reduction (Eq. 2)
	Initial	Baseline after 5 years	Estimated actual after 5 years	Avoided C losses $(\overline{e_{red}})$	Relative (*r.s.e.*)	Absolute (*s.e.*, Eq. 1)	Squared *s.e.*	
Cameroon	2844	2696	2807	111	0.010	±22	479	68
Central African Republic	2879	2861	2875	14	0.010	±22	497	-30
Chad	655	635	650	15	0.030	±15	230	-15
Congo	3448	3438	3446	8	0.010	±27	713	-45
Côte d'Ivoire	1847	1842	1846	4	0.010	±14	205	-24
Democratic Republic of the Congo	19838	19639	19788	149	0.005	±77	5888	-1
Gabon	2710	2710	2710	0	0.010	±21	441	-41
Ghana	423	381	413	32	0.030	±10	94	12
Guinea	636	619	632	13	0.030	±15	217	-16
Liberia	605	585	600	15	0.030	±14	196	-12
Nigeria	1317	1085	1259	174	0.030	±30	898	115
Indonesia	14299	13017	13979	962	0.005	±55	3001	854
Lao People's Democratic Republic	1106	1074	1098	24	0.030	±26	656	-26
Malaysia	3362	3212	3325	113	0.010	±26	671	62
Myanmar	1734	1654	1714	60	0.010	±13	178	34
Honduras	368	330	359	29	0.030	±8	71	12
Nicaragua	389	349	379	30	0.030	±9	80	13
Papua New Guinea	2365	2306	2350	44	0.010	±18	334	8
Mexico	2076	2043	2068	25	0.010	±16	258	-7
Argentina	3143	3062	3123	61	0.010	±24	589	13

Table 2 (continued)

Country	C stocks and avoided C losses in million tons							
	C stocks (million tons)				Standard error (s.e.)			Guaranteed emission reduction (Eq. 2)
	Initial	Baseline after 5 years	Estimated actual after 5 years	Avoided C losses ($\overline{e_{red}}$)	Relative (*r.s.e.*)	Absolute (*s.e.*, Eq. 1)	Squared *s.e.*	
Bolivia	4561	4442	4531	89	0.010	±35	1240	20
Brazil	63679	62607	63411	804	0.005	±246	60571	322
Colombia	6862	6805	6848	43	0.010	±53	2819	-61
French Guiana	1654	1651	1653	2	0.010	±13	164	-23
Peru	8654	8560	8631	71	0.005	±33	1120	5
Total sum squared errors							81609	1236 (country level)
Best statistical estimate for expected emission reduction					2888	Total s.e.	±286	2328 (global approach)

reductions is frequently negative (Table 2). In the Central African Republic, for example, the *s.e.* alone (without the 1.96 multiplication factor) is even greater than the avoided emissions. A negative estimated emission reduction would mean, of course, that emissions actually would have increased. However, this could also be only a statistical effect resulting from taking this conservative approach, and may lead to the paradox that a country which has, in reality, reduced emissions is obliged to report increased emissions. Such countries would thus be forced to compensate for hypothetical emissions (e.g. through forest expansion), which most likely have not occurred in reality. In an earlier study, Köhl et al. (2009) mention such effects. The above analysis suggests that a situation where negative emission reductions result from applying the conservativeness principle is not an exception, as it holds for 12 of the 25 countries analyzed.

Moreover, when summing up the national contributions, we see only 1,236 million tons of reduced C emissions which would qualify for REDD+, although the best statistical estimate of the actual emission reduction is 2,888 million tons. If, however, we leave the national-level considerations aside and move instead to the global level - represented here by the aggregated figures for the 25 countries analyzed -, we benefit from the compensatory effects between the errors that occur at the level of individual nations. Such effects are similar to those called risk compensatory effects when analyzing a portfolio of financial stocks. One can assume the *s.e.* obtained for single countries are independent from one another. Under this assumption we may sum the squared *s.e.* and obtain a relatively small total *s.e.* for all of the 25 nations considered together, which is only ±286 million tons C. Using this global level *s.e.* we may still apply the principle of conservativeness according to Eq. 2, but would instead achieve 2,328 million tons of guaranteed reduced C emissions which would qualify for REDD+, with a risk of not actually being achieved of only 0.025.

Another issue to be discussed is the effective insurance fee implicit in using the principle of conservativeness. Guaranteeing emission reductions means that, on average, more emission reductions must be achieved than what, in the end, would actually qualify for compensation through REDD+. Our example shows that, even at the global level, the countries must achieve an average of 560 million tons of emission reductions more than what could be rewarded under the principle of conservativeness. The opportunity costs involved in this additional reduction - obtained for “free” by the industrial nations - would be incurred by the developing nations themselves. It may well be questioned whether this can be considered fair.

3 Conclusions

Climatic change is a global problem, and requires global solutions. We should thus consider a global view when analyzing possible emission reductions achieved by REDD+ mechanisms. Improved records about C stocks in any country contribute to better global information. It is not important if the sampling units are located in Brazil - a huge country with large absolute potential for emission reductions - or in Honduras - a much smaller country with lower absolute potential for emission reductions. Any additional sampling unit enlarges the number of degrees of freedom for our estimates. Of course, for reasons of fairness, detailed requirements on sampling precision to be applied during national C surveys must be defined. However, we should think about whether it is really necessary for each small country to guarantee its emission reductions. Perhaps a global-level guarantee is sufficient. Additionally, agreement must be reached about who actually pays the insurance fee to achieve guaranteed emission reductions.

Another basic problem illustrated by Table 2 is that of accurately measuring fluxes in large C stocks, which, in short periods, remain more or less unchanged over much of their forest area, and where only the relatively small areas where change actually occurs are interesting. If by using remote sensing techniques we stratify, by distinguishing areas which remain more or less unchanged from areas where human activities have actually led to tangible forest loss (this should already be possible) or to forest degradation (this is still rather difficult to quantify), then we can concentrate sampling/ground truthing on those areas which are, in fact, being affected by human activities. Promising results on a similar concept have been reported for example, by Bucki et al. (2012), who stratify forests into intact/non-intact for their remote sensing-based approach. Much better precision of estimates in C stock changes can thus be expected, and even countries with low monitoring capacities can be included in the REDD+ program on this basis.

Finally, the conservation of existing forests remains one of the most cost-effective options for achieving reduction in C emissions (e.g. Fisher et al. 2011; Knoke et al. 2011, 2012). Moreover, it is connected with many co-benefits, such as the possible alleviation of poverty and conservation of biodiversity. Consequently, everything possible must be done to develop practical survey concepts to enable utilization of this option.

The paper by Plugge et al. (this issue) identifies some potentially critical considerations when assessing the combined effects of uncertainties of estimates, conservativeness and costs of monitoring for REDD+. Some of these aspects could, however, potentially be addressed by a global-level approach. Moreover, additional questions may arise, for example, regarding the fairness of implementing the conservativeness principle for evaluating developing countries. Each of these concerns must be carefully considered when designing REDD+ implementation.

Acknowledgments I would like to thank the anonymous reviewer, who improved my springboard editorial substantially by most useful comments. Furthermore, I thank Laura Carlson for the language editing.

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