Journal of Resources Development and Management www.iiste.org
ISSN 2422-8397 An International Peer-reviewed Journal
Vol.42, 2018

The Potential Role of Bamboo within the REDD+ Mechanism: Discussion and Review

Asli Gargili Kuehl[1*] Yannick Kuehl[2] Jose Alan Castillo[3]
1.College of Humanities and Development Studies, China Agricultural University,100083 Beijing, PR China;
2.Hong Kong, PR China
3.Ecosystems Research and Development Bureau, Los Baños, Philippines

Abstract
REDD+ (Reducing Emissions from Deforestation and Forest Degradation-plus) provides financial incentives for forest conservation through storing or enhancing forest carbon stocks. Bamboo is amongst the economically most important nontimber forest products, but only limited scientific and practical evidence is available regarding its potential role in REDD+. As this review shows, however, bamboo can grow in nearly all UN-REDD partner countries. In order to determine its potential role within the REDD+ mechanism, bamboo's possible applications and functions within each of the REDD+ components are discussed. The findings from this study indicate that bamboo could indeed represent an efficient tool in REDD+ – mostly due to its characteristics as a fast growing and highly renewable plant with a wide range of uses and applications. This study demonstrates that bamboo can play an effective role in all components of REDD+. Nevertheless, it also highlights the need for intensified research to fill critical knowledge gaps and provide verifiable data for quantifying emission reductions, baseline scenarios and reference levels for monitoring and evaluation (M&E) of REDD+ projects. Finally, the study argues that bamboo-specific policy making might lead towards an optimal utilization of bamboo within REDD+; especially with regards to bamboo's ability to be regularly extracted.
Keywords: Agriculture, Agroforestry, Ecosystems, Forestry, REDD

1. Introduction

Climate Change represents a major challenge for the environment, development, energy and industrial sectors. Under the changing climate: land and sea surface temperature will rise; heat waves will become more frequent and last longer; extreme precipitation events will become more intense; the ocean will acidify, and sea level will rise (IPCC 2014).

Climate change is largely a result of anthropogenic greenhouse gas (GHG) emissions, mainly carbon dioxide. Unless actions to halt the increasing concentration of CO2 in the atmosphere and stabilize its atmospheric concentration within a range of 450–550 parts per million (ppm) will be implemented, the warming will continue to reach dangerous levels with the already felt impacts likely to intensify further (ADB 2009). Limiting climate change would require substantial and sustained reductions in carbon dioxide emissions (IPCC 2014).

The Land Use, Land Use Change and Forestry (LULUCF) sector, mainly through tropical deforestation, accounts for 17% - 20% of the global GHG emissions (Lasco *et al.* 2011). Reducing the emissions from the forest and land use sector, thus, is an efficient approach to stabilize and to reduce the further increase of the atmospheric concentration of CO2 in order to constrain the impacts of climate change (www.unredd.org). In this context, the scheme Reducing Emissions from Deforestation and Forest Degradation (REDD) and its later version, REDD+, were developed by global policy makers to target this aspect of climate change. REDD+ has been defined as: "mitigation actions in the forestry sector by undertaking the following activities, as deemed appropriate by each Party and in accordance with their respective capabilities and national circumstances: (a) Reducing emissions from deforestation, (b) Reducing emissions from forest degradation, (c) Conservation of forest carbon stocks, (d) Sustainable management of forests and (e) Enhancement of forest carbon stocks" (UNFCCC 2010). REDD+ represents a compensation mechanism for stakeholders for the foregone profits from not cutting down forests for agriculture, urbanization, biomass, energy or other purposes; i.e. it aims at incentivizing stakeholders to conserve, protect or enhance forest carbon stocks. REDD+, thus, represents a global effort to create a financial value for the carbon stored in forests. REDD+ also offers incentives for developing countries to reduce emissions from forested lands and invest in low carbon paths to sustainable development. As an economically important Non-timber forest product (NTFP), bamboo is a key forest product (CFI 2006). Bamboo is popularly known as "poor man's timber" denoting its popularity among poor people as a good substitute for expensive wood from trees (Lobovikov *et al.* 2012). Global data puts the area covered by bamboos to at least 37M ha, which is about 1% of the global forest area (Lobovikov *et al.* 2007). Botanically bamboo is defined as a grass, which typically grows in many forms within forestry or agroforestry systems. It has been argued that promoting the use of bamboo instead of wood from trees (in form of fuel wood, charcoal, wood tiles, walls, beams and columns, furniture, etc.) may reduce pressures on tree-dominated forests thereby helping to avoid further deforestation and forest degradation and therefore contributing to carbon conservation and enhancement (Lobovikov *et al.* 2009).

This paper aims to discuss and analyze the characteristics of REDD+ with regard to bamboo. Challenges, potentials and opportunities of an integration of bamboo in REDD+ activities are determined and discussed to identify and to determine how and if bamboo can contribute to the goals of REDD+. Moreover, recommendations for further research are forwarded. Another goal of this paper is to contribute to the ongoing scientific discussion and analysis of REDD+. The approach of this study is to summarize and synthesize the state of the art knowledge on bamboo with regard to climate change and then to analyze its potential role in light of the components of REDD+.

2. Bamboo and Climate Change Mitigation

Bamboos are fast-growing woody grasses that grow in the tropics and subtropics in mixed forests or as pure stands. They can be cultivated in plantations, on homesteads and on farms. Bamboos are grown for their long, usually hollow, stems (called culms) that can be used as whole or sectioned poles and that yield softwood and fibre for processing; shoots of several species are also edible (Mohanan 2002). Millions of the world's poor people live with and rely on bamboo for their livelihoods, and it can be a significant pathway out of poverty (Belcher 1995; Hogarth & Belcher 2013). However, "remarkably little is known about this entire sub-family of tall graminaceous plants, despite its everyday utilization, by about 2.5 billion people" (Scurlock *et al.* 2000). Besides insufficient research activities, bamboo has been characterized as an "institutional orphan" (Buckingham *et al.* 2011). This indicates needs for increased research activities about bamboo and its utilization. This chapter surveys bamboo's potential in climate change mitigation and adaptation. Figure 1 shows the areas in which bamboo grows naturally.

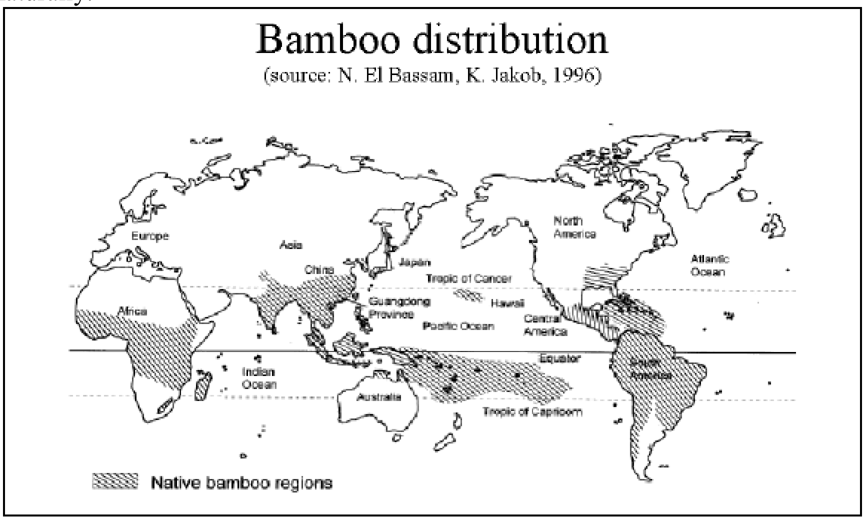

Figure 1. Global Distribution of Bamboo
Source: FAO (2012A)

When comparing Figures 1 and 2, considerable overlaps of countries with UN-REDD National Programmes as well as with UN-REDD Partner countries and the global bamboo distribution can be identified. This means that bamboos grow in many countries which are currently preparing the implementation of REDD+ (Lobovikov *et al.* 2012). The climatic conditions of only 2 UN-REDD Partner countries are not suitable for growing bamboo (Morocco and Mongolia); the conditions in the remaining 62 UN-REDD Partner countries support bamboo production. In addition, of the 33 countries with bamboo resources listed in 2010 Global Forest Resources Assessment (FAO 2010B), 23 are UN-REDD partner countries and they hold around 50% of the global bamboo resources as of 2010. This supports that bamboo's role in REDD+ deserves to be studied. At the same time, Table 1 shows that the 2 countries with the biggest bamboo resources (i.e. Brazil and China) are UN-REDD partner countries. It also needs to be noted, though, that the 2015 Global Forest Assessment does not include a specific category for "bamboo" (FAO 2015), therefore the assessment needs to be made with 2010 data.

Table 1. Bamboo area by country and region

Region	Country	Bamboo area (in 1,000 ha)				UN-REDD Country
		1990	2000	2005	2010	
Africa	Ethiopia	1,000	1,000	1,000	1,000	X
	Kenya	150	150	150	150	X
	Mauritius	n.s.	n.s.	n.s.	n.s.	
	Nigeria	1,590	1,590	1,590	1,590	X
	Senegal	723	691	675	661	
	Sudan	30	30	30	31	X
	Uganda	67	67	67	67	X
	Tanzania	128	128	128	128	X
	Total Africa	**3,688**	**3,656**	**3,640**	**3,627**	
Asia	Bangladesh	90	86	83	186	X
	Cambodia	31	31	36	37	X
	China	3,856	4,869	5,426	5,712	
	India	5,116	5,232	5,418	5,476	X
	Indonesia	1	1	1	1	X
	Japan	149	156	172	188	
	Lao PDR	1,612	1,612	1,612	1,612	X
	Malaysia	422	592	677	677	X
	Myanmar	963	895	859	859	X
	Pakistan	9	14	20	20	X
	Philippines	127	156	172	188	X
	Republic of Korea	8	6	7	8	
	Sri Lanka	1,221	989	742	742	X
	Thailand	261	261	261	261	
	Viet Nam	1,547	1,415	1,475	1,425	X
	Total Asia	**15,412**	**16,311**	**16,943**	**17,360**	
Europe	**Total Europe**	**0**	**0**	**0**	**0**	
North and Central America	Cuba	n.s.	n.s.	n.s.	2	
	El Salvador	n.s.	n.s.	n.s.	n.s.	X
	Jamaica	34	34	34	34	X
	Martinique	2	2	2	2	
	Trinidad and Tobago	1	1	1	1	
	Total North and Central America	**37**	**37**	**37**	**39**	
Oceania	Papua New Guinea	23	38	45	45	X
	Total Oceania	**23**	**38**	**45**	**45**	
South America	Brazil	9,300	9,300	9,300	9,300	
	Chile	900	900	900	900	X
	Ecuador	9	9	9	9	X
	Peru	190	190	190	190	X
	Total South America	**10,399**	**10,399**	**10,399**	**10,399**	
Global Total		**29,560**	**30,442**	**31,065**	**31,470**	
Total UN-REDD Countries		**15,260**	**15,159**	**15,238**	**15,367**	
% in UN-REDD countries		**51.6%**	**49.8%**	**49.1%**	**48.8%**	

Typical climate change mitigation activities in forestry include afforestation/reforestation, forest management and avoided deforestation. Bamboos are amongst the fastest-growing plants in the world, growing up to a meter per day (Lobovikov *et al.* 2012). Unlike trees, bamboos form extensive rhizome and root systems which can extend up to 150 km/ha (Liese 1985). For most bamboo types, culms that emerge from the rhizomes die naturally after about 10 years. The rhizome system, however, survives the harvest of individual culms. That means that – as opposed to most trees – the bamboo ecosystem can be productive whilst continuing to store carbon, as new culms will replace harvested ones (Kuehl *et al.* 2013). The respective lost biomass is usually replaced within a year (Lou *et al.* 2010). Consequently, bamboo can be classified as highly renewable. In order to utilize bamboo's benefits of renewability, it is important that bamboo is tended regularly; studies recommend that 1/5 of standing biomass should be removed annually – this means that total standing above-ground biomass would be replaced every 5 years (Yen & Lee 2011).

As C3 plants, bamboos do not possess the fast C4 photosynthetic pathway (Lobovikov *et al.* 2012), so their main advantages for mitigating climate change lies in their fast biomass generation and in their renewability. Table 2 displays the carbon cycle in a bamboo stand.

Table 2. Pattern of bamboo carbon cycle

	Storage	Release
Above-Ground	• CO_2 sequestration by photosynthesis • Carbon in standing biomass • Carbon in harvested products	• O_2 release • CO_2 release (decomposition of dead organic matter)
Below-Ground	1. Long-term CO_2 sequestration in soil 2. Carbon in below-ground biomass (rhizome and root system) which survives selective harvest	• CO_2 release due to soil respiration

Source: Kuehl *et al.* (2011) (modified)

Bamboos sequester more carbon in the early years of a plantation than comparable forest trees. The biomass of newly planted bamboo forests increases rapidly for more than 10 years before reaching a plateau, at which point emergence and death of culms each year is approximately equal. The biomass of underground rhizome systems follows a similar pattern. Consequently, unmanaged bamboo stands do not store high levels of carbon, as their productivity is low. In managed stands, however, cultivation and harvesting practices enable much higher biomass production per unit area (Lou *et al.* 2010). In a managed stand, mature bamboo culms are harvested before they decay, so the total amount of carbon stored by the ecosystem increases, as new culms will emerge in subsequent years and sequester additional carbon. Unlike trees, which are commonly clear cut, the regular and selective harvesting of bamboo culms does not kill the plant nor damage the ecosystem; moreover below-ground carbon in the soil and rhizome is not emitted as the bamboo ecosystem continues to live after harvest. Therefore, bamboos produce more biomass when selectively and regularly harvested; modeling studies demonstrated that managed bamboo forests can sequester more carbon than fast growing tree species – such as Chinese Fir (Lou *et al.* 2010; Kuehl *et al.* 2013; Yen & Lee 2011). However, these studies assume that harvested culms are turned into durable products. Policy makers recently acknowledged the importance and role of Harvested Wood Products (HWP) and, thus, work towards enabling mechanisms and pathways to include HWP in the accounting of carbon balances.

The potential of managed bamboo stands to sequester carbon depends on the use, lifetime and durability of the harvested material or products. Only replacing old forest products does not increase the total sink function of forest systems. As long as the total volume of forest products keeps increasing, the forest system represents a sink, as the rate of extraction is higher than the rate of release (UK FORESTRY COMMISSION 2012). Bamboo is put to over 1250 uses (Jiang & Peng 2007). However, until recently, the lifespans of many of these products were short (Lobovikov *et al.* 2007). Recent improvements in processing and the development of new types of products mean that many have longer lifespans (Benton *et al.* 2011) – consequently carbon can be stored for much longer, which increases the carbon sink function of the complete bamboo system (ecosystem, processing and final products). In China and in other countries, bamboo plantations are now used for carbon offsetting as verified emission reduction (VERs) in the voluntary carbon market (INBAR 2012).

Bamboo can be applied as a renewable and sustainable substitute. Bamboo is selectively harvested and regularly provides woody biomass. If this harvested bamboo biomass is converted into products which would otherwise be made from non-renewable timber sources, bamboo can take pressure off other forest resources and contribute to avoided deforestation. The renewable and sustainable production of bamboo biomass can be integrated into "permanent agroforestry systems, and as a means to curb the spread of slash-and-burn agriculture" (FAO 2010A). These substitution processes make use of bamboo's characteristic as a fast growing and highly renewable plant.

Bamboo charcoal is recognized as a sustainable alternative to meet household energy demands (Benton *et al.* 2011). Bamboos can help to reduce deforestation by replacing trees for firewood and charcoal, providing a more renewable source of energy (Song *et al.* 2011). Options to use bamboo biomass for gasification have also been explored (NMBA 2007). Also, the use of bamboo as a renewable energy source utilizes its characteristics as a fast growing and highly renewable plant.

The use of and growing bamboo can help to adapt to changing climates and to challenges of extreme weather events. Planting bamboos can be used to reduce soil erosion, as bamboo's extensive root and rhizome system binds the soil. Bamboo can grow on poor soils, so it can be effective in areas prone to runoff – such as steep slopes, river banks or degraded lands (Song *et al.* 2011). That way bamboo can be utilized to increase the resilience of productive ecosystems.

Bamboo is often an integral part of agro-forestry systems (Christanty *et al.* 1997) – directly (e.g. in form of edible shoots or biomass) or indirectly (e.g. by providing windbreaks or shelterbelts). Bamboo culms bend in high winds, but usually do not break– so they are commonly used as windbreaks to protect cash crops (Kigomo 2007). By increasing the variety and season of foods, bamboos can also partially contribute to food security. Nutritious bamboo shoots can be part of human and livestock diets. The shoots of many species are edible, protein-rich and nutritious and they are a common ingredient in many dishes (Song *et al.* 2011). Bamboo leaves are also used as fodder for livestock (IDRC 1989). The fast growth and early maturation of bamboo culms means that a bamboo stand can be selectively harvested just a few years after planting. Regular selective harvesting of bamboo generates a regular income that provides bamboo farmers and an important financial safety net (Ly *et al.* 2012) – this increases their financial resilience. Bamboos' ability to replace wood in high demand products such as furniture or housing, along with biomass energy uses, are of particular importance in adapting to climate change. Bamboos' versatility and unique characteristics provides communities with options to diversify their income options to decrease their sensitivity. Bamboos can be a tool in local coping strategies that aim to increase the resilience of livelihoods (Lobovikov *et al.* 2009).

Bamboos provide a low-energy resource for construction and infrastructure. The culms represent a light and strong material (Benton *et al.* 2011). Bamboos have been popular housing materials for centuries. A Life Cycle Assessment (LCA) study demonstrated that bamboo houses have around half of the environmental impacts of conventional masonry houses – and much of that is due to the bamboo houses' concrete foundations (Murphy *et al.* 2004). Innovation has produced other bamboo structures such as bridges and housing components which are considered to be equivalent to those of more energy-intensive materials (Xiao *et al.* 2009). This means that bamboo can be integrated into a wide range of infrastructure oriented measures – using bamboos instead of trees can reduce pressure on other woody forest resources and help avoid deforestation.

3. Discussion

This chapter analyzes and discusses how the characteristics of bamboo fit into the REDD+ scheme. The discussion in this chapter proceeds on how bamboo may fit into each of the 5 components of REDD+. Bamboo belongs to the family of grasses (Graminae/Poaceae). But bamboos are varied in terms of growth form and excluding the non-woody herbaceous/bush forms of bamboo, the medium to tall woody bamboos are much like trees – in terms of biomass; with cellulose, hemicelluloses and lignin accounting for over 90% of total biomass, with stems (culms) that can reach heights of 15-20m, with diameters of over 30cm and with wood densities that resemble trees (Lobovikov *et al.* 2007).

REDD+ is targeted at the forestry sector and its scope does not exclude non-tree plants. However, national definitions and classifications of forests and trees are not uniform; i.e. if bamboo is part of "forests" depends on the respective national definition. "The term 'forest' refers to woody vegetation, but it is also linked to specific institutions empowered to manage forests. For example, the FAO statistics on forest cover suffer from ambiguity in definitions and the way these are used. In many countries, custodians of woody vegetation outside institutional forests tend to have an ambivalent relationship with forest authorities" (ASB 2013). Such an ambiguity also affects land use systems which might be climate effective, but not clearly defined as forests – such as agroforestry. This makes a general and global discussion on this topic difficult, as the situation varies from country to country. Some definitions, for example the FAO forest definition (FAO 2006), include bamboos (and other tall woody grasses) – others do not. For the utilization of bamboo within REDD+, it is a pre-condition that the respective national definitions and classifications recognize bamboo as part of forestry. This lack of globally uniform classifications and definitions also represents a problem for policy and decision makers.

Currently, there are 64 UN-REDD partner developing countries in Africa, Asia-Pacific and Latin America (UN-REDD 2013A). Figure 2 displays the countries with UN-REDD National Programs (highlighted in dark colors) and the UN-REDD Partner Countries (highlighted in lighter colors).

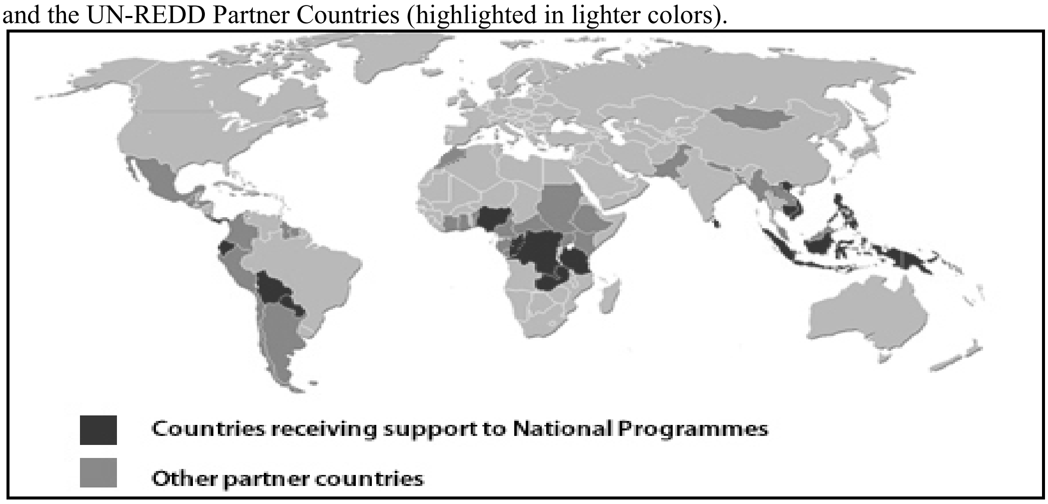

Figure 2. Countries with REDD+ Activities
Source: UN-REDD (2013A)

In order to assess whether bamboo is already specifically integrated in REDD+ strategies, this study reviewed the submitted official strategy documents of the 27 countries with UN-REDD National Programmes. This basic review simply searches for specific mentions of the term “bamboo” within submitted strategy documents (see Table 3).

Table 3. Review of strategy documents of Countries with UN-REDD National Programmes

Country	“Bamboo” Mentioned?
Congo	No
Cote d’Ivoire	No
Democratic Republic of the Congo	No
Nigeria	No
Republic of Zambia	No
Tanzania	No
Uganda	No
Zambia	No
Argentina	No
Bolivia	No
Chile	No
Colombia	No
Ecuador	No
Honduras	No
Panama	No
Paraguay	No
Peru	No
Bangladesh	Yes
Cambodia	Yes
Indonesia	No
Mongolia	No
Myanmar	No
Papua New Guinea	No
Philippines	No
Solomon Islands	No
Sri Lanka	No
Vietnam	Yes

As can be seen in Table 3, only 3 out of 27 countries specifically mention “bamboo” in their REDD+ strategy. This does not imply that bamboo is excluded in the respective strategies of the other countries, but it indicates the lack of a specific bamboo strategy. With regard to the tree and forest classification definition: bamboo might be classified as a regular component of a forest in some of these countries, which simply does not require specific mentioning. However, compared to many trees, bamboo indeed holds different characteristics and requirements with regard to growth and management. Therefore, it is questionable if assimilating them with trees is the optimal solution for policy making processes. For example, as explained before, bamboo can be regularly extracted without threatening the sustainability of the ecosystem, as the rhizome and root system survives selective harvest. As most trees do not hold comparable characteristics, many forest carbon mechanisms ban or punish biomass removal. Such a ban limits bamboo’s potential capacity as a climate change mitigation tool.

Globally, there are around 31.5 million ha of bamboo forests (FAO 2010B). REDD+ targets existing forests and their conservation, so these figures show that bamboo is a relevant part of global forests and can, thus, have significant policy leverage. It should be noted here that the 31.5 M ha do not include data from all countries which have bamboo resources and that “there is clearly a need for better internal communication and more accurate assessments of the area of bamboo in many countries” (FAO 2010B). This needs to be changed, as resource assessments and related reliable, standardized and comparable data are prerequisite for the introduction of REDD+ programs. In order to be able to protect existing bamboo forests, it is important to assess the quantity and state of bamboo resource on country-level.

The mentioned limited data availability and policy confusion of bamboo links to challenges with regards to the definition of reference levels and baseline scenarios and M&E in general. In this context, it is imperative to map and quantify existing bamboo resources on country level and to assess the quality and condition of these existing resources. Also, research on the impacts of management to bamboo resource need to be intensified – in order to be able to quantify impacts of bamboo-related REDD+ initiatives.

Some studies argue that not considering bamboos as plants which can form a forest increases their vulnerability for conversion to other land uses since no carbon payments can be generated within forestry schemes like REDD+ (Lobovikov *et al.* 2009). Policy makers reacted to this limitation, by widening the eligible land uses for creating emissions reductions. This is why, recently, concepts for climate change mitigation schemes which include agricultural land uses (besides forestry) have been discussed (FAO 2013). Some experts expect that the range of eligible land uses will be further extended; i.e. the REDD+ mechanism might be extended to REALU (Reduced Emissions from All Land Uses) (ASB 2013). Such extensions would make the discussion about definitions and classifications less relevant.

3.1 Reducing Emission from Deforestation

Clearing forest land to make way for more profitable land-uses is considered a main driver of deforestation in the tropics; as pointed out, up to 20% of total global GHG emissions stem from the LULUCF sector, mainly from tropical deforestation. Under this REDD+ component, deforestation must be shown to be on-going to merit carbon payments for communities. Countries which show an increasing forest cover cannot expect carbon payment since deforestation is already declining even without carbon payments (Lasco *et al.* 2011). For this argument, however, it is important to assess the local level, as forest losses and gains can occur simultaneously in the same country (FAO 2012B). That is why it is questionable if a country-level assessment of forest cover change is the adequate level for such an assessment.

The situation regarding bamboo resources on the country-level is not uniform: bamboo areas in some countries have been expanding in the last years (e.g. China, India and Malaysia), in others they have been decreasing (e.g. Bangladesh, Indonesia and South Korea) (FAO 2007). Therefore, a global assessment on this component is not possible; only specific local data can provide conclusion on whether bamboo is under threat of deforestation. In addition, as mentioned above, not all national forest or tree definitions are uniform and consider bamboo. In this context, it is also important to question if bamboos can be under threat of deforestation in countries in which bamboos are – by definition or classification – not considered as trees or part of forests.

In Asia alone, there are 21M ha occupied by bamboo either as pure stand or mixed with trees (Lobovikov *et al.* 2009). In the light of REDD+ framework, tall and medium bamboos in diffuse or cluster form should be included in order not to "single them out for conversion to other land uses" (Lobovikov *et al.* 2009). An exclusion of bamboo and other NTFPs could result in biomass and carbon loss, because they would not be "protected" through REDD+. In this context, it should be considered that "NTFPs have an important role in forests and – consequently – in their conservation" (Nadkarni & Kuehl 2013).

Bamboo, as a wood substitute, might reduce pressure on standing forest trees. Over 1250 uses for bamboo have been recorded, but if and where bamboo can act as a full substitute needs to be reliably defined by research. In addition, it is questionable if markets will fully adopt available and possible substitution opportunities. Nevertheless, successful use of bamboo in a wide range of different products demonstrates the high potential for bamboo as a sustainable "potential key substitute for timber, cotton, construction material and edible products" (Buckingham 2009). Therefore, further promotion and research of bamboo as a renewable and sustainable substitute should be advocated. The fact that bamboo is such a useful commercial plant creates respective demand. Depending on factors like land ownership, access, availability of bamboo resources and a range of other socio-economic and environmental issues, such demand could either motivate stakeholders towards sustainable management or lead to overexploitation of the resource. In cases where overexploitation threatens bamboo resources, REDD+ could provide incentives to protect the bamboo resources.

Bamboo is regarded a very resilient and strong plant. Some bamboo species – especially monopodial species – have even been considered to be invasive (Czarnota & Derr 2007). Therefore, it is questionable if bamboo is under similar threat of deforestation as trees. Moreover, there are countries in which the bamboo area is increasing – e.g. China saw an annual increase of bamboo area of 3% since 1980 (Cao *et al.* 2011). On the other hand – in other countries – bamboo resources are under pressure from deforestation; several bamboo species are even listed on the "IUCN Red List of Threatened Plants" indicating that they are under threat of being extinct (Bystriakova *et al.* 2004). This means that bamboo resources can indeed be under threat of deforestation or degradation, as such they could play a role within this REDD+ component.

As outlined above, bamboo can take pressure of forests by acting as an alternative and substitute product to wood from trees (FAO 2010A). So, avoided deforestation is an important role that bamboo can play with regard to reducing emissions from deforestation. The sustainable use of bamboo as a substitute can prevent the unsustainable use and harvest of trees. This concept seems to be an attractive feature of bamboo in REDD+, however, quantifiable data on the substitution and adoption processes and the resulting avoided deforestation are rare. Therefore, the impacts need to be further researched and quantified in order to yield verifiable emission reductions. Nevertheless, this represents a potentially important and stand-alone feature of bamboo within REDD+.

3.2 Reducing Emission from Forest Degradation

Forest degradation is the decrease in carbon locked in the biomass lost in a forest stand through harvesting or other reasons. Communities in forest areas may benefit through carbon payments under the reduced emissions from forest degradation component by shifting to alternative and sustainable sources of biomass for fuel wood, raw material, charcoal or construction. Bamboo can contribute to reducing forest degradation as an alternative fuel wood and material for wood-based construction. Bamboo has the advantage of faster biomass production and growth, as well as earlier maturity. The bamboo biomass and the carbon stock lost from harvesting will be replenished in shorter time compared to harvested trees (Henley & Lou 2009; Lobovikov *et al.* 2009).

Bamboo has proven to be an effective tool in regenerating degraded lands or rehabilitating degraded ecosystems (INBAR 2003). As such bamboo can play an important role in re-establishing forests – especially mixed forests including trees and other plants. Mosaic degradation, i.e. partial degradation of large forests, can also be combated through planting bamboo in the respective areas (such as riverbanks or steep slopes) – that way the overall resilience of the forest can be increased.

As shown before, incidences of degraded bamboo stands exist. Intensive or unsustainable management practices can lead to degraded bamboo stands (with decreased standing biomass, decreased resilience and productivity). In this context, it is essential to define the driving forces for such degradation. By doing so, effective strategies to avoid bamboo forest degradation can be developed for the application in the REDD+ mechanism. Additionally, it is important to consider if a definition for degraded bamboo stands exist.

Bamboos are an important component of agroforestry systems (Kumar *et al.* 2002). These systems might not fall into the category of "forest" degradation, as they might not meet the classification requirement of a "forest", but they represent multifunctional systems which provide food, feed, energy, biomass as well as other goods and services to communities. Therefore, such systems have the potential to reduce pressure on forests through the provision of a wide range of substitution products and services. As such, bamboo agroforestry systems can contribute to reduced forest degradation within REDD+ through reducing pressures on "forest" systems.

3.3 Conservation of Forest Carbon Stocks

Forest communities can also earn carbon payments by conserving forest carbon stocks. Studies in China revealed that bamboo ecosystems fix 1.69 and 1.63 times as much C as Chinese fir or Mason pine forest ecosystems (Jiang *et al.* 2011). This indicates that bamboo ecosystems have a large potential for the conservation of forest carbon stocks, as they can sequester and store high levels of carbon. Thus, bamboo can act as an effective plant within this component.

Bamboo holds characteristics of gregarious and partial flowering (Kuehl *et al.* 2013). This characteristic could lead to uncertainty regarding the permanence of carbon stocks in bamboo forests. On the other hand, flowering triggers the release of seeds – which can re-establish a new ecosystem. Therefore, it is unlikely that carbon is permanently lost through flowering. In addition, databases and knowledge on the flowering determinants for many commercial bamboo species exists. Nevertheless, flowering has to be carefully considered when developing related bamboo projects. Moreover, it is advised that monitoring and research on bamboo flowering cycles is further extended.

Bamboo is generally considered a resilient and tolerant plant. Nevertheless, they can be affected by pests and diseases. In this context, it is important to point out that bamboo pests and diseases are little investigated and – consequently – available control measures can be limited (Mohanan 2002). Pests and diseases can represent a serious a severe threat to efforts aiming at conserving forest carbon stocks. Therefore, it is recommended to extend research on bamboo pests and diseases and available control measures.

Planting bamboo can increase resilience against extreme climatic events (e.g. erosion, floods) and protect ecosystem. By increasing resilience, bamboo can help to conserve forest carbon stocks. Therefore, bamboo can contribute to this component of REDD+, also to protect larger mixed forests – particularly in risk areas (such as river banks or steep slopes).

Bamboo has a high tolerance and is suitable to grow on degraded lands. This characteristic can be useful for conserving forest carbon stocks – through improving the soil quality or through protecting other plants from floods, storms or erosion. In addition, bamboo has a comparable high share of below-ground biomass. Moso bamboo, for example, stores 66.6% of its total carbon below-ground (Isagi *et al.* 1997). Below-ground biomass is less susceptible to pest and diseases, natural disasters, fires or harvest; therefore bamboo might represent a safe and efficient tool for conserving forest carbon stocks within REDD+.

3.4 Sustainable Management of Forests

In REDD+, communities can also receive carbon payments for the sustainable management of forests. As pointed out before, sustainably managed bamboo stands can produce more biomass than comparable trees, as they can be periodically harvested. Many studies pointed out the significance of managing bamboo forests for their carbon sequestration potential (Kuehl *et al.* 2013; Yen & Lee 2011). Therefore, this REDD+ component is particularly relevant to bamboo.

For bamboo, the life of un-harvested mature culms in non-managed stand will be about a decade before their decay. As a result, an unmanaged bamboo forest does not store high levels of carbon, as the carbon accumulated during the rapid growth also returns relatively quickly to the atmosphere as the culms decay (INBAR 2009). In managed stands, mature bamboo culms are removed before they decay, so the net amount of carbon sequestered by the system increases. The periodic and selective harvesting of (mature) bamboo culms does not kill the ecosystem, as sustainable bamboo management implies that carbon is stored below-ground in the rhizome layer and instead encourages production of more shoots and larger biomass for culms (INBAR 2009).

Extensively managed bamboo forests have a carbon stock of 288.5 t C/ha while intensive management systems can have 262-227 t C/ha (Lou *et al.* 2010). Sustainable management of bamboo can improve the productivity of the stand and – consequently – its carbon sequestration and storage capacity. On the other hand, the type of management needs to be considered, as studies demonstrated that management practices impact the carbon sequestration capacity of bamboo ecosystems; intensive management of bamboo stands decreased carbon sequestration by 9.1% (compared to extensive management) (Zhou *et al.* 2011). In this context, it is also important to consider that "the growth performance of bamboo in mixed stands exceeds the performance found in pure stands" (Fu 2001), so bamboo can also be an effective tool within mixed forests and their respective sustainable management measures.

In order to assess the potential global impact of sustainable management of bamboo resources, it is important to quantify the share of non-managed and managed bamboo resources. Moreover, many aspects of bamboo management and its impacts on carbon sequestration are only inadequately researched. Therefore, it is difficult to quantify emission reductions from sustainable bamboo forest management measures. Concluding, though, that bamboo also offers scope to be an effective tool in this REDD+ component.

3.5 Enhancement of Forest Carbon Stocks

Communities can also earn carbon payments under the enhancement of forest carbon stocks component of REDD+ which is targeted at open, denuded and under stocked forest lands. Bamboo-based agroforestry systems are very popular across the globe, for example in China and Indonesia (Mailly *et al.* 1997; Xu & Nie 1994). The successful examples of integrating bamboo in a range of agroforestry systems – as outlined before – is also relevant for the discussion of bamboo's potential to enhance carbon stocks; as such systems can represent pathways to sustainable management practices and resulting enhanced carbon stocks. These systems also represent opportunities for providing substitutes which can reduce pressure on forests and – consequently – enhance forest carbon stocks. Similarly, bamboo can also be used for afforestation and reforestation (A/R) activities (Lasco *et al.* 2011). Several studies regard bamboos as an effective tool for A/R activities – due to its high carbon sequestration rate (Cao *et al.* 2011). A/R activities, however, are outside of the scope of REDD+.

Bamboo has the advantage to be able to grow on degraded, open forest lands which are otherwise not suitable for growth of trees due to limited soil nutrients. As such bamboo can be used to enhance carbon stocks of existing forests, i.e. through assisted natural regeneration.

Reported above-ground biomass values of medium to tall bamboos such as Gigantochloa levis (146.80 t/ha), Schizostachyum lumampao (58.2 t/ha), Phyllostachys pubescens (137.9 t/ha) and Bambusa blumeana (143 t/ha) are roughly similar to that of fast-growing tree plantation species such as Gmelina arborea (127 t/ha) and Paraserianthes falcataria (75.6 t/ha) (Suzuki & Jacalne 1986). These figures indicate that bamboo, if adequately managed, has potential to enhance forest carbon stocks – especially considering that bamboo can also thrive in mixed forests.

4. Conclusions and Recommendations

This study analyzed bamboo's characteristics according to the 5 components of REDD+. It demonstrated that bamboo can play a role in all components of REDD+. Nevertheless, the study also highlights the need for intensified research in order to overcome knowledge gaps and provide verifiable data for emission reductions. A precondition for the full applicability of bamboo within REDD+ is that reference values and baselines for the respective resources are defined, in order to allow for adequate M&E. Current bamboo resource assessment data are not sufficient. The first step to do so, are country-level, regional-level and global assessments of the quantity and state of existing bamboo resources.

An FAO (2010A) study states that "not considering tree-like bamboo stands as forests in the REDD-processes neglects significant carbon stores, highly effective carbon sinks and proven pillars of rural livelihoods. It invites the destruction of bamboo forests". This present study also showed that an important role of bamboo within REDD+ could be its ability to act as a substitute for non-renewable forest products. With regard to bamboo as a substitute to avoid deforestation, "incentives for bamboo plantations could become an important component of a REDD strategy" (FAO 2010A). In this context, interdisciplinary research on these substitution processes and quantification of respective impacts is recommended.

However, the integration of non-tree species into schemes like REDD+ faces specific hurdles, such as sampling designs, carbon assessment methods and default parameters – which are available for trees but might not accurately apply to bamboo (FAO 2010A). Therefore, further research and development of specific respective methods and approaches are strongly suggested – especially with regard to bamboo's ability to be regularly harvested, a necessary input to determine baselines and reference levels.

Moreover, policy makers need to be made aware of the potentials bamboo offers in mitigating and adapting to climate change. Intensified promotion of bamboo's potentials is thus recommended. Pilot sites are needed to demonstrate bamboo's unique role and potential benefits within REDD+. Accordingly, a more structured approach to scientific and policy exchange is recommended. Such processes should involve China and India and other southern countries, in order to realize the global potential of bamboo (Buckingham *et al.* 2011).

The study highlighted the confusion regarding the definition and classification of bamboo; if bamboo is regarded as a tree or part of forest depends on the national definitions. An evolved form of REDD+ might represent an opportunity for bamboo and other NTFPs, as the focus rather lies on land use options and respective verifiable emission reductions and not on discussions about definitions or classifications. Consequently, not only bamboo, but also other climate effective land uses and plants would benefit from such an evolvement of REDD+. This study argues that bamboo specific policy making might provide pathways to optimal utilization within REDD+ and similar carbon schemes. Bamboo is "similar but not equal" due to different growth characteristics, utilization and application options, but also due to its management requirements; the most significant difference is, however, bamboo's potential for regular and sustainable harvest.

In many parts of the world, bamboo is an integral part of forests, but not the main part; in other parts bamboo can represent the dominant species. Bamboo can grow in mixed forests, monocultures, agroforestry systems or specific niche systems. Bamboo's role and importance in these different systems should be quantified to assess bamboo's effectiveness within REDD+. This will allow the development of adequate policy and management recommendations.

This study shows that bamboo seems well placed to contribute to the goals of REDD+ of pursuing multiple benefits in order to protect forests and their carbon stocks. But bamboo plantations can raise concerns about biodiversity – especially monopodial bamboo can be considered invasive. Therefore – similar to other plants – the impacts on biodiversity and other environmental aspects should be considered when integrating bamboo in REDD+ activities. In this regard, it is also suggested to extend respective research efforts. It can be concluded that bamboo's advantages lie in the fact that it can combine mitigation, adaptation and rural development efforts into one, such comprehensive opportunities are in line with the aims of REDD+. Therefore, provided that adequate data exists, bamboo can represent an effective and versatile option in REDD+ activities.

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