Bamboo's Global Carbon Sequestration Potential for Climate Change Mitigation

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Widmung / Dedication

Ich widme diese Masterarbeit meinen Großeltern, in deren Gärten ich als Kind spielen, wo ich spielerisch die Pflanzen- und Tierwelt erkunden und somit der Natur nahe aufwachsen konnte. Insbesondere widme ich diese Arbeit meiner kürzlich verstorbenen Großmutter, welche mich bedingungslos in meinem Leben moralisch und finanziell trotz weniger Möglichkeiten unterstützt hat und leider das Resultat meines Studiums in Umweltwissenschaften und dieser Arbeit nicht mehr erleben kann. Und ich danke meiner Mutter mit dieser Arbeit für ihren unumstößlichen Zuspruch und Ermutigung in meinen harterarbeiteten internationalen, professionellen und akademischen Errungenschaften.

I dedicate this master thesis to my grandparents in whose gardens I played as a child, where I could playfully explore the flora and fauna and, thus, grow up close to nature. In particular, I dedicate this work to my recently deceased grandmother, who unconditionally supported me morally and financially in my life despite limited opportunities and who unfortunately can no longer experience the result of my studies in environmental sciences and this work. And with this work, I thank my mother for her incontrovertible encouragement and motivation in my hard-won international, professional and academic achievements.

Dedico esta tesis de maestría a mis abuelos en cuyos jardines jugaba de niño, donde pude explorar lúdicamente la flora y la fauna y, así, crecer cerca de la naturaleza. En particular, dedico este trabajo a mi abuela recientemente fallecida, quien me apoyó incondicionalmente moral y económicamente en mi vida a pesar de las limitadas oportunidades y que lamentablemente ya no puede experimentar el resultado de mis estudios en ciencias ambientales y este trabajo. Y con este trabajo, agradezco a mi madre por su incontrovertible aliento y motivación en mis logros internacionales, profesionales y académicos ganados con tanto esfuerzo.

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1. Abstracts

Weltweit werden die Länder dazu aufgerufen, Strategien zur Eindämmung des Klimawandels zu verabschieden. Eine CO_2-Entfernung durch Abscheidung und Speicherung von Kohlenstoff wird als wesentlich angesehen. Eine Option ist die Kohlenstoffbindung durch als Senken dienende Forstplantagen. Bambusse haben aufgrund ihres schnellen Wachstums und ihrer vielseitigen Verarbeitungsmöglichkeiten zunehmend Aufmerksamkeit erhalten. Mit dieser Arbeit soll abgeschätzt werden, wieviel CO_2 gebunden werden kann, wenn allen Ländern, in denen Bambus für den Anbau geeignet ist, eine bestimmte Fläche für das Anpflanzen von Bambussen zugewiesen werden würde. Es wird diskutiert, welche Wirkungen von Waldplantagen und Bambussen resultieren können und ob aufgrund dieser Wirkungen Bambuswaldplantagen zur globalen CO_2-Speicherung aus Sicht internationaler, politischer Instrumente realisierbar sind. Auf der Grundlage von Sekundärdaten werden Sequestrierungspotenziale bis zum Jahr 2070 hochgerechnet und eine ausgiebige Literaturrecherche und Analyse erörtert mögliche Konsequenzen von Waldplantagen und Bambussen. Im Resultat benötigen Bambusplantagen weniger Platz als traditionelle Waldplantagen mit nicht zu vernachlässigendem Sequestrierungspotential. Allerdings muss die Bambusverarbeitung in die Markwirtschaft integriert werden. Aus politischer Sicht sind Bambusse in internationalen Abkommen bereits berücksichtigt und damit anwendbar. Jedoch müssen gesonderte Definitionen gefunden werden, um Bambusse in traditionellem Forstmanagement von Bäumen zu unterscheiden.

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Countries around the world are called upon to adopt strategies to contain climate change. Comprehensive CO_2 removal through carbon capture and storage is seen as essential. One option is carbon sequestration by means of forest plantations serving as natural sinks. Bamboos have received increasing attention due to their rapid growth and versatile processing options. The aim of this thesis is to estimate how much CO_2 can be sequestered if all countries in which bamboo is suitable for cultivation are allocated a certain amount of space for planting bamboos. It is discussed which effects can result from forest plantations and bamboos, and from the perspective of international, political instruments whether bamboo forest plantations for global CO_2 storage are feasible based on these effects. On the basis of secondary data, sequestration potentials are extrapolated up to the year 2070, and extensive literature research discusses possible consequences of forest plantations and bamboos. As a result, bamboo plantations require less space than traditional forest plantations with a non-negligible sequestration potential. However, bamboo processing must be integrated into the market economy. From a political point of view, bamboos have already been taken into account in international agreements and are therefore applicable, but separate definitions must be found in order to distinguish bamboos from trees in traditional forest management.

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Se pide a los países del mundo que adopten estrategias para contener el cambio climático. La reducción de CO_2 mediante la captura y almacenamiento de carbono se considera esencial. Una opción es el secuestro de carbono a través de plantaciones forestales que sirven como sumideros. Los bambúes han recibido una atención cada vez mayor debido a su crecimiento rápido y opciones de procesamiento versátiles. El objetivo de esta tesis es estimar la cantidad de CO_2 que se puede acumular si a todos los países en los que el bambú es apto para el cultivo se les asigna un espacio determinado para plantarlos. Se discute qué efectos pueden resultar de las plantaciones forestales y bambúes, y desde la perspectiva de los instrumentos políticos internacionales si las plantaciones forestales de bambú son factibles para el almacenamiento global de CO_2. Basado en datos secundarios, los potenciales de secuestro se extrapolan hasta el año 2070, y una extensa investigación bibliográfica analiza las posibles consecuencias de las plantaciones forestales y los bambúes. Como resultado, las plantaciones de bambú requieren menos espacio que las plantaciones forestales tradicionales con un potencial de secuestro no despreciable. Sin embargo, el procesamiento del bambú debe integrarse en la economía de mercado. Desde un punto de vista político, los bambúes ya se han tenido en cuenta en los acuerdos internacionales y, por lo tanto, son aplicables, pero se debe encontrar definiciones particulares para distinguir los bambúes de los árboles en el manejo forestal tradicional.

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2. Introduction

This present paper has attempted collecting a wealth of secondary data on carbon sequestered in different bamboo species' biomasses, and from which to estimate how much carbon can be accumulated in bamboos over time for the purpose of mitigating atmospheric carbon dioxide. The idea of using bamboos for carbon sequestration in form of forest plantations will be explored from primarily ecological aspects but also refer to relevant social and economic aspects, which speak in favour and disfavour of the plant as well as forest plantations. The topic of carbon sequestration by means of bamboo forest plantations on a global scale will be looked at through the lens of political forestry and climate change frameworks. The guiding question has been whether bamboo forest plantations are a viable means for atmospheric carbon dioxide reduction and, consequently, climate change mitigation.

The primary methodology of this paper rests in extensive literature review for relevant knowledge on the topics of tree plantations and bamboos as well as for the retrieval of secondary data on carbon sequestration by different bamboo species. Furthermore, countries with relevant climate conditions will be identified, and the bamboo species that grow or might grow in those countries.

Past the brief background of the topic and the subsequent outline of the applied methodologies, this paper opens with the chapter on the contextual settings, introducing some of the concurrent international regulatory frameworks and mechanisms which address climate change and carbon dioxide reduction, in particular with reference to forestry. Following, commonly critiqued aspects of tree plantations are discussed in order to highlight many issues that come with such plantations. The critical, related and unique aspects are then furthered specifically for bamboos, addressing some of their positive, negative and ambiguous impacts. It may appear too extensive to go into much detail on the topic of bamboos; however, glossing over the plant too quickly is exactly the issue surrounding the plant: lack of awareness and misunderstanding.

After the extensive theoretical backdrop, the carbon sequestration potentials will be estimated. That chapter outlines every step and consideration for the arrival at the estimated values, which includes inconsistencies in measuring carbon data among bamboos and the resulting short-coming and steps trying to remediate them.

Finally, the estimated carbon sequestration potentials are put into perspective with actual carbon dioxide emission sources, land use as well as carbon sequestered in natural forests. The results will be contrasted with actual carbon dioxide emissions in the world and carbon stocks in tropical forests. The feasibility of bamboo forest plantations will finally be discussed in the context of international forestry and climate change policy. Bamboo forest plantations will be examined from ecological but also social and economic perspectives, before tying everything back into the international policy context.

It must be noted that forest plantations for climate change mitigation can be debated from remarkably numerous angles. Indeed, there is so much to say about bamboos alone, it may better fit a series of papers with each picking one perspective than a single paper like this one trying to apply *interdisciplinary* perspectives. It is out of scope to go into every single aspect that has been debated in the academic and public discourse. It may not be a surprise that the topic has been in discussion without much accord for decades.

It is acknowledged that the estimations may or may not be accurate, as they are based upon individual sequestration estimations among different bamboo species with plenty uncertainties. It is a fact that bamboos have remained an under-researched topic with a variety of knowledge shortcomings if not contradictions. Due to this fact, this paper is also meant to serve as a knowledge compendium by trying to summarise, highlight and discuss the many aspects around bamboos.

3. Background

The 2015 Paris Agreement stated that country efforts to stay below 2 °C average global warming have to take effect "as soon as possible" and need to be strengthened "significantly", while costing needs and financing options need to be considered particularly for developing countries (UN, 2015). Extensive carbon dioxide removal "through managed biomass growth and subsequent carbon capture and storage" is considered essential to avoid exceeding the temperature increase (Boysen et al., 2017). For this purpose, most if not all countries have pledged to reduce their carbon emissions by 2030, and to develop long-term strategic plans.

One way to remove atmospheric carbon is carbon sequestration. The concept suggests to capture carbon dioxide in solid matter after it was released through the burning of fossil fuels or as an industrial by-product. It is distinguished between industrial and natural carbon sequestration methods. The latter primarily refers to planting or improved management of biomass, and in particular trees, with the aim to absorb carbon dioxide through photosynthesis and keeping it sequestered as carbon in a plant's biomass (Jansson et al., 2010). For this method, steadily increasing attention-receiving plants are bamboos. Bamboo forest biomasses have shown to rival natural forests by storing significant amounts of carbon over- and underground as well as after harvesting (Kuehl, Henley and Lou, 2013). Bamboos have rapid growth characteristics and versatile processing and application possibilities.

Research exists on carbon sequestration for a variety of plants of terrestrial and aquatic zones. For terrestrial areas, several tree species have been researched. Fast-growing *Eucalyptus camaldulensis* (i.e. Du, 2015; Keeratiurai et al., 2012; Zhang et al., 2020), acacia (i.e. Zhang et al., 2020), legume and Leichardt pine (i.e. Keeratiurai et al., 2012), or Chinese fir (*Cunninghamia lanceolata*) (i.e. Yen and Lee, 2011) are some examples. However, trees require growth periods of between 10 and 30 years until they reach their optimum state for carbon sequestration (Australian Greenhouse Office, 2001: 14). The difference and most important aspect of bamboos is that they sequester carbon fast, since they grow at a much faster pace than trees. Lou et al. (2010: 16, 17) reported that Moso bamboo (*Phyllostachys pubescens*) within its first 5 to 6 years growth period sequesters more carbon than Chinese fir. Another important aspect is that bamboos' rapid growth allows for a frequent harvest, after which the plant can regenerate fast. The harvesting aspect requires keeping in mind that bamboos need to be managed just like other agroforestry plantations.

4. Methodology

The paper is structured in layers to address the topic in a multidisciplinary way. The chapter on the contextual settings introduces international political agreements on or related to climate change mitigation and adaptation as well as forestry development. The introduction of these frameworks creates the 'frame' of this paper by highlighting certain elements in those frameworks which are necessary to address by bamboo forest plantations for the purpose of climate change mitigation by means of carbon sequestration.

The following chapter discusses crucial aspects of planting trees, or better tree plantations on a large scale. The topic is primarily concerned with ecological aspects, but also introduces relevant social and economic aspects as they necessarily relate to earlier settings.

Then, bamboos are introduced regarding their characteristics and the beneficial, detrimental as well as contradictory or uncertain consequences they can have. It cannot be stated yet that enough experiences exist that would justify discussing bamboos and tree plantations as one combined topic from the start; the entire issue with bamboos originates from the plant being misunderstood and lumped together with trees – which they are not. The approach to these chapters is based on extensive literature review and analysis, including research articles, case studies and other information references to obtain relevant knowledge and annotating the missing of such knowledge on bamboos.

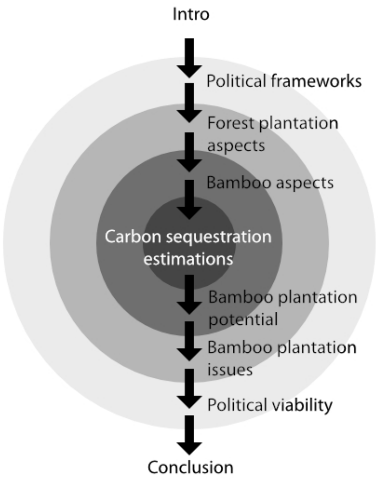

Figure 1: Illustrative structuring of the topic.

The core of the paper are the approximate estimations of the carbon sequestration rates which could theoretically be achieved if all countries, where bamboo species can be cultivated, allocated a certain amount of space for bamboo planting. The approach was to collect secondary data on bamboos' biomasses and/or carbon as sequestered in the biomasses. Retrieving such data required narrowing down the relevant (tall-growing) bamboo species for carbon sequestration, and then the bamboo species for which such data is available. As there are 1600 and more species, it required a meticulous comparison of multiple sources. As there have been numerous difficulties in retrieving and aligning the relevant data due to inconsistencies in research on bamboos, every undertaken step will be explained in the corresponding chapter.

For this purpose of identifying all the potential countries where bamboos grow or might grow, comparisons with existing documentations were made, primarily based on Ohrenberger's work on documenting bamboos (1999). Further potential countries for bamboo cultivation were identified by means of the Köppen-Geiger climate classification (as in Beck et al., 2018).

In addition to identifying the relevant countries, space allocations for bamboo planting needed to be made. The considerations have been based on existing natural forests and bamboo forests and the space they occupy, and subsequently expanded upon in reference to space allocations made by other authors. As a result, different space scenarios find consideration.

In the outcome, a 'conservative' minimum sequestration rate and an 'optimistic' maximum sequestration will be presented, which are used to extrapolate the sequestration potential over several decades up to 2030, 2050 and 2070. Each time reference was chosen either from the political frameworks, as they reference them, or from relevant authors and their estimations for comparison. The estimations consider distinctions in aboveground and belowground sequestration, whereas the main focus rests on aboveground sequestrations rates. Data for belowground sequestration estimations are too scarce. Carbon contained in soils are discussed too, but not estimated as even less data was available. Further considerations in the estimations include the harvesting and re-growing of biomass as well as an indicative decay rate of wooden products as to account for continuous carbon intake and release over time.

Once the estimated sequestration rates have been established, they will be discussed and compared to current carbon dioxide emission sources, emission reduction targets (as set out by the major political frameworks) and carbon sequestration rates of standing forests. This has the purpose of illustrating what the abstract numbers mean and, thus, highlight the global carbon sequestration potential of bamboos.

Following the estimations, the viability of such bamboo forest plantation scenarios is discussed from pro and contra aspects by referring back to and tying together the individual aspects from tree plantations and bamboos. By doing so, it becomes apparent that bamboo forest plantations' carbon sequestration potential hinges on plantation management (harvesting) and repurposing of the harvested materials for longevity, which is tied to socio-economic integration. With these consideration in mind, the final discussion re-contextualises bamboo forest plantations with regards to climate change, forestry and other political development agreements. The major framework is REDD+ due to representing a central mechanism which other international policy frameworks utilise. Finally, remaining issues are highlighted as they are indispensable to address in the political context.

5. Contextual Settings

5.1. Political Embedding of Carbon Sequestration

With increasing global temperatures, most notable by melting Arctic and Antarctic ice (see Harvey, 2020), reducing carbon dioxide together with other greenhouse gases in the atmosphere to mitigate global warming has received political response. Research has proclaimed that the 2 °C-goal will inevitably be exceeded due to emissions already existing in the atmosphere (Zhou et al., 2021). To address climate change mitigation, political frameworks have been designed and institutionalised worldwide. They vary in scope and means of implementation and address the reduction if not reversal of carbon emissions to varying extents. Some global and regional frameworks commonly set a first milestone for climate change mitigation to be achieved by 2030, while other national and regional frameworks pursue strategies up to 2050 and beyond. The following sections will serve as an overview over some important political frameworks which address climate change.

5.1.1. International Development and Forestry Frameworks

The Paris Agreement

The most important political framework on climate change is the 2015 Paris Agreement. It is a binding international law that formulated "the need for an effective and progressive response to the urgent threat of climate change" (UN, 2015: 1) and nationally-determined aims are to be developed in order to strengthen the "response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty" (ibid.: 3). The overarching purpose is to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels" and to pursue "efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (ibid.: 4).

While countries are to take measures to contribute to the set temperature goal, they are able to choose how they intend to mitigate climate harmful effects (nationally determined contributions), in particular greenhouse gas emissions (ibid.: 6). The option to choose arises from the difficult economic circumstances. Developing countries have yet to establish stable socio-economic conditions for their citizens and cannot impose any restrictive measure per se without jeopardising the livelihood of their struggling populace (ibid.: 4). But the Agreement is meant to develop strategies with co-benefits from "adaptation actions and/or economic diversification plans" through capacity building, financial flows and technology exchange (ibid.). This also includes the carbon offset option of other countries in one's own country (ibid.: 7). A specific condition set out in this agreement is to foster climate change adaptation strategies that do not threaten food production (ibid.: 3).

The Agreement seeks its enforcement by means of monitoring and reporting, but encourages the realisation of the enforcement to each country's own capacities; specifically, through cost-effective solutions. Strategies are welcomed which stimulate economic opportunities in both developed and developing countries. One specific recommendation is conserving and enhancing natural sinks and reservoirs of greenhouse gases, such as forests (ibid.: 7).

Agenda 2030

Agenda 2030 is a global action plan for sustainability, centred around the three pillars labelled as the people, the planet and universal prosperity. The agenda has been prepared through a multi-stakeholder communication and agreement process, involving the civil society, the private sector and the world's governments. The Agenda is comprised of the 17 Sustainable Development Goals (SDGs), with Goal being comprised of multiple targets, and which are measured by another multitude of indicators. SDG 13 specifically builds on the Paris Agreement in that it outlines specific actions which are meant to address climate change impacts, including greenhouse gas emissions going as far as 2050.[1] Unlike the Paris Agreement, the Agenda 2030 is not binding, despite the countries or United Nations Member States officially committing to achieve the SDGs (UN, 2021). This has the disadvantage of countries not taking appropriate measures to pursue and achieve any SDG. However, one may argue that the efforts of the United Nation to shine a spotlight on the achievers versus non-achievers of the goals (naming and shaming) as with the Paris Agreement may exercise pressure on all countries to find some solution to achieving the goals to some extent in their individual contexts (Clark, 2018: 127, 128); which may be better than not implementing any mitigation measure at all.

The Kyoto Protocol

The Kyoto Protocol, originally proposed in 1997, was the first international agreement and treaty to reduce greenhouse gas emissions (UNFCCC, 1997; UNFCCC, 2020) until it was superseded by the Paris Agreement. Unlike the Paris Agreement, the Kyoto Protocol was aimed at primarily developed and transitioning countries. It also addressed the option for "promotion of sustainable forest management practices, afforestation and reforestation (UNFCCC, 1997: 2). The Protocol saw amendments over time to increase emission reduction efforts in the face of an increasing public awareness on a changing climate putting pressure on governments. Relevant for later use in this paper, unlike the Paris Agreement, the Kyoto Protocol set greenhouse gas emission reduction targets. By 2020, it was aimed to reduce emissions to at least 18% of the emission level from 1990 (UNFCCC, 2012). The realisation was backed with the Adaptation Fund to allow for internationally collaborated and financed projects, which

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[1] SDG 13, overview available at: https://indicators.report/goals/goal-13/ (last accessed 23 January 2021).

countries of lesser economic power otherwise may not implement.[2] Since 2019, the Fund serves as the financing mechanism of the Paris Agreement.

Regional development frameworks

National and regional climate change mitigation and adaptation frameworks have also been developed, setting individual ambitions without necessarily undermining international agreements. The European Union developed its long-term strategy to "lead in global climate action and to present a vision that can lead to achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition in a cost-efficient manner" (European Commission, 2018: 3). Reducing greenhouse gas emissions, such as carbon dioxide, is specifically addressed through "the large scale (sic) deployment of natural land based (sic) carbon sinks including in the agricultural and forestry sectors" (ibid.: 8). As the aim clearly states, the strategies to address climate change mitigation and adaptation are to go beyond 2030, too. The EU has set the clear aim to reduce greenhouse gas emissions by 40%, compared to the level in 1990. There is another proposal to reduce emissions by 55%, which will be decided on in June 2021 (European Commission, 2020).

The Association of Southeast Asian Nations (ASEAN) has formulated its strategic framework for the Southeast Asian region (ASEAN, 2018). Unlike the European framework, the ASEAN framework orients on the 2030 milestone; however, the so-called strategic thrusts intend for "long-term low carbon emission strategies" (ASEAN, 2018: 3) and other long-term adaptation of the economic and social landscape. Due to a significant proportion of the economic landscape pertaining to the agroforestry sector (ibid.: 2), forestry strategies are an integral part of the ASEAN's greenhouse gas reduction approach.

The African Union (AU) has developed the Agenda 2063. It envisions similar goals and ambitions as the Agenda 2030, contextualised to the African communities, within which climate change is a mainstreamed concern. "Africa will participate in global efforts for climate change mitigation" (African Union Commission, 2015: 4). Specific monitorable strategies have been set for 2023 only, and greenhouse gas emissions are not mentioned (AU, 2015). The unspecific addressing of climate change mitigation may derive from the fact that Africa is not a significant source of greenhouse gas emissions (UNFCCC, 2006). It can be expected that the African countries will take part in climate change mitigation activities when those activities have economic benefits for the region.

Latin America has no unifying framework, and strategies are primarily country-set and -led. Climate change mitigation goals orient primarily on the 2030 deadline, with eight out of 18 Latin American countries (excluding the Caribbean) having begun the development of long-

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[2] UNFCCC Adaptation Fund, available at: https://unfccc.int/Adaptation-Fund (last accessed 24 January 2021).

term strategies until 2050, and five countries greenhouse gas emissions (European Commission, 2019: pp.40). Mexico is the only country with a formalised long-term strategy (European Commission, 2019: 14). This strategy makes it a pillar to improve agroforestry practices to increase and preserve natural carbon reservoirs (ENCC, 2013: 21).

The various regional frameworks indicate a general awareness among governments to deal with a changing climate. The extent to or means with which it is addressed varies by country or region, or is left unspecified. Forests have received increased attention, although they always had attention, but were never governed under a singular framework nor for an internationally agreed purpose but contextually different purposes (see Sotirov et al., 2020).

REDD+

REDD+ addresses emissions and climate change action more specifically. REDD+ refers to "Reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks" (UN-REDD, 2016: 1), with the "+" highlighting the importance of forest carbon stock management for the purpose of reducing carbon emissions from deforestation; reducing carbon emissions from forest degradation; conservation of forest carbon stocks; sustainable management of forests; and enhancement of forest carbon stocks (ibid.; Kuehl, Kuehl and Castillo, 2018; UNFCCC, 2011). REDD+ is directly linked to the Kyoto Protocol as an outcome of the 2007 Conference of the Parties (UNFCCC, 2008) and has henceforth been updated to make it a tool for the achievement of the transformative 2030 Agenda for Sustainable Development and thereby the Paris Agreement, too (UN-REDD, 2016: 2). In essence, REDD+ has been developed for the purpose of discouraging deforestation and encouraging re- and afforestation to build, operating under national sovereignty and statutory law as well as respecting international Human Rights, conventions on nature (biodiversity), and the inclusion of all stakeholders (local communities) (UNFCCC, 2016; UN-REDD, 2016).

It is this framework from which the rebuilding forests as carbon sinks through land use, land-use change and forestry (LULUCF) activities derives as well as the concepts of providing a financial compensation mechanism (Kuehl, Kuehl and Castillo, 2018: 47). The framework requires national monitoring and reporting systems on carbon stocks for the purpose of tracking REDD+ financed projects (UNFCCC, 2016: 7, 37).

Expanded through key decisions over time, REDD+ implementation must consider socio-economic issues in addition to environmental threats, such as land tenure, displacement of local communities and their participation, and implement necessary safeguards for the protection of nature but also eradication or at least not worsening of poverty (UNFCCC, 2016).

FLEGT

The Forest Law Enforcement, Governance and Trade (FLEGT) of the European Union is meant to ensure nationally existing policies and laws are applied in the forestry sector to account for sustainable and legal logging of timber (European Forest Institute, 2020). FLEGT considers the legality of environmental and social conditions in the management and selling of timber resources as well as the products thereof by means of national laws in consumer and producer countries (ibid.). FLEGT requires traceability of the products licensed under the framework through bilateral agreements. These agreements determine the legality aspect under FLEGT and are negotiated in the country with all forestry stakeholders to fulfil the EU's requirements by means of finding a set of nationally applicable laws in each country on several aspects ranging from labour conditions, to tax governance and biodiversity protection (European Commission, 2012: pp 60).

FLEGT and REDD+ are meant to be compatible, with FLEGT feeding into REDD+ implementation by addressing forest degradation, promoting improved forest governance and law enforcement, resource monitoring, and multi-stakeholder exchanges on national land use policies (European Forest Institute, 2014: 2). Though sovereignty is meant to remain in the producing country, FLEGT can stimulate sustainable forest governance required for REDD+ projects in those countries if and when timber products are to be sold in the European Union.

FSC

The Forest Stewardship Council (FSC) developed a timber certification framework with the aim of creating an instrument for sustainable forests management, including the supply of forest products from such forests (Brotto et al., 2010: 16). The sustainability verification is addressed with evaluation regarding a forests (national) regulatory compliance (ibid.: 32, 33). In that sense, it is similar to FLEGT as compliance to FSC standards can facilitate complying to REDD+ requirements (ibid.: 13). The difference is that FSC certification is voluntary and only applicable to the stakeholder managing a forest (not a country). Yet, it can be an enabler for timber trade by means of demonstrating verified good forest management practices. Certification also requires independent assessment of the practices. The assessment orients on a number principles, which address compliance with national and international regulations, reducing and averting environmental impacts, recognising local communities and their participation (including forest workers and indigenous populations) as well as the promotion of *natural* forests and resolving land tenure conflicts (FSC, 2015).

5.1.2. Different Forest Definitions

The Food and Agricultural Organisation (FAO, 2012: 3) defines forests as "land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use." It does include bamboo areas, provided they match the previous criteria. This definition "excludes tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards and agroforestry systems when crops are grown under tree cover." (ibid.) Tree planting does not imply a primary forest, as in "naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed." (ibid.) Carbon sinks can be planted forests or forest plantations as in being "forest predominantly composed of trees established through planting and/or deliberate seeding." (ibid.) The discussion in this paper specifically refers to forest plantations; not natural forests.

While FAO (2012) has provided a technical definition for international adoption, in reality national definitions of forest often differ and are not uniform in comparison (Ciasullo, Simone and Conti, 2014: 186; Kuehl, Kuehl and Castillo, 2018: 51), leading to different forest administrations, derived from different (or absent) national policies, which treat the varying purposes of a forest (FAO, 2010). But in essence, every forest is treated as a resource (FAO, 2010: 7), but the same resource is sought out by different stakeholders who seek to maximise the use of a forest for their individual purpose. The resource may not even be the forest itself but the space the forest occupies. The conversion of jungle into cropland and pastures is a prime example of interests beyond the forestry sector (Abranches, 2015: 6).

Depending on the purpose, the stakeholders with their respective interests in a forest range from local individuals, to small private companies, civil organisations, local and national governmental bodies, as well as international organisations and enterprises (for details, see Brotto et al, 2010: pp. 25). Economic, social and environmental interests compete with one another (FAO, 2001: 4). Each stakeholder has different motivations and goals, different perspectives, and differing access to information and resources.

5.1.3. Other Greenhouse Gases

There are other greenhouse gases which are released into the atmosphere as a direct result of anthropogenic actions and which are much more potent than carbon dioxide. The Kyoto Protocol referred to five such greenhouse gases: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (UNFCCC, 1997: 22), besides carbon dioxide.

Anthropogenic influences on the global methane budget are suggested to have begun thousands of years earlier than the time considered as 'pre-industrial' (IPCC, 2013: 167). Methane is 25 times more potent in its greenhouse effect than carbon dioxide and a by-product of organic decomposition in agriculture and livestock or cattle farming (UBA, 2020). There appears to have surged an uncertainty regarding the extent of anthropogenic influences on the atmospheric methane budget. Microbial and fossil sources, the burning of biomass as well as the role of permafrost emission charges are considered (Saunois et al., 2020: 1601). However, the increasing emission are found in tropical areas (ibid.).

Nitrous oxide is 298 times more potent than carbon dioxide and lasts in the atmosphere for 121 years (UBA, 2020). It is released in chemical, industrial processes and in agricultural fertilising. The human-caused creation nitrogen increased steadily over the last two decades and has been linked to the production of ammonia for fertilizers (IPCC, 2013: 97). Even though its ratio as component of the air is marginal, its longevity contributes to a non-negligent effect on the anthropogenic greenhouse effect (UBA, 2020).

The fluorinated hydrocarbon compounds (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) are also considered more potent than carbon dioxide (UBA, 2020). Depending on the compound, it may last between above one year only to above 220 years in the atmosphere (IPCC, 2013: 168, 169). Currently, these compound gases continue to increase rapidly due to industry applications, but their contributions to the atmospheric greenhouse gas budget have been low (IPCC, 2013: 169). Reducing these gases should not be neglected in combating climate change. Fluorinated hydrocarbon compounds can be avoided during production or thereafter, which requires technological changes.

Avoiding the release of methane and nitrous oxide will be bound to changing agricultural practices and consumption behaviours among societies by reducing the demand for animal-based products and reverting to natural fertilisers.

5.2. Pro and Contra Aspects of Tree Planting

Spatial collisions

Despite appearing as a natural option, carbon sequestration is criticised for the space it requires. Boysen et al. (2017) argued that planting forests with the intention to absorb enough carbon dioxide from the air to maintain global temperature levels at 2°C would require 1.1 Gha (11 million km^2) of the most productive agricultural land (ibid.: 468).[3] This space is larger than either China, the USA or Europe. In a similar scenario, the Carbon Sequestration Leadership Forum (CSLF) estimated that such an undertaking would require "approximately one-third of the arable land on the planet or about half of the U.S. land area" (CSLF, 2018: 3). The National Academy of Sciences (NAS, 2018) stated that every giga tonne of carbon dioxide (0.27 GtC) stored per year requires 30 to 40 million hectares of space. This equates to 300 to 700 million hectares (3-7 million km^2) of land (Consoli, 2019: 10).

The respective authors argue that such undertaking would disrupt food production and biosphere functioning due to its space-consuming and, therefore, space colliding properties

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[3] The authors chose the time period of between 2050 to 2100 for this figure assumed carbon dioxide emission levels for that time period, as opposed to more recent 2016/2017's emissions.

(Boysen et al., 2017: 468, CSLF, 2018: 11). The primary space collision would occur with agricultural lands and natural biospheres due to the competition for cultivatable land. However, agricultural expansion has been the constant driver of the conversion and loss of natural biospheres (FAO, 2016). Tropical forests in particular have been decimated due to the conversion to local subsistence and macro-commercial agriculture (including pasture) which has been most extensive in the South American region (ibid.: 21).

Forest land to timber plantation conversion has also been documented. Private sector companies took advantage of regulatory schemes, cheap land and labour to establish tree plantations in developing countries (Szulecka, Pretszch and Secco, 2014: 142). This effect has been attributed to a cycle of deforestation, wood scarcity, followed by the need for plantations once deforestation reached an unsustainable level (Pirard, Secco and Warman, 2016: 123). The need for re-establishing timber sources is a direct competition for land (ibid.).

While the urban areas also expand, they have lower conflict potential. More impactful is the continuing urban population growth, which influences the expansion of land use for economic purposes, and to which accounts the food supply (FAO, 2016). Urban-based and international demand for agricultural commodities drives the conversion of forest land (ibid.: 22).

The alternative to competing with agricultural land may be to convert unused land into carbon sinks. Under the presumption that existing and potentially more effective carbon sinks (i.e. natural forests) would not be substituted by artificially created plantations for carbon sequestration, the idea is to substitute lesser effective landscapes or vegetation. Bastin et al. (2019: 77) argued that "areas that were previously degraded, dominated by sparse vegetation, grasslands, and degraded bare soils" may serve as convertible land. However, such unused land may be of poor fertility. As a result of competition for arable land, "forests are usually relegated to sites of moderate to poor fertility" (Oren et al., 2001: 469). With insufficient organic and mineral nutrients available in the soil, plant growth and biomass production are stunted (Lorenz and Lal, 2009; Oren et al., 2001). In other words, carbon sequestration in trees is limited by soil fertility (Oren et al., 2001: 469). Furthermore, certain landscape, such as grasslands, are also home to plants specialised in such landscape, i.e. herbaceous plants with medicinal purposes for humans but also soil nutrient cycling effects (Birge, 2019: 85). They would be lost in land conversion.

The competition for land is further complicated by rights to land (tenure and ownership) among different stakeholders. Land management by one stakeholder (usually private) can be hindered by being administered by another stakeholder (usually public) with differing interests, thus limiting the available land to certain land use (FAO, 2001; Katila et al., 2020). As different land ownership regulations allow stakeholders to manage their land differently, plantations can be efficient in some areas but inefficient or counterproductive to carbon sequestration in other areas. There is a general problematic between (forest) land management by private or communal entities and (forest) land ownership by the state, as rights to the land tend to be blurred in developing countries (Chokkalingam and Phanvilay, 2014; Enters, Brown and Durst, 2003; FAO, 2001; Katila et al., 2020; Shepherd, 1986). In particular, conflict potential arises from land access being arbitrarily withdrawn by administering owners (the state) (Katila et al., 2020).

Lastly, plantations may drive out local populations (e.g. indigenous) who have to make space for such plantations, in particular in developing countries (Bäckstrand and Lövbrand, 2006: 65). The ethical aspect aside, monoculture plantations cannot provide livelihoods for these populations (Enters, Durst and Brown, 2003: 10). Displacement of local communities, who are dependent on the uninhibited interaction with a landscape, leads to resettling elsewhere, followed by ecosystem and thus space disturbances elsewhere (forest logging) (ibid.).

Biodiversity and monoculture interactions

The replacement of species brings about biodiversity concerns. As the purpose with tree planting is to establish effective carbon sinks, it appears trivial that those species will be prioritised which absorb large amounts of carbon dioxide. A reduction of biodiversity can be found as the result of land use changes, to which account *planted* carbon sinks, as opposed to existent, natural carbon sinks (natural forests) (Whitehead, 2011). However, plantation forests support greater biodiversity than agricultural land and can act as corridors to natural forests, supporting wildlife movement and biodiversity (ibid.: 899). The greater problematic are monoculture plantations where biodiversity is lower than in natural forests, as demonstrated in a comparison of primary and converted plantation forest in Gardner et al. (2007).

Monoculture plantations also risk the spreading of diseases or parasitic infestations. Nair (2001) compared the extent of pest susceptibility among tree plantations and found a generally greater damage to pests (Nair, 2001: 48). In particular the increase in insect population can damage a plantation, as more host species become available alongside suitable climate and site conditions (Nair, 2001: 50, 51). Being introduced to non-native regions may further increase either the susceptibility of the monoculture plantation or the transmission of pests or diseases onto other species. Disease and pests may then not only affect the plantation but adjacent natural and agricultural areas.

The introduction of plants on a large scale may feed and advantage a pre-existing flora and fauna, or dominate and subsequently disadvantage other species. Non-native species can cause considerable negative impacts in natural ecosystems due to the fact that these species occur in habitats where they did not evolve (Canavan et al., 2019: 119). An introduction of non-native plant species may position them at an advantage, in the sense that they may reproduce and grow faster than the native florae. For example, the absence of natural enemies as well as cold/heat conditions may allow the uninhibited spread, including of the disease or pest they introduce (Cock, 2003: 14, 17).

Water interactions

As land use changes it changes not only space and species composition, it also changes functions of the pre-existent ecosystem by altering ecological conditions of, e.g., water infiltration, soil erosion, nutrient cycles and subsequently the food web (Wittenberg and Cock, 2001: 18). But every planted tree – and bamboo – requires nutrients, and in particular water.

Establishing large-scale and tall-growing vegetation (forests) for the purpose of carbon intake will require large volumes of irrigation inputs (Boysen et al., 2017). Whitehead (2011) compiled a number of studies showing that water infiltration and storage in the soil as well as flow on the surface reduces when forests replace other vegetation (in particular short vegetation such as grassland) or is planted for re-/afforestation (Whitehead, 2011: 898). Primarily, foliage rainwater interception leading to increased evapotranspiration and the water consumption during grows negatively impacts on the groundwater table (ibid.).

The wider consequences of a changed water flow over- and underground will be significant when those changes affect economic activities. Plantations may interfere with other land use, and in particular with water-reliant agricultural fields nearby. Industrial forest plantations have been directly associated with diminishing water resources (Unda, Poschen and Stuardo, 1997). A general lesser availability of water interferes with crop irrigation. This circumstance may not only affect the local population in their income opportunities but become a political problem when such effect traverses national borders.

Forest plantations were also supplemented in their growth with chemical fertilisers and pesticides. For example, the large-scale Plantar Project in Brazil impacted on the surrounding flora and fauna by contaminating the nearby river with leaching fertilizers and pesticides (WRI, 2000). Unless natural options (manure and compost) are used, this intervention would undermine the ecological aspect almost certainly, and should be avoided from the beginning.

Socio-economic aspects

Nowadays, governments pursue environmental, social and economically competing interests by trying to balance one against the other depending on the need of the country (FAO, 2001; FAO, 2004, Enter, Durst and Brown, 2003) and in particular depending on which other stakeholder has most influence on a government (FAO, 2001: 5). Governments have shown to emphasise forest conservation over exploitation for reasons of environmental (e.g. wildlife protection) and social (e.g. livelihood) concerns (Chokkalingam and Phanvilay, 2014). Governments are key in steering commercialisation by creating regulations on the use of timber derived from natural forests or incentivising forest plantations (FAO, 2001: pp. 5). Originally, forest plantations were a response to the decline of timber resources derived from natural forests (see FAO, 2004). But the concern was less with the loss of the natural environment than with access to timber for industrial and manufacturing purposes, for which in particular fast-growing tree species (Eucalyptus and Pine) received attention (ibid.: 7, 8). Timber became valued as export good with the potential to alter the composition of wood and fibre markets, and which in turn led to a shift from relying on natural forest to establishing plantation forests with fast rotations for harvesting (ibid.: 9).

With growing awareness among governmental stakeholders for natural forest conservation and a changing climate, forest plantations have been attributed with a value-added potential for carbon capturing and storing, as highlighted under the Kyoto Protocol, REDD+ and later the Paris Agreement. As under the Paris Agreement cross-country partnerships are encouraged to mitigate carbon where it is the least expensive, the re- and afforestation for carbon capturing, including forest plantations, has incentivised the financing of projects in developing countries by developed countries (Bäckstrand and Lövbrand, 2006: 58) – commonly referred to as North-South relations. Due to lower market costs, the plantations are more cost effective to establish in southern countries. Forest plantations have become of international financial interest for the purpose of capturing carbon and trading, in addition to serving as resource material.

Plantations for carbon mitigation are not without criticism, because they represent a scheme of offsetting emitted carbon dioxide by developed countries in the territory of developing countries in exchange for financial incentives without necessarily reducing emissions (Bäckstrand and Lövbrand, 2006: 60). The initial opposition changed when co-benefits of poverty reduction were highlighted as opportunity of said plantations (ibid.: 61). A cross-stakeholder benefit for private and public actors were anticipated income opportunities as individuals would find employment, private investors offer employment on the plantations, and governmental actors could promote plantations for sustainable development in rural economies (Andersson et al., 2016; Bäckstrand and Lövbrand, 2006; Cuong et al., 2020; Pirard, Secco and Warman, 2016). Establishing socio-economically productive forest plantations, which prevent the logging of natural forests and provide a livelihood for local communities, appears a 'natural' conclusion. In reality, alternative effects were studied, i.e. the displacement of local populations through outmigration for work, poor working conditions (no contractual nor social securities), missing employment due to insufficient skills, or the conversion - as opposed to addition - of work due to converting farms to plantations (Andersson et al., 2016; Ciasullo, Simone and Conti, 2014; Cossalter and Pye-Smith, 2003; Nerede, Pirard and Kassa, 2015; Pirard, Secco and Warman, 2016). Examples of timber plantations worsening local poverty instead, due to missing skills to manage a forest either as smallholders or potential employees, were studied in Chile (Andersson et al., 2016), Indonesia (Rohadi et al., 2015) and Kenya (Negede, Pirard and Kassa, 2015). Plantations became neglected in favour of agriculture. Also, local stakeholders were neglected in decision-making regarding the use and benefits of the plantations in Brazil, Belize and Bolivia (Bäckstrand and Lövbrand, 2006: 70).

International actors are part of the criticism. "Northern investors have been interested in low-cost projects that will offer quick carbon offsets at maximum flexibility rather than projects focusing on poverty reduction and sustainable development in the host country." (Bäckstrand and Lövbrand, 2006: 70) International interests in local plantations may vitalise an economy for a specific product, but it may also increase conflicts by pitting different interests against one another. The palm oil plantations in Indonesia, for example, have been critiqued for their extensive environmental disruptions (Meijaard et al., 2020), but their existence also been criticised as incentivised by international funding (Ramdani and Lounela, 2020).

Forest plantations require an initial financial investment to establish the site and bridge the time until the timber is ready for harvesting and processing and eventually selling. The investment is criticised, because trees require a relatively long-maturation time while markets may change during the maturation period, and timber prices may not be as attractive later, in addition to the risk of falling victim to disasters (Enters, Durst and Brown, 2003: 6, 7). Investments in plantations are financially risky. To counter the lack of investment and establish forest plantations, incentives can be provided. The incentives need to take place on local scale with a country's governmental actors providing incentives to local market players, and it needs to be on an international scale, in the sense of providing finances for North-South carbon offsetting. While it would go beyond this paper to discuss the varying incentive methods, tried and tested methods showed that varying local direct and indirect incentives provided enabling environments to establish and maintain plantations (Enters, Durst and Brown, 2003; FAO, 2016).

Climate engineering concerns

Extensively removing carbon dioxide from the atmosphere for the purpose of climate change mitigation may count as climate engineering. The term 'climate engineering' refers to anthropological interventions in the natural environment with the aim of alleviating global warming (Shepherd et al., 2009: 83). It describes a variety of techniques for the purposeful manipulation of the local weather as well as global climate to mitigate or prevent the (most severe) effects of climate change (Liu and Chen, 2015: 197) and it intends to change regional and global weather conditions in such a way that the concurrent global warming will be slowed down or reversed in order to keep global warming below the targeted 2 °C (UNFCCC, 2010). The techniques for changing the global climate may be distinguished by means of solar reflection[4] and carbon capture and storage (SPP 1689, 2018). This two-fold categorisation does not exclude further distinctions within either category. Carbon capture and storage involves

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[4] Tree planting or afforestation has also been discussed regarding its albedo effect and found that afforestation in the tropical regions are likely to slow down global warming, meaning that higher tree coverage is beneficial, which is the opposite in northern and temperate regions. (Bala et al., 2007: 6550).

removing carbon dioxide from the air by using either artificially engineered, chemically-enhanced or natural filters. The natural option for removing carbon dioxide from the air tends to refer to the planting of fast-growing plants and preferably trees, and on a more holistic scale the restoration of forests. Tree-planting and forest restoration means to capture and store carbon in large volumes of biomass, in particular in stems. As with chemically-bound carbon, the carbon in tree biomass may be stored through various means or used as energy source (i.e. as coal). But using the sequestered carbon as energy source would counteract the purpose of removing it from the air. Underground storage of captured carbon is another option (Consoli, 2019).

Large-scale climate intervention methodologies harbour not only advantages but complex systemic consequences. Perspectives on climate engineering can be diverse, depending on the influencer, beneficiary, decision-maker or other stakeholder and their respective access to knowledge or the lack thereof (non-knowledge) (Scheer and Renn, 2014). The knowledge about technologies and their interdependencies influences debates around risks, impacts, accountability, financing and ethical values (Rickels et al., 2011). Nature-based solutions to engineering the climate may therefore not be harmless nor without controversy despite being appearing as natural. The consequences are uncertain due to insufficient long-term experiences, making outcomes hard to predict (Rickels et al., 2011: 2). In a nutshell, risks may arise from the deployment of large-scale carbon capturing measures by causing undesired changes in local weather patterns, disrupting food chains, replacing flora and fauna, tipping the biodiversity scale or impacting on groundwater of transboundary nature (Latam, Rasch and Launder, 2014; NAS, 2018).

Carbon dioxide re-release

Forests can be subject to a variety of natural and anthropogenic disturbances, such as insect infestation, fire, frost or storm damage, logging or conversion to another land use and a changing climate itself (Bäckstrand and Lövbrand, 2006: 64, 65; Galik and Jackson, 2009: 2211). These disturbances make the idea of forests (plantations) for the purpose of carbon sequestration a potential risk, because those disturbances may release captured carbon back into the atmosphere (Galik and Jackson, 2009: 2210).

Some forest fires are considered a natural phenomenon and part of the nutrient cycles these fires mineralise organic matter into its components of minerals, water (vapor) and also carbon dioxide (Gorte, 2009: 11). Establishing carbon sinks in areas prone to fires may undermine the idea of capturing carbon dioxide. However, these fires are prevalent in climates which is primarily arid and facilitates the ignition of dry biomass, or fires are kindled from human activity. The latter refers to farmers clearing the land, which is a decades old problem and yet continues to this day especially but not exclusively in the Amazon (in particular in Brazil) but also in central

African region in the Congo Basin (Floyd, 1982; Lopes, 2019; Megevand, 2013). Natural forest fires, such as ignited from lightning, in tropical regions are rare due to the ever-moist conditions (Pivello, 2011: 24). Therefore, they should not be a concern unless they are anthropogenically initiated.

Even without the interference of fire, in order to store carbon dioxide in woody plants' biomasses requires them to stay alive. Once decay sets in, carbon is return to the atmosphere (Jansson et al., 2010: 685). This accounts for alive above- as well as belowground biomass. By transferring carbon from the aboveground biomass to their roots, it enters the soil, and should this soil become unprotected carbon will be returned to the atmosphere (ibid.). Wrong forest plantation management techniques disturb the soil in which carbon is sequestered re-releasing it to the atmosphere (Galik and Jackson, 2009: pp. 2216). The intensity of harvesting directly affects the loss of soil carbon (James and Harrison, 2016: pp.10).

Neglect of carbon dioxide reductions

Carbon storage in plantations may be a temporary solution and not a durable carbon sink. This ties in with a critique on forest plantations as short-term carbon offset solutions that do not change the production and consumption patterns which cause carbon dioxide emissions in the first place (Bäckstrand and Lövbrand 2006: 64). The continuation of fossil fuel reliance while establishing carbon sinks may lead to neglecting or avoiding the reduction of carbon dioxide emissions by offering instead an option to offset them (Rickels et al., 2011: 34). The reduction of fossil fuel burning may then be postponed with the potential for a riskier situation in the future requiring more urgent carbon intake solutions (Latam, Rasch and Launder, 2014). This thought applies to individuals not changing their transportation habits as well as companies offsetting emissions instead of reducing them (Zhou and Zhang, 2020). On an international scale, forest carbon sequestration may represent a loophole for "rich countries to evade their historical responsibility for the elevated concentrations of greenhouse gases in the atmosphere" (Latam, Rasch and Launder, 2014).

5.3. Characteristics of Bamboos

5.3.1. Why Bamboos are Discussed for Climate Change Mitigation

Under optimal conditions, bamboo culms may elongate by 50 cm to 125 cm a week, reach final height within two to four months, mature within three to seven years, and some species (i.e. Moso bamboo) grow up to 1.2 m per day (Lobovikov et al. 2009, Fu 2001). Moso bamboo (*Phyllostachys pubescens*) can grow up to 24 m in 50 days (Fu, 2001: 5). Tall bamboo species reach typical heights of 15 m to 20 m, but can reach 40 m and higher, and can develop a culm diameter at breast height (DBH) of more than 30 cm (Lobovikov, 2009: 7). The tall- and fast-growing bamboo species have been argued to generate biomass comparable to trees, but at a much faster pace.[5] Three fourths of bamboos' biomass can be reached within 40 days, also indicating that biomass accumulation occurs mainly in the initial growth stage (Yen, 2016). Depending on the processing purpose of bamboo culms, they are said to be harvestable between 3 years and 7 years, after which they re-grow by spurting new culms from the rhizome, and produce 6 t/year to 10 t/year of new culms (Akwada and Akinlabi, 2018; Durai and Long, 2019; Fu, 2001; Lou et al., 2010; Mera and Xu, 2014; Scheba, Blanchard and Mayeki, 2017).[6]

As a result of such remarkable growth, bamboo species have been researched regarding how much carbon dioxide they can store in the form of carbon in their biomass, and potentially be promoted as carbon sinks through international frameworks for climate change mitigation (Buckingham et al., 2011; Düking, Gielis and Walter Liese, 2011; Fu, 2001; Gu et al., 2019; Hermis and Dumago, 2014; INBAR, 2014; Kuehl, Henley and Lou, 2013; Lobovikov et al., 2009; Lou, Kuehl and Giles, 2013; Lou et al., 2010; Seethalakshmi, Jijeesh, and Balagopalan, 2009; van der Lugt, Trinh and King, 2018). Unlike most trees, bamboos do not need decades to reach maturity, which suggests they have more potential to mitigate climate change fast (Sohel et al., 2015: 143). Bamboo planting may therefore serve as a plant-based carbon sequestration method for the purpose of climate change mitigation if and when it is applied on a large scale. However, bamboos have positive and negative impacts, which shall be discussed below, beginning with their ecology.

5.3.2. General Ecology of Bamboos

Bamboos are endemic to every continent, except Europe and Antarctica, and found around the world in tropical to warm temperate ecosystems, with some occurrences in temperate regions, and grow from sea level to over 4000 m in mainly forest and mountainous grassland (Kelchner and Bamboo Phylogeny Group, 2013: 404; Vorontsova, 2016: 6). Most bamboos grow on variable terrain ranging from sandy to clay soil (Huberman, 1959: 1). Bamboos tend to prefer well-drained soils, although it is also found in wet or swampy grounds, with the exclusion of saline soils (ibid.). *Bambusa polymorpha* prefers a moist but well-drained soil characteristic, while *Dendrocalamus strictus* prefers drier conditions. *Bambusa arundinacea* prefers richly moist soils, such as alluvial strips along streams (ibid). Different bamboo species can be planted in different soil types.

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[5] Hermis and Dumago (2014) compared *Gigantochloa levis* grown in the Philippines and a mature plantation of *P. pubescens* in Japan, which had a respective aboveground biomass of 146.8 t/ha and 137.9 t/ha; fast-growing *Gmelina arborea* had 127 t/ha. Du (2015) recorded eucalyptus plantations sequestering between 112.9 t/ha and 203.8 t/ha in the region of Southern China, which can be above, below or equal to bamboo plantations. Seethalakshmi, Jijeesh and Balagopalan (2009: 127) stated *Chusquea culeou* with between 156 t/ha and 162 t/ha and *B. bamboos* with 286 t/ha biomass, compared to a 10-year-old fast-growing *Causarina equisetifolia* with 293 t/ha.

[6] There is, however, an experience blog report that states bamboo plantations reach higher biomass from around eight to ten years (and later) after its first establishment due to culms becoming wider and taller in later sprouts with increasing age of the plant (see Schröder, 2011). A similar statement can be found in Abe and Shibata (2009). This requires further research.

Taxonomically, bamboos belong to the grass family Poaceae, the subfamily Bambusoideae, and comprise three genera: tropical woody bamboos (Bambuseae), temperate woody bamboos (Arundinarieae) and herbaceous bamboos (Olyreae) (Wysocki et al., 2015; Vorontsova et al., 2016: 6; Xu et al., 2019: 1). The woody bamboos form solid wood-like culms, which are hollow in their interior and segmented by internodes, with each node appearing as a ring at the base of the plant.

The main structural parts of a bamboo plant are the underground system of solid and hollow rhizomes,[7] the aboveground culms and the culm branches with their sheaths and leaves. Rhizomes are no roots but underground shoots. They are colourless storage- and propagation organs with fibrous roots and branch off the mother plant to spread laterally in the soil (Lobovikov, 2009: 10). Bamboo species can store a lot biomass underground in their rhizomes, which varies anywhere between more or less than half of the plants' biomass (Jijeesh, 2009; Isagi, 1994; Tripathi and Singh, 1996 or Zhou and Jiang, 2004).

Bamboos are classified into two major groups: leptomorph/monopodial (also called running) and pachymorph/sympodial (also called clumping) (Tekpetey, 2011; Canavan et. al, 2019) (Figure 2). Mixpodials also exist. The monopodial or running group allows the plant to spread more rapidly than other species (Canavan et al., 2019: 125) as they tend to extend unidirectional. The rhizomes typically occupy the top 30 cm to 50 cm of soil and may spread for tens of metres (Scurlock, 2000: 4). Running or monopodial bamboos are mostly found in the subtropical and temperate regions, while clumping (or sympodial) bamboos in the tropical and subtropical regions (Scurlock, 2000: 4, Canavan et al., 2019: 125). Clumping bamboos extend radial by forming rhizomes typically around the central node of the plant. By forming buds on the side of their rhizomes, bamboos extent underground and eventually form an upright shoot. Bamboos spread by producing culms from their rhizomes, and distribution of the plant can be achieved by separating culms with the rhizomes and transplanting it (cloning) (Fu, 2001: 5).

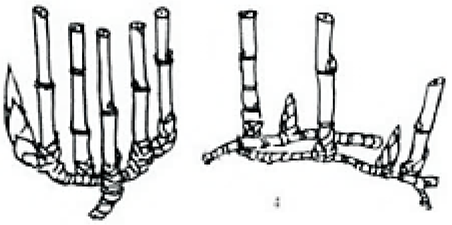

Figure 2: Sympodial (left) vs monopodial (right) bamboo, by Tekpetey, 2011.

Bamboos reproduce through flowering, dispersing their seeds. Most species take supra-annual intervals to flower, ranging between three and 120 years depending on the species (Janzen, 1976: 347, 354). Some bamboo species flower annually. Those species not flowering annually die off after their flowering cycles (ibid.). The same flowering and die-off can be avoided through human harvesting interventions.

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[7] rhizome: The segmented, complex, subterranean stem system (the "root stock" of a bamboo plant; present in two basic types — monopodial (leptomorph) and sympodial (pachymorph). (Lobovikov, 2009: 41)

Aboveground, growth takes place in form of elongation of internodes, "as much as 0.5 m/week in the case of tall bamboos" (Scurlock, 2000: 4). Leaves are attached at each internode. Nearing its final growth, sheaths are shed and branches with leaves emerge from the internodes, primarily at the top of the culm. The leaves are shed at the end of every growing season or during the following growing season, depending on the species, and reflect a biennial pattern (ibid.). Further growth sees only the thickening of the culm walls, increasing the wood density but not the height (ibid.). Depending on the species, they can remain below 1 m (in the case of shrub bamboo) or grow up to 60 m in exceptional cases (in the case of *Dendrocalamus giganteus/Bambusa gigantea*) (Rao and Rao, 1998: 29).

Due to poor definitions, rudimentary forest inventories and neglect of the plant as a resource, data on bamboos is scattered and unreliable, which is further complicated by bamboos being difficult to distinguish (Lobovikov, 2009: 15; Stapleton, 1994: 8). In consequence, the documented and reported number of bamboo species varies, such as 1400 (Xu et al., 2019) or 1662 (Canavan et al.; 2019).[8]

5.3.3. Socio-Economic Benefits

Bamboos have been labelled as 'poor man's timber' (Lobovikov et al., 2012) and 'poor man's carbon sink' (Lobovikov et al, 2009) due to its common use among poor populations who cannot afford tree timber (Kuehl, Kuehl and Castillo, 2018: 51). However, there is nothing poor about the plant's applicability, given that is has been documented with over 1250 uses (Jiang and Peng, 2007). More specifically, bamboos serve as construction and manufacturing resources, and therein most notably for furniture, flooring and other applications (Akwada and Akinlabi, 2018; Ingram et al., 2010; Lobovikov et al., 2009; Scheba, Blanchard and Mayeki, 2017; van der Lugt, 2005; van der Lugt et al., 2012).

Some bamboo species are also edible. Young bamboos (the shoots) have been reported to be rich in nutrients, such as proteins, carbohydrates and minerals (magnesium, phosphorus, calcium and especially potassium) (Karanja et al., 2015; Nongdam and Tikendra, 2014; Song et al., 2011; Tripathi and Singh, 1994). This makes bamboos an important food source. In parts of India, traditional dishes developed around bamboo shoots making them part of the local culture (Nongdam and Tikendra, 2014). It has also been attributed at as a 'health food' having anticancer, antibacterial and antiviral effects (Chongtham, Bisht and Haorongbam, 2011). Yet, the food potential of bamboo is unexplored (Satya et al., 2012: 1).

One may include that bamboos are used as firewood and charcoal, including for agricultural soil fertilisation, which allows rural populations to access basic means for heating and cooking

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[8] A good example is the overlapping taxa in Young and Judd (1992), who taxonomically re-analysed *Bambusa* (or *Guadua*) *chacoensis*, *G. aculeata* and *G. angustifolia* with the result that all three should be considered as subspecies of the species *G. angustofolia* Complex. Similarly, the species *Phyllostachys pubescens* can also be found as *P. eludis* in many sources.

(e.g. Akwada and Akinlabi, 2018; Lobovikov, 2009; Song et al., 2011). Due to the rapid (re-)growth of the culms, this in turn is believed to help reduce deforestation by replacing trees that otherwise would have been used for such purposes (Kuehl, Kuehl and Castillo, 2018: 50).

The point is, due to the manifold economic and livelihood applicability, bamboos provide income opportunities and financial safety (Kuehl, Kuehl and Castillo, 2018: 51). Serving as manufacturing resource material, they add value for being an agricultural and forestry product, serving the individual household as well as the market on a larger scale. Common agricultural and forestry goods tend to serve only one purpose at a time. Bamboos' versatility and characteristics provide communities with options to diversify their income and livelihood strategies (ibid.).

5.3.4. Ecological Benefits and Side-Effects

Bamboos have been studied with regards to their ecosystem impacts, with positive but also negative effects. Bamboos find discussion in case studies and research in relation to re- and afforestation as well as soil regeneration. The fast growth of the plant is suggested to favour a speedy revegetation of barren land, and the underground root network is suggested to prevent soil erosion. Bamboos' growth velocity has been observed to restore degraded land in many countries. But like tree plantations, so does the cultivation and spread of bamboo species have negative impacts, for example on biodiversity or landscape alteration. Some critical aspects and how they counter or promote (bamboo) forest plantations find elaboration below.

Beneficial effects of bamboos

A fast landscape revegetation was observed, for example, in Ghana where *Oxytenanthera abyssinica*, *Dendrocalamus asper* and *Bambusa textilis* were planted for the purpose of bridging forest patches in order to re-establish a coherent forest coverage (FAO and INBAR 2018: 10). In India (Uttar Pradesh) as well as in Tanzania, several *Dendrocalamus* and *Bambusa* species were utilised to restore depleted soil that resulted from intense land use (FAO and INBAR, 2018: 21, 39). Tall-growing *Bambusa* species were also among 24 other plant species planted in Nepal, which were planted to restore an eroded river bank from extensive logging and agricultural soil overuse (FAO and INBAR, 2018: 45).

By accumulating organic matter and counteracting erosion, bamboos reversed soil degradation, regulated water flows and reduced pollution from agricultural runoff (Lobovikov et al., 2009; Song et al., 2011).[9] By binding gravel and soil, soil bulk density, sedimentation and

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[9] Comparing the soil anti-erodibility of forest types in Jiangsu Province, China, *P. pubescens* surpassed Chinese fir trees, an Asian oak species (*Quercus acutissima*) and pine trees (*Pinus massoniana*) (Song et al., 2011: 421).[9] *P. pubescens* was about 30% to 45% more effective than Chinese fir in conserving water by means of higher canopy interception, water holding capacity in the litter layer and by increasing soil infiltration (ibid.). Similar findings were made in Zhejiang Province, China, with *P. pubescens* being about 46.7% and 57.4% more effective than *Pinus massoniana* and *Castaneam ollissima* respectively (Song et al., 2011: 421). However, here the bamboo species were about 37.2% and 16.7% less effective in conserving water than *Cycloba lanopsisglauca* and Chinese fir (ibid.). Also in China (Anhui Province), the average surface soil runoff in bamboo forests was recorded to be 33% less compared to a fir forests and 65% less compared to a pine forest (ibid.).

water runoff were improved in bamboo forest plantation projects in Ghana, Tanzania, Shaanxi Province of China, Nepal as well as Colombia (FAO and INBAR 2018: 10, 21, 31,47, 58). A long-term effect of bamboos was also recorded in India (Uttar Pradesh) where over a 20-year period the ground water table rose by 10 m (from 40 m to 30 m deep) (FAO and INBAR, 2018: 39). These effects have been be ascribed to bamboos' extensive root and rhizome system enhancing infiltration; its thick layer of plant litter reducing splash erosion; and its highly elastic culms and the dense canopy protecting land from extreme winds as well as from rain fall erosion. These characteristics are said to provide a high capacity for erosion control, soil and water conservation, landslide prevention, protection of riverbanks, and windbreak and shelterbelt potential (Kuehl, Henley and Lou, 2013: 18; Song et al., 2011: 421).

Another aspect is bamboo's natural resistance to extreme situations, in particular to fire. In Ghana planted bamboos to bridge remnant forests were also chosen because the region suffers from striving herdsmen who ignite bushfires (FAO and INBAR, 2018: 5). As the rhizomes are underground, they remained unaffected by these fires and sprouted new shoots shortly after fires were extinguished. This resulted in revegetation of the landscape quickly and protected the soil from weather influences. The underground parts of the plant make bamboo capable of surviving and regenerating even after the aboveground biomass was destroyed (ibid.: 1). As the rhizomes survive fires as well as harvests of the culms, they also said to preserve the sequestered carbon underground (Kuehl, Henley and Lou, 2013; Kuehl, Kuehl and Castillo, 2018; Lobovikov, 2009).

Bamboos, just like other plants, require specific physio-chemical soil compositions to grow, as in nitrogen, phosphorus and potassium, and therein a relatively high organic matter composition (Handique, 2014: pp. 82-95). From that perspective, bamboo is not a miracle plant despite its growth characteristics. Nevertheless, bamboo grows on highly acidic soils (pH 3.5) (ibid.: 92) and are therefore used in soils that had been under agricultural overuse. Lima et al. (2019) surveyed Brazilian Atlantis Forest soil regarding its composition. Within bamboo areas, the soil was significantly richer in potassium and magnesium. Also, the bamboo areas had lower potential acidity and aluminium saturation. The authors concluded that bamboo's soils are chemically more fertile (ibid.: 35).[10]

The decomposition of dead organic plant and animal matter under the influence of soil microorganisms (bacteria and fungi) and climatic conditions (preferably warm climates) forms humus (Melillo et al., 1989). As bamboos shed their leaves, it is deposited as dead leaf litter on the soil surface. Claims have been made that the planting of bamboos (*D. strictus and B.*

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[10] This conclusion, however, is based on one survey. It only means that it is the present condition; it is not exclusive of the soil properties having existed before the introduction of bamboo, or whether this is the needed composition to grow bamboo. It cannot indicate whether bamboos caused this composition. The soil in question was also predominantly clayey, while in non-bamboo plots soil was sandy. The authors acknowledge that the higher soil fertility was probably driven by the more clayey texture of soils under bamboo plots (ibid.: 36), and thus may not be attributed to bamboo at all.

bambos) added between 15 cm to 20 cm organic matter a year (INBAR, 2014: 4, 16). Cairo-Cairo et al. (2018) measured the effect of bamboo compost and leaf litter on fungi and bacteria activity, concluding that the addition of either material statistically significant increases the prevalence of bacteria and fungi in the soil (compared to an untreated control soil). This may indicate favourable conditions for decomposition and humus generation under bamboo leaf litter. Also, Handique (2014) reported an increase of soil organic matter in a bamboo dominated forest from leaf litter. This litter would act "as mulching material promoting good infiltration and thus resulting in high amount of nitrogen, phosphorous and potash status of the soil" (ibid.: 93). A high leaf litter may influence the chemical and nutrient cycle positively. The prevalence of thick leaf litter itself may, however, not suffice to conclude on a thick humus layer. The persistent remains of bamboo leaves with few to no species growing in between may indicate the absence of their decomposition instead, as suggested in Canavan et al. (2019) and Veblen (1982).

The planting of bamboos alone may not yield a high biomass; bamboos seem to require assistance to improve the soil quality and subsequently the productivity (Kuehl, Henley and Lou 2013: 21). Tripathi and Singh (1994) experimented and documented that human intervention (harvesting) of bamboos "resulted in greater allocation (83%) of dry matter to the belowground parts, which led to the development of an extensive root system, capable of absorbing substantial amounts of water and nutrients from a soil where these are essentially limited" (ibid.: 119).

Detrimental effects of bamboos

Phyllostachys and *Bambusa* genera are known for their invasive behaviour due to their running rhizomes (Canavan et al., 2019: 130; also Xu et al, 2019). It has been documented that these species were introduced to non-indigenous environments all around the world (Canavan et al., 2019). The running *B. vulgaris*, for example, has been widely distributed to 123 countries (ibid.: 130). Clumping species are said to have an acceptable to low risk of invasiveness (Dawson, Burslem, & Hulme, 2009) compared to running species with a higher risk (Buckingham, Wu, & Lou, 2013; Buckingham & Jepson, 2015). Canavan et al. (2019) as well as Xu et al. (2019) underlined, however, that both running and clumping species can be invasive. There may, in fact, not be "any comprehensive studies on the invasion ecology of bamboos, despite their reputation for being a group that contains highly 'invasive' species" and "little is known about which species have been moved where, and about the outcomes of these movements" (Canavan et al., 2019: 2, 11). When little is known about the distribution of bamboos, it may explain contradictory arguments about the plant's invasiveness.

Bamboos' fast growth rates aboveground in combination with fast clonal rhizome reproduction belowground may be considered an advantage in landscape reclamation projects where vegetation coverage is required to stabilise or improve soil conditions or connect isolated vegetation. However, this fast spread is also the reason why bamboos are considered as invasive with ecological alteration effects. Bamboos can overwhelm other seedlings, due to its competitive growth velocity, underground expansion, with little need for light aboveground, while quickly colonising the available space (Canavan et al., 2019; Larpkern, Moe and Totland, 2011). The capacity to produce large amounts biomass in short periods of time can supress the growth of adjacent plants (Canavan et al., 2019: 124). The continuously depositing bamboo leaf litter affects non-bamboo seedlings in their sprouting and growth, while they are less affected by mixed-tree litter conditions (Larpkern, Moe and Totland, 2011; Zaninovich et al., 2017). Bamboos are more successful in competing for resources of light, water, nutrients and space, and impact on the surrounding plant vegetations. They grow rapidly above a forest's canopy, allowing it to dominate over the other vegetation (Isagi and Torii, 1997; Okutomi, Shinoda and Fukuda, 1996; Zaninovich et al., 2017), and they can form densely spread bamboo stands, excluding other species from spreading (as in Larpkern, Moe and Totland, 2011; Okutomi, Shinoda and Fukuda, 1996).

In short, bamboos dominate in four stages: underground extension, aboveground sprouting, exclusive competition, and absolute dominance (Yang et al., 2015). Subsequently, the aboveground composition of vegetation changes from a variety of plant stories with different leave compositions to a dense and homogeneous bamboo culm dominated landscape (Kobayashi, Saito and Hori 1999). For an example, Bai et al. (2013) compared plant species richness with and without bamboo presence. The authors found that herbs are more often present in needle and broad-leaved forests mixed with bamboos, and that the removal of bamboos increased plant species in the shrub layers (ibid.: 294).

Shifts in vegetation structure and function due to bamboo encroachment into evergreen broadleaved forests may also have the opposite effect to carbon sequestration and increase carbon dioxide emissions from forests. Forest carbon stocks can decline through the replacement by bamboo stands (Bai et al., 2016; Xu et al., 2020). The same may affect the carbon contain in soil. Bamboos were found to have carbon detrimental effects on a forest's sequestration capacity by decreasing its soil organic carbon (SOC) and negatively affect the forest's biomass productivity (Zaninovich, Montti and Gatti, 2017: 216).

A bamboo-dominating composition was also found to have consequences on the previously benefiting water infiltration and runoff, composing the canopy only of bamboo leaves and the understory being scarce in plant variety (Ide et al., 2010: 81). This same effect was observed by bamboo canopy (*Phyllostachys makinoi)* intercepting less rain water, compared and betelnut and Chinese fir (Lu et al., 2007). The comparison with Chinese fir is particularly contradictory given the earlier findings.

Figure 3: Exemplary bamboo stands, thick leaf litter accumulation and soil coverage by the litter.
Note: These unidentified bamboo stands were encountered in the outskirts of Bangkok, Thailand among a housing community with adjacent forest patches. The space was an estimated 10m x 20m wide. The stands seemed abandoned as no signs of harvesting but only dried culm breakoffs as well as rubbish was found.

Despite indicative rainfall preferences, unclear remains how much water bamboos consume and whether the needed water amounts to problematic environmental impacts on the surrounding areas, similar to the fast-growing eucalyptus tree (compare Sunder, 1993). Indicative information was found in Bowyer et al. (2014: 8) who documented bamboos requiring an abundance of rainfall without standing water, while Scheba, Blanchard and Mayeki (2017: 34) documented from farmers in South Africa a requirement of between 600 mm to 1000 mm of rainfall a year, which is similar to Huberman (1959) stating at least 1,000 mm a year.[11] The upper limit is unknown, but bamboos can be found in areas with a rainfall greater than 6,350 mm and the most common margin may range between 1,270 and 4,050 mm of annual rainfall (ibid.: 52). Even though bamboos may improve water infiltration, they may consume a lot of water before reaching other soil layers or plants. Although the exact consumption by bamboo species seems yet under-researched or generalised, there has been no evidence that water requirements are low, considering that they thrive in tropical-humid conditions.

With ecological structures altering effects above- and belowground, bamboos can have the contrary effect of what was expected landscape restoration. Dura and Hiura (2006) concluded that bamboo stand expansion increased slope failure, because of developing a dense root mat in the upper soil which the sediment layer could not carry. This would indicate that the dense root system of bamboos may not be suited for all landscapes that involve slopes.

The mentioned natural resistance to extreme situations can also be a concern when naturally occurring interventions, e.g. hurricanes, frost or fires, cannot decimate bamboos in regions where their native counterparts would be decimated. Bamboos would quickly regrow, while other plant seedlings may not regrow due to being literally overshadowed. As bamboos are resilient to damage due to their underground rhizomes, eradicating bamboos would require removing their entire clumps, which would cause further damage to soils, trigger pollution, and kill native vegetation (Blundell et al., 2003: 17).

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[11] Germany recorded 735 mm rainfall in 2019 (Umweltbundesamt, 2020).

With an invasion of bamboo species replacing former plant variety (if any) as well as altered light and soil conditions, changes of the nutrient and chemical composition of the soil may also be expected. An influence on the chemical and nutrient properties may stem from bamboo leaf litter. The build-up of leaf litter on the top surface can slow the rate of decomposition of organic matter and, therefore, be deleterious for nutrient cycling (Canavan et al., 2019; Veblen 1982). Influential to this slowdown of decomposition appeared to be the accumulation of silica from bamboo leaf litter (Ikegami et al., 2014; Veblen, 1982). However, silica contents in soil also increase nutrient availability and uptake in other plants (Greger, Landberg and Vasilik, 2018). This would mean that other plants can benefit from increased bamboo leaf litter. Bai et al. (2016) and Song et al. (2016) further identified a positive reduction of nitrogen in forests where bamboo encroached upon.

Whether bamboos improve or deteriorate chemical and nutrient composition of the soil, either condition can expect a change in the abundance of bacterial, other microbial, insect life and vertebrates in general (Canavan et al., 2019: 125). With changes in microbial and insect life, fauna may also become more susceptible to pests and diseases. Invasive species have the potential to be a host for pathogens, with every species potentially modifying the existing structure and function of ecosystems and their services (Crowl et al., 2008: 243). Xu et al. (2007) found 208 pathogens (including fungi, bacteria, mites, virus and others) associated to 148 bamboo species in China alone. One might expect a high potential for spreading disease by introducing bamboo species. The bamboo mosaic virus was found to be a major threat to bamboos and to be easily transmitted from one plant to another by means of insects (Chang et al., 2017). Contrary to expectation, there does not seem to be research on bamboos spreading disease onto other plant or animal species.[12] Kuehl, Kuehl and Castillo (2018: 54) also highlighted that there is little investigation into bamboos' pest and disease properties. Despite the over 200 pathogens affecting bamboos themselves, there appear to be only reports on bamboos' own susceptibility to pests (FAO and INBAR, 2018: pp.16). It leaves to wonder whether bamboos' 183 fungi (Xu et al., 2007) affect other species.

Biodiversity interactions

Ecosystem functioning is affected by altered ecological conditions, such as water infiltration, soil erosion, nutrient cycles and finally the food web (Wittenberg and Cock, 2001: 18). The previous individual consequences can create scenarios which may threaten the functioning of an entire ecosystem, thus creating consequences of the consequences.

Okutomi, Shinoda and Fukuda (1996) explored the cause for the replacement of previous broad-leaved forests with bamboo forests (*P. pubescens*). The rhizomes, leaf litter, culm density and canopy did not allow other plants to vitalise, and which eventually died off (ibid.: 726).

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[12] Unless it exists in languages other than at my disposal.

More studies came to similar conclusions with a reduction in the total number of plant species (species richness) the more bamboo (*P. bambusoides*) culms where present (Suzaki and Nakatsubo, 2001), with a decrease of overall plant biomass and tree density (Lima et al., 2019; Bai et al., 2013) [13], and with a reduction of overall plant diversity among shrubs and the herbaceous layers (Kudo et al., 2012; Tao, Shi and Wang 2012; Zhang and Cao, 1995).

Measuring bamboos' biodiversity impact, Larpkern, Moe and Totland (2011) concluded that seedling species richness was lower under bamboo canopy, compared to tree canopy (ibid.: 164).[14] Seedling abundance was also affected negatively by the prevalence of bamboo (ibid.: 165). The downward trend for species richness and evenness was tested and confirmed by Yang et al. (2010), stating that *P. pubescens* led to "gradual simplification of the hierarchy and the significant change of species composition" (ibid.: 553).

Canavan et al. (2019) found that the impacts of recorded bamboo invasion in temperate and tropical forests were "similar in the native and non-native ranges of weedy bamboos" (ibid.: 121). The authors noted that the impact of bamboos on other plant species was augmented due to being "a response to human-mediated land transformation and disturbance of forests" (ibid.). With the example of *P. edulis*; this species has become increasingly problematic, because of the increased demand for bamboo products. This led to mixed-species forests being converted to bamboo monocultures (ibid.: 122, 123).

The reduction of species diversity facilitated through human intervention was confirmed by Lou and Henley (2010), which reviewed bamboo management techniques that led to declines in plant diversity in bamboo forests and ultimately established bamboo monoculture plantations (ibid.: pp.11). While bamboo species themselves have a direct impact on their environment, intensive management of bamboo forests additionally "simplify the structure of the forest and decrease the species richness and biological diversity of the tree, shrub, and herb layers" (Song et al., 2011: 424).

When bamboo dominates or replaces native plants, it impacts on those living off these plants: such as birds or insects, and herbivores in particular, and predators that depend on herbivores. Bamboo monoculture forests in Hunan and Sichuan Province of China were found to have

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[13] The reduction of biomass/carbon refers to standing stock. As Xu et al. (2020) point out: "the annual biomass yield per ha for Moso bamboo is high compared to other subtropical forest species" (ibid.: 3). The fast regrowth of bamboo species, if and when culms are harvested and processed into durable products, may counter balance the lower standing biomass. "Standing biomass is generally higher for an original forest compared to bamboo, but biomass yield calculated annually is greater due to biennial bamboo timber harvests." (ibid.)

[14] Biodiversity can be interpreted differently. Leaning on Elzinga (2001), Zhang et al. (2012), Willig and Presly (2018) and the Convention on Biological Diversity (1992), biodiversity can be understood as the biological variability within and between life forms of a location, an ecosystem or a landscape. Biodiversity can be understood as diversity within species, between species and the diversity of ecosystems. Biodiversity is defined and measured as a property, which in turn consists of two primary components: species richness and species evenness. Species richness refers to the countable number of species in a given area and "does not consider differences in species relative abundance" (Zhang et al., 2012: 1). Species evenness refers to the similarity in species' relative abundance in a given area (ibid.) Species richness and evenness can vary with change in key ecological processes such as competition, predation, and succession, each of which can alter proportional diversity (ibid.). This circumstance leads to another measure for biodiversity and is expressed as the difference between richness and evenness (ibid.; Purvis and Hector, 2000).

lower avian diversity compared to nearby mixed forests (see Lou and Henley, 2010). The removal of bamboo biomass along river banks in Japan also led to an increase in biodiversity (Suzaki and Nakatsubo, 2001). A study in Zhejiang and Fujian Province documented declines in soil fungi and bacteria diversity (by 45% and 90%) in bamboo monoculture forests over an eleven-year period (Lou and Henley, 2010: 12). The loss of biodiversity appears to increase susceptibility to pest attacks, as found with mite infestation among bamboo monocultures compared to mixed forests (see Zhang et al., 2000).

The loss of key species will upset ecological interactions (Wittenberg and Cock, 2001: 17). Losing key species reduces "the functional richness, specialization, and originality of assemblages more than expected under a random loss of species" (Leitão et al., 2016: 5). This leads to a loss of interactions among species, an eradication of specialized forms of resource utilization and an undermining of important ecological processes (ibid.).

Nevertheless, other cases depicted a positive relation between bamboo and biodiversity. Planted bamboos in Chitwan, Nepal allowed other plants to regenerate (FAO and INBAR, 2018: 47). Sanchez and Camargo (2012) recorded higher numbers of bird species in bamboo forests. And Cairo-Cairo at el. (2017) showed a regeneration of macrofauna along riverbanks in Cuba. The increase of biodiversity, however, may be based on a previously reduced biodiversity due to eroded land.

6. The Carbon Sequestration Estimations

6.1. Considerations and Limitations

With more than 1600 documented species, it would be a challenge to consider all occurring species for each country with potentially suitable grows conditions and each species' biomass or carbon content. Depending on the source, China alone is estimated to be home to between 500 and above 600 species (Lobovikov et al., 2007; Ohrenberger, 1999). Nevertheless, the demonstrative estimations require limiting the species to a select few which are present in the relevant countries of Asia, including Oceania, Africa and the Americas.

To the limitation of a select few species adds that only those species can be chosen, for which data on their biomass and/or biomass organic carbon (BOC) has been retrievable from secondary sources. Species specific data often turned out unavailable, or at least not identified in the to me available languages of understanding.[15] Also, in the available literature, the same species often tended to be the object of study (e.g. *B. vulgaris* and *P. pubescens*), which limits the variety of species-specific data. It is not excluded that more information is available on other species that was simply not identified.

Many studies delivered relevant data (Table 3 in section 6.4.), but the details on the species' characteristics (height, diameter, weight per culm, etc.) and biomass/BOC was not similarly reported. Some details, in particular the biomass to carbon content ratio, were possible to calculate, while other details, such as the plant distribution density, were not possible to calculate. The greatest obstacle rested in relating the biomass to the distribution density of bamboos in a given space. It remained uncertain whether the density of the documented bamboo forests plantations is the result of human interference or natural distribution. Despite some attempts, the limited data did not allow for a conclusive calculation of the optimum biomass in relation to the distribution density, including when taking into account the growth parameters or culm volume. The shortcoming of the available and comparable data led to multiple adjustments in the writing process – which is an important fact to document.

The biomass/BOC was usually stated by distinguishing aboveground and belowground data. Unfortunately, for the belowground distribution, the least data was available. Adapting a common above- to belowground carbon ratio also requires caution. For example, *harvested* bamboo forests can have an even above- to belowground biomass distribution, while in *unharvested* forests the aboveground biomass can be three times the belowground biomass (Li et al., 1999: 95).[16] Due to insufficient information, the focus will rest on the aboveground

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[15] English, Spanish, German, Portuguese, and Chinese to a limited extend.

[16] This finding may also suggest that a reported aboveground biomass in other literature, which is similar to the belowground biomass, may not reflect the actual capacity of that forest to sequester carbon. It may be a number of times higher.

estimations. Since the belowground biomass is to remain in the ground, the aboveground biomass is more important for this paper as only the aboveground biomass is to be harvested and regrown. For an indication, a belowground estimation will be provided.

Another uncertainty relates to the age of the plants as it can influence the carbon stock. While some studies stated the assumed age of either an entire plantation/forest or a single plant, other studies did not provide such reference. There are instances where the same plantation was researched over subsequent years, while other cases measured biomass/BOC on an ad-hoc basis. Some studies included all bamboo plants regardless of age, while others distinguished the age. Usually, the focus was on mature plants ready for harvesting when their carbon intake peaked; but the age of maturity can range from four years old and older. As the intention of this paper is to consider the carbon sequestration potential every five years (outlined below), which requires partial harvesting and regrowing of new culms, the age influences in the collected data may work in favour and account for different age structures as if it was a managed bamboo forest plantation consisting of different age structures.

Important was to consider tall and woody species in order to provide a large biomass in which carbon is sequestered. In order to narrow down to a select few species, basic information on the expected growth parameters for regionally important species needed to be found. A number of databases and information repositories was consulted, which provided the relevant information to different extents as well as for different bamboo species. Some of the databases and repositories are limited to a continent. Identifying woody, tall-growing species, judging by their culm development, and taking into account the region or country, resulted in a cumbersome and time-consuming database and species comparison activity. One all-encompassing database would be beneficial.

As there are invasiveness concerns for non-native bamboo plants, preferences for regionally existing, native species were intended (section 6.4.). Identifying a native status is difficult as bamboos have been widely artificially planted and distributed. Depending on the region and country, there are also priority species of tall-woody characteristics for economic purposes, and have been widely accepted, as in countries of Africa.

6.2. Selected Countries

Bamboo species have been found to grow in tropical to warm temperate climates (Vorontsova et al., 2016: 6). Countries or climatic regions like Northeast Asia (e.g. Republic of Korea) also have shown to be suitable for some bamboo species (Kim et.

Figure 4: Indicative map of the distribution of bamboo, by Kelchner and Bamboo Phylgeny Group, 2013.

al, 2018; Yuen et al., 2017) therefore, it is not excluded per se that bamboo can grow in non-tropical regions, including Europe. Indeed, "the bamboo species suitable for use in the European climate are temperate bamboos, such as *Sasa*, *Fargesia* and *Phyllostachys*" (Potters et al., 2013: 89). To investigate the climatic suitability of non-tropical countries or countries with occurring non-tropical climates would go beyond the scope of this paper, but it should be considered in the future if research upon this topic was expanded. It is to expect that different climate conditions will yield different productivity among the same bamboo species, when they were planted in different regions. The suitability will also depend on other factors, such as rain fall and soil nutrients.

To identify the countries with suitable climate conditions, the documented bamboo occurrences by Ohrnberger (1999) were used as the primary source of countries where bamboos grow. Subsequently, these countries were compared to the Köppen-Geiger climate classification of countries (Beck et al., 2018) (Figure 5) in order to identify additional countries with similar climate classifications and to expand the list of countries where bamboo might either be growing due to the climate similarity or can be considered for the purpose of establishing plantations.

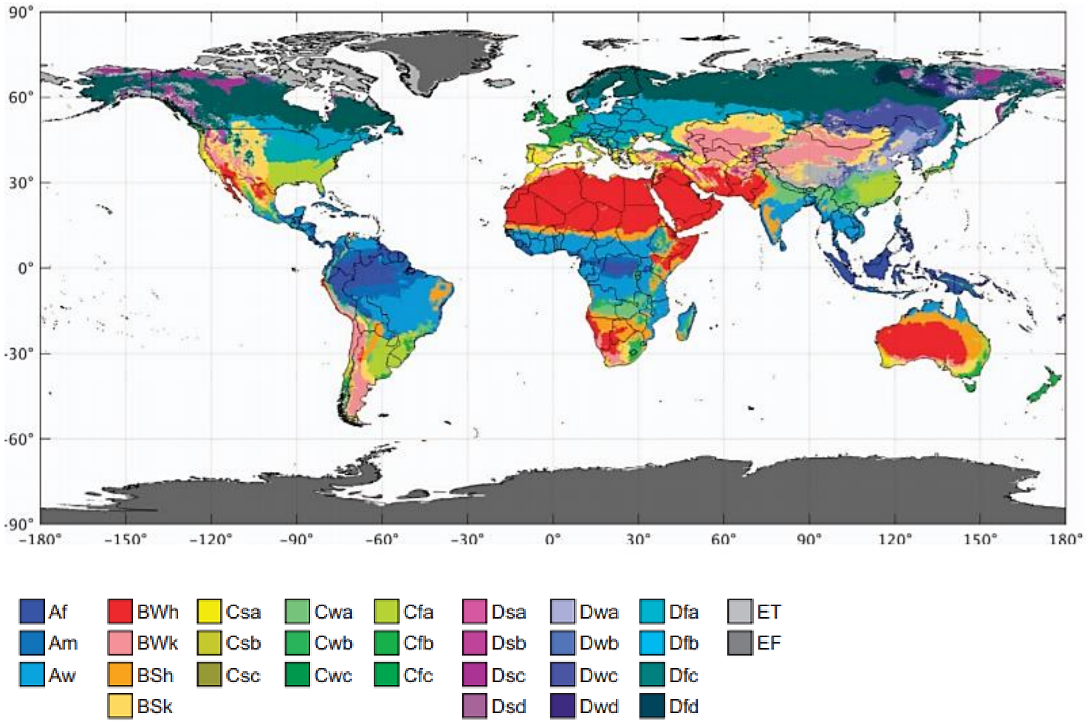

Figure 5: Köppen-Geiger classifications map representing the climate between 1980 to 2016, by Beck et al., 2018. Note: For the detailed legend, see Beck et al., 2018.

A better approach would be to determine the geography in terms location, altitude, rainfall, sunshine and soil composition for each country's varying geography. However, such methodological approach would require months if not years to investigate, which is not feasible for this paper. Thus, the made assumptions must suffice as control conditions.

The countries identified by Ohrnberger (1999) coincide with the Köppen-Geiger classification for tropical climates (indicated through the capital letter "A" in the legend) as well as countries with temperate regions but without dry season and hot or warm summers (indicated through "Cfa" and "Cfb" respectively). Table 1 below outlines the countries which can be considered for bamboo planting due to their climate conditions.

Table 1: Countries with documented bamboo occurrences or suitable climate conditions

As documented by Ohrnberger (1999)			Additional countries with suitable tropical or sub-tropical climate*		
Asia and the Pacific	Africa	South and Central America	North America	Africa	South and Central America
Australia	Cameroon	Argentina	United States of America	Angola	French Guyana
Bangladesh	Ethiopia	Belize		Benin	
Bhutan	Kenya	Bolivia		Burundi	
Brunei Darussalam	Malawi	Brazil		Central African Republic	
Cambodia	Sudan	Chile		Côte d'Ivoire	
China	Togo	Colombia		Democratic Republic of the Congo	
India	Uganda	Costa Rica		Equatorial Guinea	
Indonesia	United Republic of Tanzania	Cuba		Eswatini	
Japan	Zambia	Dominican Republic		Gabon	
Lao People's Democratic Republic	Zimbabwe	Ecuador		Ghana	
Malaysia		El Salvador		Guinea-Bissau	
Myanmar		Guatemala		Liberia	
Nepal		Guyana		Madagascar	
Pakistan		Haiti		Mozambique	
Papua New Guinea		Honduras		Nigeria	
Philippines		Mexico		Republic of the Congo	
Republic of Korea		Nicaragua		Ruanda	
Sri Lanka		Panama		Sierra Leone	
Thailand		Paraguay		South Africa	
Viet Nam		Peru			
		Puerto Rico			
		Suriname			
		Trinidad and Tobago			
		Uruguay			
		Venezuela (Bolivarian Rep. of)			

*Note: *Climate classification according to Köppen-Geiger climate in Beck et al., 2018.*

However, some countries are notably large, and in consequence span more than one climate zone. In particular, Argentina, Australia, China and the United States of America show suitable as well as non-suitable climate zones. Judging by the graphical indication of the Köppen-Geiger classification, in Argentina at best a generous half of the geography may fall under suitable climate conditions, as the other 50% appear to be dominated by arid conditions. China as well as the United States of America both span vast geographies with arid, tropical, temperate and cold climates. Judging by the graphical presentation above and with no other indication at hand, 33% of China may be considered suitable for bamboo growth and 25% of the United States of America. The continent of Australia is notably dominated by arid and desert climate, with only some coastal regions seemingly suitable for bamboo. In comparison to the indications made by Kelchner and Bamboo Phylgeny Group (2013), only the most northern coastal regions with tropical climate appear suitable for bamboo. The size may at best be 10% of the continent.

A similar case is Chile, which is a geographically narrow country, spanning arid to cold climates, and only a narrow stretch with temperate climate. This is not to say that in Chile no bamboo can grow, as evidence speaks for at least 10 documented species pertaining to one genus (*Chusquea*) (Londoño, 2001: 3). However, due to the less favourable overall climate(s) and the limited geography, bamboo growth may result less than optimal and may not fit the below estimations in comparison with other more suitable climates. For the benefit of the doubt, Chile is disregarded. In the Republic of Korea (South Korea), *P. eludis* and *bamusoides* can be found (FAO, 2006b; Kim et. al, 2018). However, the country is subject to a much lesser favourable climate and little information on bamboo forests is available, which may be attributed to the plant not playing a major role in the country. Suitable conditions are exclusively situated in the narrow subtropical southern parts of the country (Kim et. al, 2018) Therefore, the Republic of Korea is disregarded. Finally, Pakistan recorded bamboo species (FAO, 2006c; Ohrnberger, 1999). However, the arid climate may suggest not to be of optimal growth condition for a plant accustomed to a moist environment. In fact, bamboos are only grown on private farms in a condensed area of north-eastern Pakistan (FAO, 2006c). Therefore, Pakistan is not considered.

6.3. Selected Space Allocation

A reasonable size for an intended bamboo forest plantation needs to be identified. Lobovikov et al. (2007) documented existing bamboo forest in 2005 and put the size in proportion with the total forest area in a country. Not all countries where bamboo was identified by Ohrnberger (1999) coincided, but a number of countries provide an indication. It is foreseeable that forest area will have changed in the last 15 years. The recency of the data is not as important as is finding a reasonable size of bamboo forest that can be proportionately scaled to every country. Based on "bamboo area", "forest area" and "bamboo to forest ratio" by Lobovikov et al. (2007: 12), as well as taking into account the "country sizes" (World Bank database), the additional data on the "forest to country size ratio", "bamboo area" and "bamboo to country size ratio" was calculated (Table 2).

The regional averages on the "bamboo to country size ratio" differ minimally in 2005, ranging around one percent, which is reflected in the worldwide average of 1.1%. The latter is also the value corresponding the global forest area loss between 1990 and 2015 (UNDP, 2020). As it is the purpose to capture more carbon, the size of total bamboo forest needs to be increased. While a too high value will anticipatedly collide with other spaces, a too low value would undermine the idea of this paper. Therefore, the value of two percent is chosen for an initial comparison of how much the carbon intake would increase if the average global bamboo area (dated 2005) was doubled.

Table 2: Documented extent of bamboo forest and natural forest in Asia, Africa and Latin America

Country	Bamboo area (km^2)	Forest area (km^2)	Bamboo to forest ratio (%)	Country size (km^2)	Forest to country size ratio (%)	Bamboo area (km^2)	Bamboo to country size ratio (%)
Bangladesh	830	8,710	9.5	130,170	6.7	827.45	0.6
Cambodia	290	104,470	0.3	176,520	59.2	313.41	0.2
China	54,440	1,972,900	2.8	9,388,210	21.0	55,241.2	0.6
India	113,610	677,010	16.8	2,973,190	22.8	113,737.68	3.8
Indonesia	20,810	884,950	2.4	1,811,570	48.8	21,238.8	1.2
Japan	1,540	248,680	0.6	364,560	68.2	1,492.08	0.4
Lao People's Democratic Republic	16,120	161,420	10	230,800	69.9	16,142	7.0
Malaysia	6,770	208,900	3.2	328,550	63.6	6,684.8	2.0
Myanmar	8,590	322,220	2.7	653,080	49.3	8,699.94	1.3
Pakistan	200	19,020	1.1	770,880	2.5	209.22	0.0
Papua New Guinea	450	294,370	0.2	452,860	65.0	588.74	0.1
Philippines	1,720	71,620	2.4	298,170	24.0	1,718.88	0.6
Republic of Korea	60	62,650	0.1	97,489	64.3	62.65	0.1
Sri Lanka	30	19,330	0.2	62,710	30.8	38.66	0.1
Thailand	2,610	145,200	1.8	510,890	28.4	2,613.6	0.5
Viet Nam	8,130	129,310	6.3	310,070	41.7	8,146.53	2.6
Asia	236,200	5,330,760	4.4	18,559,719	28.7	234,553.44	1.3
Ethiopia	8,490	130,000	6.5	1,000,000	13.0	8,450	0.8
Kenya	1,240	35,220	3.5	569,140	6.2	1,232.7	0.2
Nigeria	15,900	110,890	14.3	910,770	12.2	15,857.27	1.7
Uganda	670	36,270	1.8	200,520	18.1	652.86	0.3
United Republic of Tanzania	1,280	352,570	0.4	885,800	39.8	1,410.28	0.2
Africa	27,580	664,950	4.1	3,566,230	18.6	27,262.95	0.8
Brazil	93,000	4,476,980	2.1	8,358,140	53.6	94,016.58	1.1
Chile	9,000	161,210	5.6	743,532	21.7	9,027.76	1.2
Ecuador	90	108,530	0.1	248,360	43.7	108.53	0.0
Peru	1,900	687,420	0.3	1,280,000	53.7	2062.26	0.2
Latin America	103,990	5,434,140	1.9	10,630,032	51.1	10,3248.66	1.0
Total	367,770	11,429,850	3.2	32,755,981	34.9	365,755.2	1.1

Source: Bamboo area, forest area and bamboo to forest ratio: Lobovikov et al., 2007: 12; Country size: World Bank database, available at: https://data.worldbank.org/ (last accessed at 24 January 2021).

In addition, the values of five percent and seven percent have been chosen to compare the carbon intake effect if and when the bamboo forest area was increased by such extent for demonstrative purposes. As there are countries with large bamboo areas, it might be relevant on a country-by-country basis. Specifically, five percent correspond to the loss of forest area as occurred during 1990 and 2015 in each Latin America and the Caribbean, Sub-Saharan Africa and Least Developed Countries (UNDP, 2020). The envisioned seven percent relate to Bastin et al. (2019) who estimated that an additional 9 million km^2 could be reserved globally for newly planted trees without impacting on other land use.[17] The additional 9 million km^2 correspond to seven percent of the total global land area. If the suggested additional space was equally distributed around the globe, it would leave to assume that seven percent are also applicable to the countries or regions considered in this paper (3,372,574 km^2).

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[17] 127.3 million km^2 total land area, according to World Bank database, available at: https://data.worldbank.org/ (last accessed at 24 January 2021).

6.4. Selected Species

Table 3: Indicative growth potential for tall-growing bamboo species

Species	Culm height (m)	Diameter at breast height (DBH) (cm)
Arundinaria/ Yushania/ Oldeania alpina	20	12.5
Bambusa balcooa	18	15
Bambusa bambos	30	18
Bambusa blumeana	20	10
Bambusa cacharensis	20	10
Bambusa oldhamii	16	10
Bambusa vulgaris	20	20
Cathariostachys madagascariensis	20	8
Dendrocalamus asper	20	12
Dendrocalamus giganteus	30	30
Dendrocalamus latiflorus	20	20
Dendrocalamus strictus	20	13
Guadua angustifolia	30	20
Guadua chacoensis	20	12
Guadua weberbaueri	18	10
Oreobambos buchwaldii	20	10
Phyllostachys pubescens/edulis	20	18

Note: The reported growth characteristics may represent potential maximums. They can result shorter depending on environmental conditions (see Table 4). Exceptional cases may result even larger.

Source: Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021); Natural Resources Conservation Service PLANTS, available at: https://plants.sc.egov.usda.gov/java/ (last accessed at 24 January 2021); Plant Resources of Tropical Africa, available at: https://www.prota4u.org/database/ (last accessed at 24 January 2021); Plants for a Future, available at: https://pfaf.org (last accessed at 24 January 2021); Plants of the World, available at: http://powo.science.kew.org (last accessed at 24 January 2021); Useful Tropical Plants, available at: http://tropical.theferns.info/ (last accessed at 24 January 2021).

Before identifying the species from a region, it should be noted that the growth information as derived from the databases may only be averages, and deviations towards being shorter or taller are possible. An example is *Dendrocalamus asper* which is stated with a height of 20 m and a culm diameter of 10 cm in different databases,[18] whereas another study (Patricio and Dumago, 2014) found parameter for the same species of and 24.2 m and 16.6 cm, respectively. In general, for biomass productivity purposes in bamboo culms, and therein carbon sequestration, may want to range around 20 metres of potential plant height and around 10 cm of culm diameter at breast height (DBH) to allow for some comparability despite considering different species. If a species was of too short height in general, resulting in too little biomass, it may undercut the purpose of sequestering carbon fast. This shall not mean that short-growing species should not be considered; they might be planted at a higher density. However, tall-growing bamboos produce larger and wider culms which have more versatile timber applications when harvested – an important fact that will be explored later.

Species in Latin America

The region of Latin America accounts for 20 bamboo genera, according to Londoño (2001). The most important bamboos in the Latin America region have been stated to belong to the endemic genus *Guadua* and *Chusquea* as well as the Asiatic-introduced genus *Bambusa* (Londoño, 2001: 3; Widmer, 1990: 14). The native genera of *Apoclada*, *Aulonemia*, *Elytrostachys*, *Otatea* and *Rhipidocladum* as well as non-native *Dendrocalamus*, *Gigantochla*, *Melocanna* and *Phyllostachys* can also be found (ibid.). Specifically, *Guadua angustifolia* has been identified in

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[18] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Plants of the World, available at: http://powo.science.kew.org (last accessed at 24 January 2021).

Colombia, Costa Rica, Ecuador, Guatemala, Panama, Mexico, Nicaragua, Venezuela and also the Caribbean islands. (Huberman, 1959; Londoño, 2001; Widmer, 1990). In Brazil, the cultivation of *G. angustifolia* has been documented, but the species is said to be limited to small scale cultivation (Lobovikov et al., 2007: 13). *G. superba* was also identified by Huberman (1959) in Brazil, and has relatively tall growth pattern (Table 3). Also in Brazil, *G. angustifolia* is ascribed to be one of the most utilised species (FAO, 2006a) As *G. angustifolia* harbours several subspecies, and each subspecies can show different growth characteristics, *G. angustifolia* Kunth is the reference species, which naturally occurs in the Central to Southern Latin American region and the Caribbean (compare Young and Judd, 1992 as well bambooweb.info).

For Bolivia and Peru *G. superba* and *G. weberbaueri* are identified by Londoño (see 2001: 9) as a commonly occurring species, while for Argentina and Uruguay with a temperate climate the *Chusquea* genera are common (see Huberman, 1959). Londoño (2001) documented *G. chacoensis* in Argentina, and which was also studied by Vega and Hernández (2008) in Uruguay.

Species in Asia and Oceania

Asia with more than 1000 documented species has the widest variety of bamboos (Lobovikov et al., 2007; Ohrnberger 1999). For some countries, like China and India, key species can be identified and applied across the country, while for the many countries of South East Asia a compromise for a common species needs to be established.

Attributed to its widespread planting in China, the extensively occurring bamboo species is *Phyllostachys pubescens*, also found under the taxonomy *P. edulis* (commonly called Moso bamboo) (Lobovikov et al., 2007; Lou and Henley, 2010; Rao, Rao and Williams, 1998; Song et al., 2011; Xu, Ji and Zhuang, 2018). Its growth can vary significantly with some sources stating heights of 28 m (Lewis and Miles, 2007) and others up to 35 m.[19] Yet other sources state a height of between 18 m and 23 m (Rao, Rao and Williams, 1998).[20] As many other, tall and woody species are commonly attributed with about 20 m height, the same average will be used for Moso bamboo. As the diameter, there seems to be coherence with 18 cm (Lewis and Miles, 2007; Rao, Rao and Williams, 1998).[21] Although Japan's geography is prone to cold climates, *P. eludis* is also commonly found in addition to *P. bambusoides* (Isagi, 1994; Isagi et al., 1997; Okumura, Kusigi and Tani, 2018; Takano et. al., 2017). These are also the species that made the Sagano Bamboo Forest popular as tourist attraction. While these are the two tallest bamboo species in Japan, both are non-native and have been introduced from China (Takano et al., 2017: 9848).

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[19] Plants of the World, available at: http://powo.science.kew.org (last accessed at 24 January 2021).

[20] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021).

[21] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021)

Despite some geographical variances, mainly influenced by being landlocked, surrounded by marine water or characteristics of the two between, the countries from South East Asia[22] share an all-year tropical climate. Most of the countries also house many bamboo species (according to Lobovikov et al., 2007; Ohrnberger, 1999). For South East Asia it is said that *P. eludis* as well as species of *Dendrocalamus* are commonly utilised in the region's countries (Dransfield and Widjaja, 1995: 17; Xu, Ji and Zhuang, 2018: 1). The several species of *Dendrocalamus* (e.g. latiflora, asper or strictus) can have varying maximum heights, but commonly average around 20 m with 12 cm diameter.[23] There is yet another *Dendrocalamus* species which towers above all: *D. giganteus*. *D. giganteus* can reach heights of 30 m to 40 m and a diameter of 30 cm.[24] D. giganteus has also been documented in Nepal, among other species (Stapleton, 1994).

The norther parts of Australia can be considered for bamboo growth, due to its climate being subtropical to tropical. Indeed, similar to the climate of South East Asia, *Dendrocalamus asper* has been shown to grow in norther Australia (Traynor and Midmore, 2009).

Sri Lanka has several endemic bamboos, dominated by the genus of *Arundinaria* and other species (FAO, 2006d). *Bambusa bambos* (giant thorny bamboo) quite literally stands out from the other species, with recorded heights of 30 m and a diameter of 18 cm.[25]

India has tropical wet and tropical dry regions, which influence how bamboo species are distributed (compare Gamble, 1896). As a result, many bamboo genera pertaining to *Arundinaria, Bambusa, Dendrocalamus, Melocanna, Ochlandra, Oxytenanthera* and *Phyllostachys* can be found in India (Yeasmin et al., 2015; FAO, 2006e). The tallest species, *D. asper, D. giganteus, D. strictus* and *B. bambos* can be found in India (FAO, 2006e). *B. Bambos* is stated to be planted throughout the country, while the others may be restricted to certain geographies (ibid.: 20). Bangladesh too has been identified to prioritise the use of *B. bambos*, among other species (FAO, 2006f).

B. blumeana (the spiney bamboo) is another tall-growing species, which can be found between India to Indonesia, and grows to about 20 m height and 10 cm in culm diameter.[26]

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[22] Brunei Darussalam, Myanmar, Cambodia, Timor-Leste, Indonesia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, and Viet Nam.

[23] Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021); Plants for a Future, available at: https://pfaf.org (last accessed at 24 January 2021).

[24] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021); Plants for a Future, available at: https://pfaf.org (last accessed at 24 January 2021).

[25] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Guadua Bamboo, available at: https://www.guaduabamboo.com (last accessed at 24 January 2021); Useful Tropical Plants, available at: http://tropical.theferns.info/ (last accessed at 24 January 2021).

[26] Bamboo Web, available at: http://www.bambooweb.info (last accessed at 24 January 2021); Useful Tropical Plants, available at: http://tropical.theferns.info/ (last accessed at 24 January 2021).

Finally, *B. oldhamii* is home to temperate countries or regions of Asia, such as China but also Australia. *B. oldhamii* is stated to reach 16 m height and 10 cm width.[27]

Species in Africa

Among the three major continental regions of Asia, the Americas and Africa, the latter accounts for the lowest number of endemic bamboos, with 15 genera in total (Kigomo, 1997) out of which only five genera are woody bamboos (Bystriakova, Kapos and Lysenko, 2004). The low diversity, compared with Asia and the Americas, has been attributed to past climatic variation on the African continent (Tekpetey, 2011: 2). Interestingly, the island state Madagascar nearby houses 32 native bamboo species (Lobovikov et al., 2007: 28). The situation of few native bamboo species brings about the shortcoming of bamboo species with similar productivity and growth capacities as their relatives, in particular compared to Asia. *Cathariostachys madagascariensis* can be identified as potentially the tallest growing species of 20 m with the on average widest culm diameter of between 5 cm and 12 cm.

In countries from Eastern Africa (Burundi, Democratic Republic of the Congo, Kenya, Malawi, Tanzania, Uganda, Zambia and Zimbabwe) *Oreobambos buchwaldii* with 20 m height and 10 cm diameter can be found.[28]

Although there are woody native bamboo species which could be utilised, it does not mean that countries in the region do not introduce non-native species with higher productivity yields for economic purposes. Kenya is an example that purposefully seeks to expand its bamboo repertoire for economic purposes, as evident in its National Bamboo Policy 2019 (Ministry of Environment and Forestry, 2019). The introduction of non-native species to continent is documented in Lobovikov et al. (2007).

The western part of Africa has a very low occurrence of endemic bamboo species. It is also especially difficult to retrieve documented bamboos in this part of the region. Tekpetey (2011: 1) refers to "only a single species of woody bamboo principally *Oxytenanthera abyssinica*" for this part of the continent. The same seems to be indicated by Lobovikov et al. (2007: 28), stating that "West Africa has fewer bamboo species with the most widespread being *Oxytenanthera abyssinica*." This species, however, only grows 15 m tall and 10 cm in culm diameter, which would explain why countries like Ghana (see Tekpetey, 2011) or Nigeria (see Ojo, Areghan and Ogutuga, 2018) rely on the non-native species *B. vulgaris* which attains a height of 20 m and a girth of up to 20 cm (Abbas and Amanabo, 2017: 39). *B. vulgaris*, meanwhile, is considered a

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[27] Useful Tropical Plants, available at: http://tropical.theferns.info/ (last accessed at 24 January 2021); Plants of the World, available at: http://powo.science.kew.org (last accessed at 24 January 2021).

[28] Plants of the World, available at: http://powo.science.kew.org (last accessed at 24 January 2021); Plant Resources of Tropical Africa, available at: https://www.prota4u.org/database/ (last accessed at 24 January 2021).

native species in Ghana (Ige, 2016: 5). Given the lack of other indications, this species may be found in other western countries of Africa.[29]

There are a number of countries that geo-politically pertain to central Africa and are neither eastern nor western, and for which information on bamboo species is insufficient or can be ambivalent.[30] For Cameroon, for example, *O. abyssinica* as well as *B. vulgaris* were identified as most utilised, in addition to *Yushania alpine* (Ingram and Tieguhong, 2013). *Yushania alpina,* also called *Arundinaria alpina* or *Oldeania alpina,* can grow up to 20 m with 12.5 cm width at breast height, but are limited to elevations of 2000 m to 4000 m.[31] And bamboo plantations exist in South Africa, where *Bambusa balcooa* is utilised (Scheba Andreas, Blanchard and Mayeki, 2017).

Species in North America (United States of America)

According to Huberman (1959), in the United States of America exist only two indigenous bamboo species: *Arundinaria gigantea* and *Arundinaria tecta.* Both species, however, are of short growth (4-8 m) with thin walls, and therefore little biomass.[32] This does not exclude, however, that no other bamboo species can feasibly grow in the south-eastern parts of the United States, as Asian *B. oldhamii* is also said to grow successfully in this temperate region of the United States of America.[33]

6.5. Biomass and Carbon Stock Estimations

Before going into the sequestration, it needs to be clarified why active management of bamboo forest plantations is needed. Research on bamboo forests showed that they produce more biomass if they are managed and regularly harvested. If no management takes place, stands deteriorate and oppress the re-growth of new culms (Lin et al. 2017; Lou et al. 2010; Tripathi and Singh, 1994), and absent harvesting hampers optimal biomass production and, therein, carbon sequestration of bamboos (Kuehl, Kuehl and Castillo, 2018: 50). Leaving bamboo plantations 'as is' would be counterproductive to the idea of planting them for carbon sequestration. Harvesting becomes a condition for the establishment of the plantations. And once bamboo culms are harvested, they become a carbon source as result of their decay. The management of bamboo plantations will furthermore control for uninhibited spread into adjacent landscapes and prevent mass-flowering. For economically efficient but also environmentally sound consideration, ongoing management is needed.

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[29] See Plant Resources of Tropical Africa, available at: https://www.prota4u.org/database/ (last accessed at 24 January 2021).

[30] Angola, Cameroon, Central African Republic, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Mozambique, Republic of the Congo, Ruanda, South Sudan (previously Sudan)

[31] Useful Tropical Plants, available at: http://tropical.theferns.info/ (last accessed at 24 January 2021).

[32] Natural Resources Conservation Service PLANTS, available at: https://plants.sc.egov.usda.gov/java/ (last accessed at 24 January 2021).

[33] Plants for a Future, available at: https://pfaf.org (last accessed at 24 January 2021).

6.5.1. Methodological Discrepancies and Available Data

Measuring or estimating biomass (in dry weight) and carbon stock of plants is an uncertain process. There are factors to consider, such as the location (for different soil and weather conditions), the time in the year (seasonal influence), the age of the plant (growing, mature or overmature), the parts of the plants (stem, leaves, roots; aboveground, belowground), and whether the plant litter is included (Lobovikov et al., 2007: 26). The biomass per hectare varies by species, location, density, site conditions and management practice (Chen et al., 2009: 1491). Lin et al. (2017), Xu, Ji and Zhuang (2018) and Yuen, Fung and Ziegler (2017) compared several studies on bamboo biomasses, showing that bamboo stands can have different biomasses, even when considering the same species in the same country and provinces. Depending on the "management treatments, such as clear-cutting, selection cutting, weeding, fertilization, as well as the lack of management", they result in varied biomasses (Lin et al., 2017: 851).

The ratio of above- to belowground distribution of biomass or carbon stock find different range reporting. The belowground biomass appears to fall below the aboveground biomass in some cases, to be at a 50% split in some cases, or to exceed aboveground values in other cases (see Lobovikov et al., 2007; Isagi 1994; Tripathi and Singh, 1996; Zhou and Jiang 2004). To complicate matters further, it appeared that different authors define biomass (and subsequently BOC) differently. The International Network on Bamboo and Rattan organisation (INBAR) argues for four carbon pools in a bamboo forest; namely, stemming from the aboveground biomass (AGB), belowground biomass (BGB), litter and soil organic carbon (Huy and Long, 2019: 5). Some studies only consider bamboos' aboveground biomass (e.g. Patricio and Dumago, 2014; Wang et al., 2010; Yen, 2016), while others consider above- and belowground (e.g. Borisade et al., 2018; Isagi, 1997; Lin et al., 2017; Song et al., 2011). Also, there are differences about whether the leaf litter and the carbon contained in the surrounding soil are to feed into the carbon sequestration measurements. In particular the latter may be able to increase the total carbon sequestration potential significantly, for example by an additional third or more of the already sequestered amount (as seen in Borisade et al., 2018; Sohel et al., 2015). A study of Isagi (1994) showed the carbon distribution for *P. pubescens* is roughly one third contained aboveground and two third belowground (20.8 tC/ha in the root system and 92 tC/ha in the soil). Such discrepancies may explain some reported opposite above- to belowground distributions.

The belowground carbon estimations will be considered in section 6.5.6. However, due to the limited data and the marginal role in sequestering carbon, the belowground will not find greater attention in this paper. The same applies to carbon sequestered in the soil (section 6.5.7) as even less data was available.

Furthermore, a total biomass depends on a plant's growth and distribution parameters (e.g. culms height, diameter, weight, distribution density). However, many studies on bamboos vary in the measured growth properties, even when the same species was considered in the same country (e.g. Lin et al. 2017: 851). It is 'natural' that plants grow unevenly. What complicates the comparison is that not all studies on biomass/BOC indicate all relevant parameters. For example, Patricio and Dumago (2014) indicate culm height and diameter as well as the number of poles/culms from which they derived their aboveground biomass estimations. However, they did not include the essential culm density per hectare or square kilometre distribution. The missing density information is a problem in carbon estimations in a certain amount of space.

Another issue is that not all studies distinguish between recently grown and mature bamboos. Yen (2016) confirmed that *P. pubescens* reached most of its biomass (based on culm development) in only 40 days, which suggests that there may not be a large difference in biomass between young and mature stands. However, some authors (Abe and Shibata, 2009; Schröder, 2011) noted that older bamboo stands sprout shoots that are wider in diameter and, thus, produce higher biomass per culm with age.

In summary, the bamboo biomass measurement remains an issue of incoherent methodology. While carbon sequestration studies on bamboos exist, without the context of growth parameters, age and culm density, the numbers are difficult to compare. In order to gain reliable bamboo biomass estimates, more species- and region-specific measurements are needed to allow for a full range of bamboo carbon models (Huy and Long, 2019: 19).

Given the circumstances, the estimations in this paper require a step-wise filling-in of missing data in Table 4, with which to allude to the carbon sequestration potential of bamboos.

Table 4: Available growth characteristics, distribution, biomass and carbon content by species

Species	Density (culms/ha)	Height (m)	DBH (m)	Pole biomass weight (kg/pole)	Pole carbon weight (kgC/pole)	Total above-ground biomass (t/ha)	Total aboveground BOC (tC/ha)	Carbon to biomass ratio (aboveground)	Total below-ground biomass (t/ha)	Total below-ground BOC (tC/ha)	Source
Arundinaria/ Yushania/ Oldeania alpina	8840	16.8	0.08			109.8			25.6		Embaye et al. (2005) in Ethopia
Arundinaria/ Yushania/ Oldeania alpina							68.4			12.8	Yuen et al. (2017) in Ethopia and Kenya
Arundinaria/ Yushania/ Oldeania alpina	10667	15.2	0.084			80			16		Mulatu and Fetene (2013) in Ethopia
B. balcooa	4800[34]			16.5		380.16	184.38	48.5	98.84	49.42	Tariyal et al. (2013) in India; Thapa and Aryal (2012) in Nepal
B. balcooa	212			12.5			2.65				Nath and Das (2010) In India
B. balcooa	1,350	14.25	0.07			31.48					Nath, Das and Das (2009 in India
B. balcooa	7,799	12.68	0.2			64.09	27.48	42.88	4.93	3.18	Jijeesh et al. (2013) in India

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[34] Under "tree stem density per hectare" (Tariyal et al 2013: 101) the number of 400 was given, which turned out to refer to 400 clumps per hectare. The age was stated with year 5. In Thapa and Aryal (2012), the number of culms per clump for *B. balcooa* was measured to be around 12 culms per clump for a 5-years old plant. The provided number of 400 clumps was therefore multiplied with 12 culms to estimate the corresponding culm density per hectare (4800 culms/ha) for *B. balcooa*.

Species	Density (culms/ha)	Height (m)	DBH (m)	Pole biomass weight (kg/pole)	Pole carbon weight (kgC/pole)	Total above-ground biomass (t/ha)	Total aboveground BOC (tC/ha)	Carbon to biomass ratio (aboveground)	Total below-ground biomass (t/ha)	Total below-ground BOC (tC/ha)	Source
B. bambos	8,023	10.76				241.7					Kumar, Rajesh and Sudheesh (2005) in India
B. bambos	4,250	28.5	0.09			286					Shangmughavel, and Francis (1996) in India
B. bambos							81.1			5.3	Yuen et al. (2017) in India
B. blumeana	4,800	19.05	0.07	17.1		82.3	38.5	46.78			Patricio and Dumago (2014) in Australia
B. blumeana	7,500	20.23	0.07	15		112.8	53.7	47.61			Patricio and Dumago (2014) in Australia
B. cacharensis	6,000	11.35	0.05			56.01					Nath, Das and Das (2009 in India
B. oldhamii	10,101	14.3	0.07			103.83	51.93	50.02			Mendoza et al. (2005) in Mexico
B. oldhamii								45.36			Mognon et al. (2017) in Brazil
B. oldhamii							25.7			4.6	Yuen et al. (2017) in China and Mexico
B. vulgaris	5,250	15.3	0.08	13.8		72.2	33.4	46.26			Patricio and Dumago (2014) in Australia
B. vulgaris	2,933	21.92	0.21			92.93	52.96	56.99	4.66	2.52	Sohel et al. (2015) in Bangladesh
B. vulgaris	9,000	12.4	0.07			106	53				Uchimura (1978) in the Philippines
B. vulgaris	17,900	20.29	0.1	6.56		257.82	138.7	53.8		32.72	Borisade et al. (2018) in Nigeria
B. vulgaris	6,267		0.08	6.13		114.97	50.76	44.15			Amoah, Assan and Dadzie (2020) in Ghana
B. vulgaris	7,171		0.06	6.78		71.47	33.87	47.39			Amoah, Assan and Dadzie (2020) in Ghana
B. vulgaris								46.15			Mognon et al (2017) in Brazil
B. vulgaris	1,600	14.52	0.07			34.02					Nath, Das and Das (2009 in India
D. asper	8,100	24.1	0.17	25.9		223.3	108.1	48.41			Patricio and Dumago (2014) in Australia
D. asper	6,100	24.45	0.17	21.7		177.6	64.9	36.54			Patricio and Dumago (2014) in Australia
D. asper								46.03			Mognon et al. (2017) in Brazil
D. asper	7,100	18.1	0.09			264.37	143.4	54.24	71.38	33.55	Pongon et al. (2016) in Philippines
D. giganteus							33.6			3.9	Yuen et al. (2017) in China and Taiwan
D. giganteus	320					15.13			4.77		Tang et al. (2011) in China
D. giganteus		16	0.14								Azzini, Santos and Pettinelli (1997) in Brazil
D. giganteus	4,433	17.5	0.15			155.1					Chen et al. (2014) in China
D. giganteus	4,867	17.5	0.15			155.8					Chen et al. (2014) in China
D. latiflorus						15.3			5.4		Yuen et al. (2017) in China, Taiwan.
D. latiflorus						28.49			4.41		Lin et al. (2000) in China
D. latiflorus	1,050[35]	15.57	0.08		8.59	27.91			3.97		Feng et al. (2010) in China
D. latiflorus	1,436					10.7					Qiu et al. (2004) in China
D. strictus							20.7			7.4	Yuen et al. (2017) in India, Myanmar
D. strictus	2,800[36]					18.91	8.39	44.37			Subbulakshmi et al. (2015) in India
D. strictus	29,787[37]	8.86				70.22	32.24	45.91			Kittur et al. (2016a) in India
D. strictus	9,028	6.81				18.75	8.85	47.2			Kittur et al. (2016a) in India
D. strictus	5,560[38]					450.89	217.34	48.2	117.19	58.6	Tariyal et al. (2013) in India; Thapa and Aryal (2012) in Nepal
G. angustifolia	8,640	16.7	0.08		5.5		43.5			10.8	Riaño et al. (2002) in Colombia

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[35] Average from the statement of culms varying between 900 and 1200 per hectare.

[36] based on 112 culms in 0.04 ha

[37] based on the number of culms for the selected plot area (47.66 for 4x4 metres, and 130 for 12x12 metres).

[38] Under "tree stem density per hectare" (Tariyal et al 2013: 101) the number of 556 was given, which turned out to refer to 556 clumps per hectare. The age was stated with year 7. In Thapa and Aryal (2012), the number of culms per clump for *D. strictus* was measured to be around 10 culms per clump for a 7-years old plant. The provided number of 556 clumps was therefore multiplied with 10 culms to estimate the corresponding culm density per hectare (5560 culms/ha) for *D. strictus*.

Species	Density (culms/ha)	Height (m)	DBH (m)	Pole biomass weight (kg/pole)	Pole carbon weight (kgC/pole)	Total above-ground biomass (t/ha)	Total aboveground BOC (tC/ha)	Carbon to biomass ratio (aboveground)	Total below-ground biomass (t/ha)	Total below-ground BOC (tC/ha)	Source
G. angustifolia	6,473					50.09	22.19	44.3		3.87	González and Vargas (2016) in Costa Rica
G. angustifolia	4,500	21.3	0.17	4.14		194.5	97.3	50.03			Rojas et al. (2013) in Bolivia
G. angustifolia								47			Fryda et al. (2014) in Colombia
G. angustifolia							69.9			7.5	Yuen et al. (2017) in Bolivia, Colombia, Ecuador
G. chacoensis	428[39]	7.9	0.05			12.6	5.4	42.86			Mognon (2015) in Brazil
G. chacoensis								42.62			Mognon et al. (2017) in Brazil
G. weberbaueri	1,420			7.18		10.2					Torezan and Silveira (2000) in Brazil
P. pubescens/ edulis	7,100		0.11				53			18.7	Isagi (1997) in Japan
P. pubescens/ edulis	6,000	12	0.08				42.04			33.69	Lin et al. (2017) in Taiwan
P. pubescens/ edulis	3,400		0.01				60.58				Xu et al. (2018) in China
P. pubescens/ edulis	4,722		0.08				48.31				Xu et al. (2018) in China
P. pubescens/ edulis	7,188	12.83	0.1	17.33	8.04	124.6	57.8	46.39			Yen (2016) in Taiwan
P. pubescens/ edulis	8,800	13.3		12		105.6					Suzuki and Domingo (1986) in Philippines
P. pubescens/ edulis							33.2			14.8	Yuen et al. (2017) in China, Japan, Korea, Taiwan
P. pubescens/ edulis	8300	18.5	0.127			224.3					Abe and Shibata (2009) in Japan
P. pubescens/ edulis	3,900	13.3				61.9				69.9	Li et al. (1999) in China

Note: For the three relevant, tall-growing species Oreobambos buchwaldii (Central America), Cathariostachys madagascariensis (Madagascar) and Guadua superba (South America), no relevant information on neither biomass nor carbon sequestration could be retrieved, irrespective of the language (including an attempted Chinese literature review) and are disregarded at this point.

6.5.2. Estimating Biomass to Carbon Ratio

As mentioned, the information on biomass and BOC and the relevant parameter to calculate biomass/BOC are reported to different extents. Where the biomass or the BOC was reported the respective missing opposite can be estimated using a mean organic carbon content ratio. Lobovikov et al. (2007) reported that about half of the total biomass of bamboos can be considered as carbon, while other sources report potentially more accurate numbers ranging between 46.01% to 49.18% (Patricio and Dumago, 2014), 42.62% to 46.15% (Mangon et al., 2017) and 47% (Fryda et al., 2014).

Where both the biomass and BOC have been retrieved, a mean organic carbon content ratio could be determined. The resulting mean organic carbon content ratio from the available literature above (Table 4) is 46.92% and falls within the reported ranges. With the mean of 46.92%, the respective missing biomasses and BOCs were calculated (Table 5).

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[39] The number of culms per clump have been measured with on average 12.6 among 34 clump samples, which in turn have been attributed to a hectare. This accumulates to 428.4 culms in total on average, or approximately 428 culms/ha.

Table 5: Calculated aboveground biomass and BOC and above- to belowground ratios

Species	Total aboveground biomass (t/ha)	Total aboveground BOC (tC/ha)	Carbon to biomass ratio (aboveground)	Source
A./ Y. / O. alpina	109.80	51.52	46.92	Embaye et al. (2005) in Ethopia
A./ Y. / O. alpina	145.77	68.40	46.92	Yuen et al. (2017) in Kenya
A./ Y. / O. alpina	80.00	37.54	46.92	Mulatu and Fetene (2013) in Ethopia
B. balcooa	380.16	184.38	48.50	Tariyal et al. (2013) in India; Thapa and Aryal (2012) in Nepal
B. balcooa	5.65	2.65	46.92	Nath and Das (2010) In India
B. balcooa	31.48	14.77	46.92	Nath, Das and Das (2009 in India
B. balcooa	64.09	27.48	42.88	Jijeesh et al. (2013) in India
B. bambos	241.70	113.41	46.92	Kumar, Rajesh and Sudheesh (2005) in India
B. bambos	286.00	134.20	46.92	Shangmughavel, and Francis (1996) in India
B. bambos	172.84	81.10	46.92	Yuen et al. (2017) in India
B. blumeana	82.30	38.50	46.78	Patricio and Dumago (2014) in Australia
B. blumeana	112.80	53.70	47.61	Patricio and Dumago (2014) in Australia
B. cacharensis	56.01	26.28	46.92	Nath, Das and Das (2009 in India
B. oldhamii	103.83	51.93	50.02	Mendoza et al. (2005) in Mexico
B. oldhamii			45.36	Mognon et al. (2017) in Brazil
B. oldhamii	54.77	25.70	46.92	Yuen et al. (2017) in China and Mexico
B. vulgaris	72.20	33.40	46.26	Patricio and Dumago (2014) in Australia
B. vulgaris	92.93	52.96	56.99	Sohel et al. (2015) in Bangladesh
B. vulgaris	106.00	53.00	50.00	Uchimura (1978) in the Philippines
B. vulgaris	257.82	138.70	53.80	Borisade et al. (2018) in Nigeria
B. vulgaris	114.97	50.76	44.15	Amoah, Assan and Dadzie (2020) in Ghana
B. vulgaris	71.47	33.87	47.39	Amoah, Assan and Dadzie (2020) in Ghana
B. vulgaris			46.15	Mognon et al. (2017) in Brazil
B. vulgaris	34.02	15.96	46.92	Nath, Das and Das (2009 in India
D. asper	223.30	108.10	48.41	Patricio and Dumago (2014) in Australia
D. asper	177.60	64.90	36.54	Patricio and Dumago (2014) in Australia
D. asper			46.03	Mognon et al. (2017) in Brazil
D. asper	264.37	143.40	54.24	Pongon et al. (2016) in Philippines
D. giganteus	71.61	33.60	46.92	Yuen et al. (2017) in China and Taiwan
D. giganteus	15.13	7.10	46.92	Tang et al. (2011) in China
D. giganteus				Azzini, Santos and Pettinelli (1997) in Brazil
D. giganteus	155.10	72.78	46.92	Chen et al. (2014) in China
D. giganteus	155.80	73.11	46.92	Chen et al. (2014) in China
D. latiflorus	32.61	15.30	46.92	Yuen et al. (2017) in China, Taiwan.
D. latiflorus	28.49	13.37	46.92	Lin et al. (2000) in China
D. latiflorus	27.91	13.10	46.92	Feng et al. (2010) in China
D. latiflorus	10.70	5.02	46.92	Qiu et al. (2004) in China
D. strictus	44.11	20.70	46.92	Yuen et al. (2017) in India, Myanmar
D. strictus	18.91	8.39	44.37	Subbulakshmi et al. (2015) in India
D. strictus	70.22	32.24	45.91	Kittur et al. (2016a) in India
D. strictus	18.75	8.85	47.20	Kittur et al. (2016a) in India
D. strictus	450.89	217.34	48.20	Tariyal et al. (2013) in India; Thapa and Aryal (2012) in Nepal
G. angustifolia	92.71	43.50	46.92	Riaño et al. (2002) in Colombia
G. angustifolia	50.09	22.19	44.30	González and Vargas (2016) in Costa Rica
G. angustifolia	194.50	97.30	50.03	Rojas et al. (2013) in Bolivia
G. angustifolia			47.00	Fryda et al. (2014) in Colombia
G. angustifolia	148.97	69.90	46.92	Yuen et al. (2017) in Bolivia, Colombia, Ecuador
G. chacoensis	12.60	5.40	42.86	Mognon (2015) in Brazil
G. chacoensis			42.62	Mognon et al. (2017) in Brazil
G. weberbaueri	10.20	4.79	46.92	Torezan and Silveira (2000) in Brazil
P. pubescens/edulis	112.95	53.00	46.92	Isagi (1997) in Japan
P. pubescens/edulis	89.59	42.04	46.92	Lin et al. (2017) in Taiwan
P. pubescens/edulis	129.11	60.58	46.92	Xu et al. (2018) in China
P. pubescens/edulis	102.96	48.31	46.92	Xu et al. (2018) in China
P. pubescens/edulis	124.57	57.79	46.39	Yen (2016) in Taiwan
P. pubescens/edulis	105.60	49.55	46.92	Suzuki and Domingo (1986) in Philippines
P. pubescens/edulis	70.75	33.20	46.92	Yuen et al. (2017) in China, Japan, Korea, Taiwan
P. pubescens/edulis	224.30	105.25	46.92	Abe and Shibata (2009) in Japan
P. pubescens/edulis	61.90	29.05	46.92	Li et al. (1999) in China

Note: The orange-coloured cells indicate the estimated carbon to biomass ratio based on the available measured ratios. The grey-coloured cells indicate estimated values which were calculated with the respective carbon to biomass ratio and available opposite BOC or biomass value. B. vulgaris by Uchimura (1978) was excluded as the author assumed a 50% split.

6.5.3. Estimating Mean Biomass and Carbon Stock

The aboveground biomasses/BOCs vary by culm density in a given area as well as by the growth characteristics of bamboo stands, which then again is influenced by management techniques, as stated earlier. The differing results pose an obstacle to applying an expected average value of the sequestration potential. The density, the growth and any potential management (or neglect) have influenced the biomass in a given area. The density with which bamboo would be planted alone will inevitably increase the biomass in a given area, as displayed for reference in Figure 6 based on the available data.

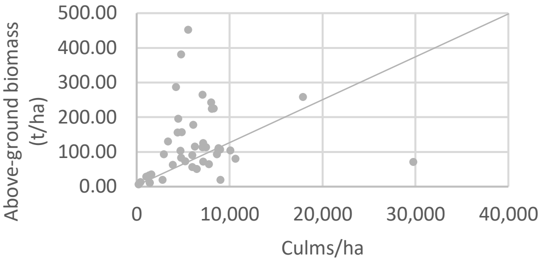

Figure 6: Indicative above-ground biomass in relation to culm density.

Relevant to know would have been whether there is an optimum density to biomass relationship, in the sense that from a certain stand density onward a lower biomass per plant would occur due to multiple plants competing for limited resources. It appears that higher biomass accumulation per bamboo clump occurs in denser bamboo plantations versus a lower biomass per clump in a lesser populated area, according to a study by Kittur et al. (2016a: 5) at a plantation in India. "With gradual increasing stand density, the aboveground biomass also increased significantly" (ibid.). An important difference was that in higher density stands more biomass is concentrated in the culms, while in wider spacing nutrients seem redistributed towards leaves and twigs instead (ibid.: 9). As the authors relevantly state: "For stand level production managing of bamboo in close spacings (4x4 m to 6x6 m) is better" (ibid.). More research will need to be carried out about this finding. Nevertheless, this finding is relevant as the biomass produced in a given area will be higher for bamboo plantations under higher density. How 'high' that density can be, however, remains to be clarified.

An indication for an optimum density to biomass ratio was attempted to calculate (Figure 7).[40] However, the weight of a bamboo culm, clump or pole will be different depending on the species and how each species grows. To even out species differences derived from their growth characteristics, the

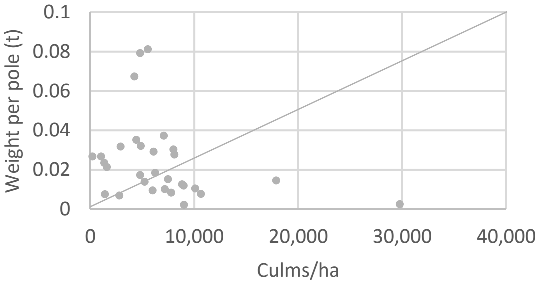

Figure 7: Weight per bamboo pole in relation to culm density.

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[40] The approximate weight per bamboo poles was calculated by dividing the total biomass in tonne per hectare through the density (counted or estimated culms per hectare).

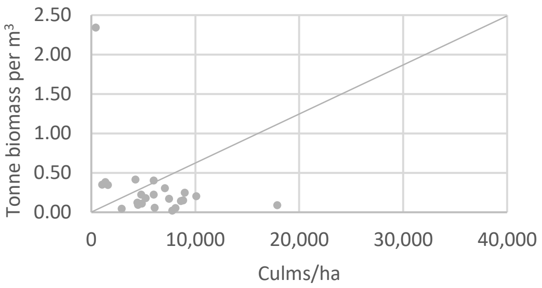

Figure 8: Biomass weight per cubic metre in ratio to culm density.

height and culm diameter was used to calculate an approximation of the volume a single pole might occupy (Figure 8). [41] A curved distribution was expected whereas the biomass weight per pole or cubic metre increases with increasing density up to a point where the density was too high to allow further biomass increase. Even when discarding the extremes on both ends of very low (428 culms/ha) and very high density (17900 culms/ha), it doesn't change the outcomes. Yet again, the results are at best inconclusive.

A more accurate biomass estimation may be to document the weight per each pole or clump, including the leaves and rhizomes and the amount of space each bamboo stand requires, and comparing these data with culm density in order to find an optimum plantation density to biomass productivity and carbon sequestration. While some information on the weight per pole was available (Table 4), it is insufficient in number and was rarely clarified whether the weight refers to the entire plant, parts of it, or whether it refers to above- and belowground.

In consequence, a simpler method for the carbon sequestration potential of bamboo species needed to be adopted. As there are notable differences in biomass and/or carbon content among the species with available data, it was ultimately decided to consider all species for which data has been retrievable, regardless of the country and whether they are native in the region, as long as they classify as tall and woody species. Considering the many different species at once allows for taking into account a different composition of species in a country, with different soil and altitude requirements for each species. This consideration may even be truer than estimating the potential by relying on values of a single species for a given country. Considering that plants naturally grow and spread unevenly, taking into account the carbon content for all those species may adjust for the data differences and yet provide an "averaged" indication for the carbon sequestration potential in different countries.

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[41] The volume per pole was multiplied with the culm density per hectare. Next, the total biomass (tonne per hectare) was divided by the resulting volume density (per hectare). The resulting weight (in tonnes) per the volume in cubic metre was also put in ratio to the culm density. This volume does not exactly capture the biomass volume, because – unlike trees – bamboo poles are hollow without biomass, except for the internodes. The culm diameter also does not take into account the leaves and rhizomes. However, this approximate volume of the biomass serves as an indication of the three-dimensional space that bamboos occupy in relation to their weight, and subsequently carbon content.

An important mention at this point is that the often-cited fast growth and reproduction rates are criticised as relying on overestimations, due to concentrating on specific plants only (Düking et al., 2009: pp. 5). *P. pubescens* is such a case that tends to serve as a benchmark for the productivity of bamboo (singular) in general. Therefore, choosing all species may eliminate the overestimation.

Table 6: Mean averages for biomass, BOC and density

Species	Density (culms/ha)	Total above-ground biomass (t/ha)	Total above-ground BOC (tC/ha)
A./Y./O. alpina	8,840	109.80	51.52
A./Y./O. alpina	…	145.77	68.40
A./Y./O. alpina	10,667	80	37.54
Total species average	…	111.86	52.49
Total species average (with density only)	9,754	95	45
B. balcooa	4,800	380.16	184.38
B. balcooa	212	5.65	2.65
B. balcooa	1,350	31.48	14.77
B. balcooa	7,799	64.09	27.48
Total species average	…	120.34	57.32
Total species average (with density only)	3,540	120.34	57.32
B. bambos	8,023	241.70	113.41
B. bambos	4,250	286.00	134.20
B. bambos	…	172.84	81.10
Total species average	…	233.51	109.57
Total species average (with density only)	6,137	263.85	123.81
B. blumeana	4,800	82.30	38.50
B. blumeana	7,500	112.80	53.70
Total species average	…	97.55	46.10
Total species average (with density only)	6,150	97.55	46.10
B. cacharensis	6,000	56.01	26.28
Total species average	…	56.01	26.47
Total species average (with density only)	6,000	56.01	26.28
B. oldhamii	10,101	103.83	51.93
B. oldhamii	…	54.77	25.70
Total species average	…	79.30	38.82
Total species average (with density only)	10,101	103.83	51.93
B. vulgaris	5,250	72.20	33.40
B. vulgaris	2,933	92.93	52.96
B. vulgaris	9,000	106.00	53.00
B. vulgaris	17,900	257.82	138.70
B. vulgaris	6,267	114.97	50.76
B. vulgaris	7,171	71.47	33.87
B. vulgaris	1,600	34.02	15.96
Total species average	…	107.06	54.09
Total species average (with density only)	7,160	107.06	54.09
D. asper	8,100	223.30	108.10
D. asper	6,100	177.60	64.90
D. asper	7,100	264.37	143.40
Total species average	…	221.76	105.47
Total species average (with density only)	7,100	221.76	105.47
D. giganteus	…	71.61	33.60
D. giganteus	…	15.13	7.10
D. giganteus	4,433	155.10	72.78
D. giganteus	4,867	155.80	73.11
Total species average	…	99.41	46.65
Total species average (with density only)	4,650	155.45	72.94
D. latiflorus	…	32.61	15.30
D. latiflorus	…	28.49	13.37
D. latiflorus	1,050	27.91	13.10
D. latiflorus	1,436	10.70	5.02
Total species average	…	24.93	11.70
Total species average (with density only)	1,243	19.30	9.06

The averages for each species and total average were calculated, where more than one data point was available. Depending on how the average is calculated, the biomass and BOC range between 102.01 t/ha to 118.18 t/ha and 48.52 tC/ha and 56.56 tC/ha, respectively (Table 6).

6.5.4. Establishing Minimum and Maximum Carbon Averages

The averages with the attribute '(with density only)' in Table 6 take into account only those biomass/BOC values where the culm density per given area was reported. The BOC for the 'total average by species averages' is 14.21% lower than the BOC for the 'total average across all species (with density only)'. If this ratio was proportionally linear, it would mean that the density would be 14.21% lower for the 'total average by species averages' with approximately 5,460 culms per hectare. However, this is speculation and may not be exact due to the missing reference information.

About the average density of 6,364 culms per hectare, this value may be an underestimation as it would mean to yield less than one bamboo culm per square metre (0.64 culms/m^2). The recorded or estimated densities per hectare showed a doubling (or more) of the number of culms to be possible. In a managed bamboo plantation, the spacing will be the influential factor for an optimum carbon sequestration rate. Depending on the species and their growth characteristics, Durai and Long (2019) instruct to apply spacing of between 4x4 m to 10x10 m. Given the number of different species (including running and clumping), the density cannot be increased in this paper's estimations, but it should be kept in mind that a higher density is possible (as documented in the sources) and, consequently, a higher BOC per given area is obtainable, too.

The resulted biomass averages may indeed not be too far off as to be considered inaccurate. Given that bamboo forests have been compared to other forests, the averaged biomass(es) are similar to tropical broad-leaf forests under harvesting activities. Brown and Lugo (1984) assessed tropical forests in the Americas, Africa and Asia concluding with biomasses of 117.9 t/ha, 178.9 t/ha and 93.2 t/ha (total average 119.6 t/ha). To provide an extent to which bamboo plantations may be able to sequester carbon the 'total average across all species (with density only)' may serve as a 'conservative' expected *minimum average* for further calculation in non-perfect settings.[42] It may be a value "closer to nature", so to speak, and provide a more realistic outlook.

Table 6 continued…

Species	Density (culms/ha)	Total above-ground biomass (t/ha)	Total above-ground BOC (tC/ha)
D. strictus	…	44.11	20.70
D. strictus	2,800	18.91	8.39
D. strictus	29,787	70.22	32.24
D. strictus	9,028	18.75	8.85
D. strictus	5,560	450.89	217.34
Total species average	…	120.58	57.50
Total species average (with density only)	11,794	139.69	66.71
G. angustifolia	8,640	92.71	43.50
G. angustifolia	6,473	50.09	22.19
G. angustifolia	4,500	194.50	97.30
G. angustifolia	…	148.97	69.90
Total species average	…	121.57	58.22
Total species average (with density only)	6,538	112.43	54.33
G. chacoensis	428	12.60	5.40
Total species average	…	12.60	5.40
Total species average (with density only)	428	12.60	5.40
G. weberbaueri	1,420	10.20	4.79
Total species average	…	10.20	4.82
Total species average (with density only)	1,420	10.20	4.79
P. pubescens/edulis	7,100	112.95	53.00
P. pubescens/edulis	6,000	89.59	42.04
P. pubescens/edulis	3,400	129.11	60.58
P. pubescens/edulis	4,722	102.96	48.31
P. pubescens/edulis	7,188	124.57	57.79
P. pubescens/edulis	8,800	105.60	49.55
P. pubescens/edulis	…	70.75	33.20
P. pubescens/edulis	8,300	224.30	105.25
P. pubescens/edulis	3,900	61.90	29.05
Total species average	…	113.53	53.20
Total species average (with density only)	5,873	103.81	48.62
Total average by species average	...	102.01	48.52
Total average by species average (with density only)	5,859	107.92	51.44
Total average across all species	…	113.32	54.07
Total average across all species (with density only)	6,364	118.18	56.56

Note: "with density only" refers to taking into account only the biomass and carbon values where a density value was provided for the purpose of having a density reference for said values.

Among the reported values, there are some exceptions which may promise a much higher carbon sequestration potential than the expected minimum average promises. To allow for a

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[42] I.e. where management techniques are not perfect, weather may impact grows, or other scenarios that may in the long- or short-term detract from the full growth potential.

varied view on the carbon sequestration potential, an additional average representing an 'optimistic' *maximum average* is established. For this purpose, only the highest reported values are considered. To identify those, the aboveground BOC has been put in proportion to the culm density, and sorted by the increasing ratio (Table 7). The resulting BOC/density ratios range notably wide, while three instances perform notably high. The three highest performing instances are found in *B. bambos*, *B. balcooa* and *D. strictus* and shall compose the potential *maximum average* for bamboos' carbon sequestration potential, presuming that adequate management techniques can yield the same results in a bamboo forest plantation.

Table 7: Aboveground BOC to culm density ratio

Species	Density (culms/ha)	Total above-ground BOC (tC/ha)	BOC/density ratio
D. strictus	9,028	8.85	0.001
D. strictus	29,787	32.24	0.001
D. strictus	2,800	8.39	0.003
G. weberbaueri	1,420	4.79	0.003
G. angustifolia	6,473	22.19	0.003
D. latiflorus	1,436	5.02	0.003
A./Y./O. alpina	10,667	37.54	0.004
B. balcooa	7,799	27.48	0.004
B. cacharensis	6,000	26.28	0.004
B. vulgaris	7,171	33.87	0.005
G. angustifolia	8,640	43.50	0.005
B. oldhamii	10,101	51.93	0.005
P. pubescens/edulis	8,800	49.55	0.006
A./Y./O. alpina	8,840	51.52	0.006
B. vulgaris	9,000	53.00	0.006
B. vulgaris	5,250	33.40	0.006
P. pubescens/edulis	6,000	42.04	0.007
B. blumeana	7,500	53.70	0.007
P. pubescens/edulis	3,900	29.05	0.007
P. pubescens/edulis	7,100	53.00	0.007
B. vulgaris	17,900	138.70	0.008
B. blumeana	4,800	38.50	0.008
P. pubescens/edulis	7,188	57.79	0.008
B. vulgaris	6,267	50.76	0.008
B. vulgaris	1,600	15.96	0.010
P. pubescens/edulis	4,722	48.31	0.010
D. asper	6,100	64.90	0.011
B. balcooa	1,350	14.77	0.011
D. latiflorus	1,050	13.10	0.012
B. balcooa	212	2.65	0.013
G. chacoensis	428	5.40	0.013
P. pubescens/edulis	8,300	105.25	0.013
D. asper	8,100	108.10	0.013
B. bambos	8,023	113.41	0.014
D. giganteus	4,867	73.11	0.015
D. giganteus	4,433	72.78	0.016
P. pubescens/edulis	3,400	60.58	0.018
B. vulgaris	2,933	52.96	0.018
D. asper	7,100	143.40	0.020
G. angustifolia	4,500	97.30	0.022
B. bambos	4,250	134.20	0.032
B. balcooa	4,800	184.38	0.038
D. strictus	5,560	217.34	0.039

Note: The three highlighted cells mark the notably high performing instances found for bamboos.

Finally, the resulted expected *minimum average* (minimum) and potential *maximum average* (maximum) values can be attributed to the previously established percentage-wise space allocation for each suitable country. To do so, the values per hectare were converted to square kilometre (Table 8).

Table 8: Expected minimum and maximum aboveground biomass and BOC values per hectare and square kilometre

	Total above-ground biomass (t/ha)	Total above-ground BOC (tC/ha)	Total above-ground biomass (t/km^2)	Total above-ground BOC (tC/km^2)	Reference culm density (culms/ha)
Minimum	118.18	56.56	11,817.96	5,656.50	4,870
Maximum	372.35	178.64	37,235.00	17,863.98	6,364

6.5.5. Estimating the Carbon Sequestration Potential

For the further estimations, the maturity and harvesting time of the standing bamboo culms is necessary to consider. Depending on the site condition, species and scientific management practices, harvesting of bamboos is said to commence between three and seven years (Akwada and Akinlabi, 2018; Durai and Long, 2019; Fu, 2001; Lou et al., 2010; Mera and Xu, 2014; Scheba, Blanchard and Mayeki, 2017). If mature bamboos are not harvested regularly, their biomass productivity declines; four years old culms become weak and brittle, and over five-year-old culms start decaying (Durai and Long, 2019: 44, 47). Therefore, the first harvest onset has been chosen with five years. Subsequently, the "cutting of mature culms can be done annually or at predetermined intervals of years, according to the management plan and the end use of culms" (UNIDO, 2009: 51). Only a certain number of culms can be harvested annually in order to circumvent clear-felling and will correspond to the oldest culms (in this case culms of year 5). As bamboos produce shoots annually, the ratio with which culms are assumed to be harvestable is 1:5, corresponding to one year of age. In other words, one fifth of the standing bamboo culms can be harvested every year, and after at least the first five years of planting.

Onwards, only the carbon stocks will be further included. With the calculated values per square kilometre, a region-wise carbon sequestration estimation overview can be created (Table 9). The distinctions for minimum and maximum estimated carbon sequestration rates between one percent to seven percent territory of each country have been applied (see Annex for details). These estimations in giga tonne carbon can be understood as the sequestration rate if bamboo plantations were established for the first time and under the assumption that these values represent a maturity period of five years.

Table 9: Estimated minimum and maximum carbon sequestration rates, initial five-years

Region	Region size (km²)	Size allocated for bamboo plantation (km²)				Minimum estimated BOC per allocated space (GtC)				Maximum estimated BOC per allocated space (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
Asia and the Pacific	13,133,004	131,330	262,660	656,650	919,310	0.74	1.49	3.71	5.20	2.35	4.69	11.73	16.42
Africa	14,407,924	144,079	288,158	720,396	1,008,555	0.81	1.63	4.07	5.70	2.57	5.15	12.87	18.02
South and Central America	18,180,201	181,802	363,604	909,010	1,272,614	1.03	2.06	5.14	7.20	3.25	6.50	16.24	22.73
North America	2,458,500	24,585	49,170	122,925	172,095	0.14	0.28	0.70	0.97	0.44	0.88	2.20	3.07
Total	48,179,629	481,796	963,593	2,408,981	3,372,574	2.73	5.45	13.63	19.08	8.61	17.21	43.03	60.25

Note: The aforementioned country size reductions have been applied to Argentina with 50%, Australia with 10%, China with 33% and USA with 25% to account for potentially less or non-favourable geographically determined climate conditions.

The allocated 1% of territory may also be considered as an estimation for the current standing carbon stock by year 2020 for those countries that previously have been included in recorded forest space (section 6.3.).

It is entirely possible that the biomass and the therein contained carbon would increase over time due to developing wider and taller culms, as indicated by Abe and Shibata (2009) or Schröder (2011). However, as the present data has been derived from a variety of forests and plantations of varying age as well as different bamboo species, it cannot be determined by which factor the underground biomass would increase. On the contrary, it is entirely possible that some of the data may already represent the optimum growth parameters, while other will fall below their future optimum.

With the results from Table 9, under the assumption that the BOC remains at the same level after re-growing a harvested plantation each year, one fifth of the harvested carbon stock will be added each year (corresponding to taking out one fifth of mature culms each year). To estimate the carbon sequestration rate by 2030, five times one fifth of the base total will be added. For 2050, 25 times, and for 2070, 45 times one fifth of the base total will be added to the same total.

At this stage, the valid concern will be that the harvested culms will decay over time, even when processed into durable bamboo products. Bamboos are traditionally used in over 1250 applications (Kuehl, Kuehl and Castillo, 2018: 53). The decay process may counter the effort of capturing carbon dioxide in the form of carbon within bamboo's biomass. For the ongoing carbon storage in bamboos after harvesting, the amount of carbon released in the decay process needs to be included. The problem is that different products for different purposes will have different lifespans, which are further influenced by user behaviours. Within the scope of this paper, it cannot be feasibly found out how much carbon is released over the lifespan of bamboo products. However, an indicative comparison can be made based on the greenhouse gas impact study of wood and paper products by Pingoud et al. (2003). Across different short-lived and long-lasting wood products (from paper to flooring), the authors arrived at an average yearly decay scenario between 2.5% and 3.3% of carbon being released over the products lifespan. Not to underestimate the decay, the higher 3.3% will subsequently be subtracted from the yearly-harvested carbon stock. Table 10 summarises the results by subregion (details by country in the Annex).

Table 10: Estimated minimum and maximum estimated carbon sequestration at maturity age, 2030, 2050 and 2070, by region

Region	Minimum estimated BOC per allocated space (by 2030) (GtC)				Maximum estimated BOC per allocated space (by 2030) (GtC)				Minimum estimated BOC per allocated space (by 2050) (GtC)				Maximum estimated BOC per allocated space (by 2050) (GtC)				Minimum estimated BOC per allocated space (by 2070) (GtC)				Maximum estimated BOC per allocated space (by 2070) (GtC)			
	1%	**2%**	**5%**	**7%**	**1%**	**2%**	**5%**	**7%**	**1%**	**2%**	**5%**	**7%**	**1%**	**2%**	**5%**	**7%**	**1%**	**2%**	**5%**	**7%**	**1%**	**2%**	**5%**	**7%**
Asia and the Pacific	1.46	2.92	7.31	10.23	4.61	9.23	23.07	32.30	4.33	8.67	21.67	30.34	13.69	27.38	68.45	95.83	7.21	14.42	36.04	50.46	22.76	45.53	113.82	159.35
Africa	1.60	3.21	8.02	11.22	5.06	10.13	25.31	35.44	4.76	9.51	23.78	33.29	15.02	30.04	75.09	105.13	7.91	15.82	39.54	55.35	24.97	49.95	124.87	174.82
South and Central America	2.02	4.05	10.11	14.16	6.39	12.78	31.94	44.72	6.00	12.00	30.00	42.00	18.95	37.90	94.75	132.65	9.98	19.96	49.89	69.85	31.51	63.03	157.56	220.59
North America	0.27	0.55	1.37	1.91	0.86	1.73	4.32	6.05	0.81	1.62	4.06	5.68	2.56	5.13	12.81	17.94	1.35	2.70	6.75	9.45	4.26	8.52	21.31	29.83
Total	**5.36**	**10.72**	**26.80**	**37.52**	**16.93**	**33.86**	**84.65**	**118.51**	**15.90**	**31.80**	**79.51**	**111.31**	**50.22**	**100.44**	**251.10**	**351.54**	**26.44**	**52.89**	**132.22**	**185.10**	**83.51**	**167.02**	**417.56**	**584.58**

6.5.6. Belowground Carbon Stock

Based on the carbon stock documentation by Yuen et al. (2017), the authors listed ranges of aboveground carbon between 16 tC/ha and 128 tC/ha, compared to between 8 tC/ha and 64 tC/ha belowground. This would indicate a BOC distribution of 50% above- and 50% belowground. However, there are deviations to this distribution. Lobovikov et al. (2007) reported a below- to aboveground BOC stock comparison to be at 26% for bamboos in India, and 15.92% in Pakistan. In China, a 50% split for above- and belowground distribution was reported (ibid.). Isagi (1994) reported 68.3% of bamboos (*P. bamusoides*) to be contained belowground in Japan. Tripathi and Singh (1996) reported about 70% to 75% being contained belowground in India (*D. strictus*). And 67.7% was reported belowground by Zhou and Jiang (2004) for *P. pubescens* in China. While the *Phyllostachys* are running species, the *Dendrocalamus* is or are clumping species. The rhizome type may not be a major factor in the above- to belowground distribution. As indicated earlier, the management of the forest or plantation aboveground is likely the factor on the higher or lower aboveground ratio with clear- or selective cutting, weeding and fertilization or none taking place (Lin et al. 2017: 851). Estimating the belowground carbon content in bamboos' biomass is an uncertain process with data that is further limited compared to data for aboveground biomass/carbon stock, and the wide ranges of reported values.

Applying a similar approach of averaging the ratio of below- to aboveground carbon (from Table 4) yields an average ratio of about 25% carbon being stored in the root and rhizome system of bamboos (Table 11). If this was to be taken at face value, this would mean to add another 25% sequestered carbon once in addition to the minimum estimated BOC after its initial growth period. This is not to say that the belowground BOC may not increase over time, but in the absence of other information specifically indicating a certain increase over time it cannot be estimated.

Table 11: Estimated minimum and maximum carbon sequestration rates with added 25% of carbon contained belowground (initial five-years growth period)

Region	Country size (km^2)	Size allocated for bamboo plantation (km^2)				Minimum estimated BOC per allocated space (GtC)				Maximum estimated BOC per allocated space (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
Asia and the Pacific	13,133,004	131,330	262,660	656,650	919,310	0.74	1.49	3.71	5.20	2.35	4.69	11.73	16.42
Africa	14,407,924	144,079	288,158	720,396	1,008,555	0.81	1.63	4.07	5.70	2.57	5.15	12.87	18.02
South and Central America	18,180,201	181,802	363,604	909,010	1,272,614	1.03	2.06	5.14	7.20	3.25	6.50	16.24	22.73
North America	2,458,500	24,585	49,170	122,925	172,095	0.14	0.28	0.70	0.97	0.44	0.88	2.20	3.07
Total	48,179,629	481,796	963,593	2,408,981	3,372,574	2.73	5.45	13.63	19.08	8.61	17.21	43.03	60.25
Total + 25% belowground						*3.41*	*6.81*	*17.03*	*23.85*	*10.76*	*21.52*	*53.79*	*75.31*

Assuming that the sequestered BOC underground remains relatively stable over time, and provided no interference takes place, the most important aspect remains with the aboveground productivity of bamboos, because the aboveground plant material (the culms) is to be re-grown.

6.5.7. Soil Organic Carbon Stock

The soil organic carbon (SOC) sequestered into the soil surrounding bamboos' root networks should be considered. The total BOC by various bamboos species as reviewed by Yuen et al. (2017) ranged between an average of 3.2 tC/ha to 185.2 tC/ha, with an additional SOC of between 13 tC/ha to 142 tC/ha. It is uncertain which SOC corresponded to which BOC, as several different locations and species were compiled. However, for an idea about the BOC to SOC ratio, Xu, Ji and Zhuang (2018) determined an averaged 20 tC/ha to 37.1 tC/ha in the soil layer of 0 cm to 60 cm, corresponding to an additional 41.4% to 62% of what has been sequestered in the biomass. The variation was influenced by altitude, with decreasing values from north to south. Sohel et al. (2015) calculated 24.7 tC/ha to be contained in the soil, compared to 52.96 tC/ha in the total biomass, equalling to 46.7% carbon in the soil.

Irrespective of whether SOC would add about half of the sequestered carbon in the biomass, similar to the belowground-contained BOC, it would add a certain percentage only once. This is certainly not irrelevant. Moreover, every plant and in particular forests will bind carbon in the soil to some extent for which the aim should be to retain the carbon by not disturbing the soil condition. Chiti et al. (2010), for example, stated that the soil in tropical forests (in Ghana) sequesters on average 151 tC/ha, while Cusack et al. (2018) determined a variable SOC in tropical forests (in Panama) of between 73 tC/ha 203 tC/ha. This may indicate that bamboo forest plantations can sequester the same amount of carbon or less than tropical forests. However, it may be redundant to argue that bamboos will assist the carbon dioxide reduction from the atmosphere by binding carbon in the soil, as other plant species (trees) will do the same. With root networks reaching deeper than 60 cm, those other species may be more effective in sequestering carbon in the soil than bamboos. The only difference may again be the velocity with which bamboos grow and therefore sequester carbon above- and belowground. Without sufficient comparable data to make any assumption about how much carbon would be sequestered in the soil, excluding the biomass of the root network, it is not considered in this paper, and as the attention rests on regrowing bamboos aboveground, and SOC provides little added value in that regard.

7. Discussing the Sequestration Potential of Bamboos

The estimated carbon sequestration potentials are compared with actual space consumption, with concurrent carbon dioxide emissions by sources, the carbon sequestered in natural forests as well as the effectiveness if bamboos were not harvested. Bamboo forest plantations will then be examined from ecological but also social and economic perspectives as they tie into the international forestry and climate change policy context.

7.1. Putting the Results into Perspective

Compared to space consumption

Boysen et al. (2017) argued that planting forests dedicated to carbon capture and storage would disrupt food production and biosphere functioning due to requiring over 1.1 Gha (11,000,000 km^2) of space in order to sequester 320 GtC in 50 years (ibid.: 468).

At the one percent territory size worldwide, 481,796.29 km^2 would be dedicated to the planting of bamboos for carbon sequestration, which corresponds to 4.4% of the 1.1 Gha. At this allocated space, bamboo plantations would sequester between 5.36 GtC (minimum) to 16.93 GtC (maximum) by 2030, or in a ten-years' timeframe. By the year 2050, 30 years from now, it would correspond to 15.9 GtC to 50.22 GtC, as seen in Table 9 previously. Further extrapolated for comparison with the timeframe of 50 years as set by Boysen et al. (2017), the sequestered amount of carbon would correspond to between 26.44 GtC and 83.51 GtC by 2070. In further comparison, this would mean that at one percent of allocated space, the potential to sequester carbon ranges between one twelfth to one fourth of the 320 GtC by the authors.

In addition, by putting in proportion the total sequestration rate over 50 years from Boysen et al. (2017) to the total allocated space (320 GtC/11,000,000km^2), the sequestration rate to space ratio would arrive at 29,090.9 tC/km^2. Compared to the minimum and maximum sequestration rates of this paper over the allocated space (26.44 GtC/481,796.29 km^2 and 83.51 GtC/481,796.29 km^2), the ratio would be at 54,878 tC/km^2 and 173,331 tC/km^2 respectively when extrapolated to 50 years. That means, bamboo forests plantations would be between two and six times more effective compared to tree plantations, as per Boysen et al. (2017), but in 4.4% of the space required by the authors. It is the more significant, when considering that the bamboo stand density can be increased, leading to a higher sequestration rate per square kilometre or hectare. However, these estimations are based upon harvesting and subsequent processing for durable carbon storage within bamboo.

Similar to increasing the stand density, increasing the allocated planting space would reduce the time in which the same amount of carbon would be sequestered within bamboos. At the considered allocated space of five percent or 2.4 million km^2 by the year 2050, bamboos might sequester 79.51 GtC under minimum expectations and 251.10 GtC under maximum expectations. In comparison to Boysen et al. (2017), roughly one fourth to four fifth of the required 320 GtC might be sequestered at the five-percentage scenario - but in only 30 years, and in only about one fifth (21.9%) of the space as required by the authors.

For comparison with Bastin et al. (2019) who estimated that an additional 9 million km^2 could be reserved worldwide for newly planted trees without impacting on other land use: This might be a contradiction to the claim by Boysen et al. (2017) who argued that such large space (11 million km^2 in that case) would disrupt food production. With a reference time of 2050, Bastin et al. (2019: 76) stated that 205 GtC could be sequestered in the 9 million km^2. Corresponding to seven percent allocated space, such a scenario would achieve sequestering 111.31 GtC (minimum) and 351.54 GtC (maximum) by 2050 or in 30 years by means of growing bamboos and their harvesting and processing. If the maximum expectations where to come true, it would exceed each sequestration needs of 205 GtC and 320 GtC, as set by the respective authors. To re-emphasise, the authors' estimations are based on standing carbon stocks; while this paper considers harvesting and re-growing the carbon stock in the same space.

The Food and Agricultural Organisation estimated in 2007 that between 22 million ha to 36.8 million ha (220,000 km^2 to 368,000 km^2) of bamboo forests existed worldwide, which corresponded to about 1% of global forest area (FAO, 2007). The suggested additionally viable 9 million km^2 by Bastin et al. (2019) correspond to adding 22.2% to today's remaining total forest area (40.6 million km^2).[43] The in this paper allocated one percent of worldwide territory would increase existing bamboo forests area by between 23% and 46%. This may cause concern, given the potential spatial consequences discussed previously. However, if the 9 million km^2 scenario by Bastin et al. (2019) holds true, 481,796.29 km^2 in the one-percentage scenario are a marginal expansion of land use for bamboo forest plantations and constitute only 5% of the 9 million km^2; the seven-percentage scenario would occupy only 37.5%.

Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. Land under permanent crops is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee, and rubber. This category includes land under flowering shrubs, fruit trees, nut trees, and vines, but excludes land under trees grown for wood or timber.

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[43] 40,600,000 km^2 total forest area worldwide in 2020, according to FAO and UNEP, 2020.

Permanent pasture is land used for five or more years for forage, including natural and cultivated crops.

The suggested space allocation ranges from roughly the size of at least Angola for on percent (481,796 km^2) to at most Brazil for seven percent (3,372,574 km^2). Distributing these percentages across the 73 countries may appear more or less feasible in accordance with the size differences. However, putting into perspective how much those numbers are may make either percentage scenario appear more feasible. The worldwide arable land allocated for agriculture in 2016 stood at 48,632,688 km^2.[44] For the 73 countries considered in this paper, the agricultural land consumes about 30,540,971 km^2. Even at the seven-percentage scenario, bamboo forest plantations would compare to only 11% of the space that agriculture is already consuming. At the two percent scenario, bamboo forest plantations would constitute only 3.2% compared to the space agriculture is consuming in the relevant countries. This is not much additional space. Worldwide, 33% of arable land is estimated as degraded due to agricultural overuse (ELD Initiative and UNEP, 2015), and sub-Saharan Africa constitutes as most affected with 22% (Nkonya et al., 2015). The comparatively little land consumption by either percentage scenario may not appear conflictious in terms of space. A debate on whether large-scale plantations to save the climate are to be preferred over large-scale agricultural plantations to maintain food security may yet be out of the picture. If space collision with agriculture was to be an issue, it may more likely arise from future agricultural expansion as the world population continues to grow with growing demand for food products. Then, without changes in carbon dioxide emissions, the debates may revolve around what the humanity is willing to sacrifice.

Compared to natural forests

Table 12: Undisturbed closed tropical forests biomass and carbon estimation

	Broadleaf forest		Conifer forest	
	Biomass (t/km^2)	Carbon (tC/km^2)*	Biomass (t/km^2)	Carbon (tC/km^2)*
Americas	15,510	7,755	13,600	6,800
Africa	23,770	11,885	11,850	5,925
Asia	19,630	9,815	14,490	7,245
Average	17,570	8,785	14,010	7,005

*Note: * Conversion factor 0.5, as applied in Chaudhury and Upadhaya, 2016.*

Source: Brown and Lugo (1984: 1291).

Bastin et al. (2019) also estimated to lose 4.5 million km^2 by 2050 under current economic and emissions trends, with the greatest forest losses occurring in the tropical and particular South American continent. Whether a conservative one percent or optimistic seven percent would be reserved for bamboo forest plantations, neither option would replenish the lost forest coverage in terms of space**, which is why bamboo plantations alone won't** reverse carbon release. For a direct comparison, Brown and Lugo (1984) assessed undisturbed and stored biomass in standing tropical forests in Africa, America and Asia. Distinguishing between closed broadleaf and closed coniferous forests, their estimations

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[44] World Bank data on agricultural land, available at: https://data.worldbank.org/ (last accessed at 24 January 2021).

ranged between 140,10 t/km^2 (140.1 t/ha) (conifer) and 175,70 t/km^2 (175.7 t/ha) (broadleaf) on average (Table 12).

The estimated carbon sequestration rates of 5,656.50 tC/km^2 and 17,863.98 tC/km^2 for bamboo forests (from Table 8) may fall in between the same or exceed the range of standing carbon stock in the estimations by Brown and Lugo (1984). However, as there are more effective bamboo species leading to higher sequestration rates, so exist tree species with much higher sequestration potentials which exceed the average values by far. A more recent study estimated *Eucalyptus regnans* forests to account for 105,300 tC/km^2 (1053 tC/ha) in living aboveground biomass. In terms of standing carbon stock, it would make *Eucalyptus regnans* almost six times more effective than the optimistic maximum sequestration rate for the most productive bamboo species. Replacing natural habitats sequestering carbon to high extents, like forests, should be no option because replacing one carbon sink with another is a zero-sum game or might worsen the capacity in a given area to store carbon.

Compared to carbon dioxide emissions

As it is difficult to comprehend the theoretical estimations due to being excessively large numbers, this section may help understand the amount of carbon that can be sequestered in bamboo forest plantations by comparing sequestration rates to actual and intended emissions.

Table 13: Annual carbon dioxide emissions versus annual carbon dioxide intake

Carbon dioxide emissions from:*		Reference time	Source		Annual estimated carbon sequestration (GtC) at:**		
						min	max
Global freight ship transportation	0.9 GtCO$_2$ (0.25 GtC)	2018	IEA, 2020	vs	1% allocated space	1.94 GtCO$_2$ (0.53 GtC)	6.08 GtCO$_2$ (1.66 GtC)
Global aviation (passenger and freight	0.9 GtCO$_2$ (0.25 GtC)	2018	IEA, 2020				
Global road freight transportation	2.4 GtCO$_2$ (0.66 GtC)	2018	IEA, 2020				
Global passenger cars	3.6 GtCO$_2$ (0.98 GtC)	2018	IEA, 2020		2% allocated space	3.84 GtCO$_2$ (1.05 GtC)	12.2 GtCO$_2$ (3.33 GtC)
Global natural and man-made wildfires	7.4 GtCO$_2$ (2.02 GtC)	1997-2019 (average)	Lombrana, Warren and Rathi, 2020				
Global tree cover loss	4.8 GtCO2 (1.31 GtC)	2015-2017 (average)	Seymour and Bush, 2016				
Global fossil fuel burning	36.46 GtCO2 (9.95 GtC)	2019	Andrew et al., 2020		5% allocated space	9.67 GtCO$_2$ (2.64 GtC)	30.48 GtCO$_2$ (8.32 GtC)
China	10.06 GtCO$_2$ (2.75 GtC)	2018	UCS, 2020				
USA	5.41 GtCO$_2$ (1.48 GtC)	2018	UCS, 2020		7% allocated space	13.52 GtCO$_2$ (3.69 GtC)	42.69 GtCO$_2$ (11.65 GtC)
India	2.65 GtCO$_2$ (0.72 GtC)	2018	UCS, 2020				
Russian Federation	1.71 GtCO$_2$ (0.47 GtC)	2018	UCS, 2020				

*Note: * 1 million tonnes of carbon = 3.664 million tonnes of CO$_2$. ** It does not take into account the initial five years of sequestration after planting for the first time and refers to the one fifth annual sequestration yield less 3.3% of annual decay, as established in section 6.5.5.*

Table 13 lists selected annual carbon dioxide emissions by source, and compares it to the estimated annual carbon sequestration rates. As no timeframe is considered, only the annual carbon dioxide intake without the sequestration that would be achieved in the initial four years' growth period is considered. In other words, the initial standing carbon stock has been neglected at this point to emphasise on comparing annual emissions versus annual intake.

Under one percent - perhaps two percent - of allocated space, the expected minimum sequestration cannot reverse all global carbon dioxide emissions per se. At the one-percentage scenario, bamboo forest plantations may be able to sequester the amount of carbon dioxide as released from some of the transportation-related sources. On at least two percent of space, bamboo plantations may sequester enough carbon dioxide to take in the emissions stemming from either sea, air and land freight transportation, or only passenger cars- derived emissions. Under maximum expectation, the same space may be able to reverse the emissions from wildfires and tree cover loss together or all transport related emissions. A generous five percent space would notably sequester larger amounts, and the optimistic maximum estimations come closer to the total global emissions from burning fossil fuels (8.32 GtC sequestered versus 9.95 GtC released). At the minimum expectations, five percent of space may reverse the emissions caused by China (2.64 GtC sequestered versus 2.75 GtC released). At the seven-percentage scenario and under maximum estimations, bamboo forest plantations may be able to reverse all annual emissions and take in more carbon dioxide than is released through anthropogenic means.

Even under conservative estimations, establishing bamboo forest plantations will be able to contribute to reversing some carbon emissions of some source, which could be increased with increased stand density. Sequestering enough carbon dioxide to cover at least the transport sector may already be a necessary achievement, given that mobility is expected to quadruple by 2050 (Schäfer and Victor, 2000).

The reduction of greenhouse gas emissions, including carbon dioxide, has been addressed in international climate change mitigation frameworks. The EU's ambition is to reduce those emissions by 40% by 2030, compared to 1990. The Kyoto Protocol prescribed a comparatively moderate reduction of 18%, which, was meant to be achieved by 2020, however. The global emissions of carbon dioxide in 1990 stood at 24.97 $GtCO_2$ (6.81 GtC). A reduction by 40% would correspond to reducing carbon dioxide emissions to 14.98 $GtCO_2$ (4.08 GtC) and a reduction by 18% to 20.48 $GtCO_2$ (5.59 GtC) per year. The proposed 55% of the European Commission correspond to a reducing to 11.24 $GtCO_2$ (3.07 GtC) in a year. Irrespective of whether the percentage-wise reduction is purposeful, the aim is to reach a maximum output of emissions.

In a scenario where the yearly carbon dioxide emissions prevailed at 36.46 $GtCO_2$ (9.95 GtC), bamboo forest plantations may come close to the 18-percentage goal in ten years or by 2030 only if seven percent of space was allocated under the considered minimum sequestration potential (Table 14). If the most effective species were chosen, bamboo plantation forests may come close to the 18-percentage goal on only two percent allocated space. A reduction goal to 40% or 55% of the 1990s emission levels appears least unattainable by bamboo forest plantations alone, even if stand density was doubled. However, for a scenario where seven percent of space was allocated under the minimum estimated sequestration rates, 50% of the targeted carbon dioxide emissions at the EU's 55-percentage goal could be sequestered in bamboo plantations. In the scenario where the most effective species were chosen in 7% of space, bamboos may sequester more carbon dioxide than is emitted (achieving negative carbon emissions) and exceed the 55-percentage goal by 2030.

Table 14: CO_2 emissions mitigation by means of bamboo plantations, annually for 10 years (or 2030)

Region	Minimum estimated BOC per allocated space (by 2030) (GtC)				Maximum estimated BOC per allocated space (by 2030) (GtC)			
	1%	2%	5%	7%	1%	2%	5%	7%
Total	5.45	10.90	27.25	38.15	17.21	34.43	86.07	120.50
Annual average (Total/10 years)*	0.545	1.09	2.725	3.815	1.721	3.443	8.607	12.05
Difference between global fossil fuel burning 2019** (in GtC) and the annual average	9.405	8.86	7.225	6.135	8.229	6.507	1.343	-2.1

*Note: * It refers to the sequestration rate of the initial five years growth period. ** Global fossil fuel burning: 36.46 GtCO2 (9.95 GtC).*

As with carbon dioxide emissions by source, bamboo plantations may not be able to reverse all carbon dioxide emissions to the degree required in public discourse and set out in national or international frameworks. However, taking up some percentage of the targeted emissions reductions may still be an advantage than no uptake of carbon dioxide from the air at all.

What if bamboo plantations were not harvested?

Although it is a condition to harvest bamboo plantations in order to maximise the carbon intake effect, it remains to understand the effectiveness of those plantations if they were not harvested. Going back to the sequestration estimations after the initial growth period, including the added 25% of sequestered carbon belowground (Table 15), bamboo forest plantations cannot come near the required 320 GtC, if those plantations remained unharvested and under presumed stable growth conditions.

Table 15: Total carbon sequestration estimation as standing carbon sinks

Region	Minimum estimated BOC per allocated space (GtC)				Maximum estimated BOC per allocated space (GtC)			
	1%	2%	5%	7%	1%	2%	5%	7%
Total + 25% belowground)	3.41	6.81	17.03	23.85	10.76	21.52	53.79	75.31

In the unlikely scenario that the once sequestered BOC in bamboos was to remain stable, only the most optimistic and generous estimations indicate any quantitatively large carbon uptake effect. Compared to the annual carbon dioxide emissions above (Table 13), unharvested bamboo plantations may take in a couple of times the emissions from transportation for a couple of years. However, the capacity of the sink to sequester carbon is 'naturally' limited by its growth-decay cycle of the same few years with which a bamboo culm grows and dies. The problem would remain with carbon dioxide continuing to be emitted by anthropogenic activities, while the available space for carbon sinks has been used up. The only remaining value by bamboo forest plantations on a global scale would then be the fast one-off sequestration for a few years to provide a short-lived buffer period to reduce fossil fuel or deforestation related emissions.

7.2. Pro and Contra Aspects of Bamboo Forest Plantations

Ongoing management required

A barrier to including bamboo forest plantations for carbon offsets in forestry policy is the risk of carbon emissions reversal back into the atmosphere due to natural hazards (Galik and Jackson, 2009: 2209) While bamboos are relatively resistant to storms or fires, their mass-flowering may be an issue. Therefore, management at the individual stand level to avert re-carbon release is indispensable (ibid.). The invasiveness of bamboos, whether they are clumping or running bamboos, remains a concern that has yet to be properly understood (compare Canavan, 2019). Once bamboo plantations have been established, even in degraded lands, it will be a requirement to limit their spread into neighbouring natural, agricultural or political territory. The relatively little observed synchronous flowering event of different bamboo species can be a concern, when flowering ends in a mass die-off of the plantation and in consequence releases the sequestered carbon back into the atmosphere (Liese, 2009). To avert the negative but foster the desired impacts, some form of bamboo management will be required for optimal growth and biomass production. From ecological effects, the management of bamboo forest plantations will revolve around the issues of invasiveness and flowering if left uncontrolled.

Water consumption unclear

Water consumption may need to be assumed as high, given their humid climate preferences. This preference will require ensuring enough irrigation, which should take place from naturally occurring rainfall and therefore be planted in regions where water is readily available. Bamboos are not considered for arid regions in the first place, so that the water requirements may be less critical. However, as weather changes, manual irrigation may need to supplement rainfall and therefore access standing and flowing water reservoirs. Depending on the need for water by bamboos on a large scale, they too could theoretically drain water reservoirs for other land use purposes, such as agricultural or natural habitats, or drinking water itself in periods of rainfall shortages. However, there is not enough experience with bamboos. Nevertheless, groundwater tables were found to have increased after the planting of bamboos (FAO and INBAR, 2018), which requires investigating the circumstances for replication.

Biodiversity impacts unclear

Establishing large-scale bamboo plantations may count as monoculture, which goes against biodiversity conservation frameworks stating that "no climate-related geoengineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity" (Honegger, 2013: 26). Though it is non-binding, bamboo forest plantations may count as too homogenous for a climate altering intervention under REDD+. Whether or not bamboos threaten biodiversity may depend on what perspective would be applied. Biodiversity is described as the biological diversity within and between life forms in given space, landscape or ecosystem (Elzinga, 2001; Willig and Presly, 2018; Zhang et al., 2012). Bamboos are with 1600+ species diverse in themselves and several species of similar biomass productivity can be planted. Biodiversity can be distinguished as genetic diversity, species diversity and diversity within a habitat. Zhang et al. (2012) pointed out that habitat size influences the determination of existing or absent biodiversity, because in more space a greater biodiversity can be found. Allocating one percent of space to bamboos may count as homogenous in that one percent, but from the perspective of a country it would be heterogenous, as other species grow elsewhere. Depending on the circumstances and whether any national definitions exist, it may cause a struggle in policy-making driven by different interests of different stakeholders. A policy is "a product of discursive struggles driven by different interests [that] favour certain descriptions of reality, empower certain actors while marginalizing others." (Bäckstrand and Lövbrand, 2006: 52). Policies on bamboo plantations and biodiversity are no exception.

Furthermore, bamboos have been found to provide shelter to numerous faunae of small and large mammals and birds (Yeasmin, 2015). They could improve habitats where they were disturbed previous. The potential for negative side-effects remains, however, with other plant families due to bamboos' encroachment and suppression tendencies, which may remove food sources and shelter of other faunae dependent on certain plants. A logical conclusion would be not to plant bamboos in sensitive habitats in the first place. The same applies to not replacing natural ecosystems, in particular natural forests, which sequester carbon potentially more effectively than bamboos forests. In fact, it has been proposed and practiced to plant bamboos only in degraded landscapes (Kuehl, Kuehl and Castillo, 2018). For example, the mosaic forest degradation can be improved with bamboos serving as bridges connecting isolated forest patches (FAO and INBAR 2018: 10; Kuehl, Kuehl and Castillo, 2018: 54) or barren land from mining or other exploitative operations can be revegetated with bamboos quickly FAO and INBAR 2018: 8, 9). A question that results even from those limitations is whether bamboos should fill the 'gaps' in vegetation or whether the previously native florae can be re-introduced in its stead. As mentioned earlier, bamboos may not allow for other plant species to grow once they have established themselves due to oppressive biomass production if left untreated. The competition with other plants may require intensified bamboo management.

Land use integration beneficial

Another question is whether enough space can be made available for bamboo plantations as required for a desired carbon sequestration rate, if it was limited to degraded landscapes. Mapping and quantifying existing bamboo forests and their condition should be prioritised before allocating plantations (Kuehl, Kuehl and Castillo, 2018: 52). Mapping might enable enough space allocation when including (or limiting to) degraded landscapes and depending on which sequestration aim is to be achieved. It should be noted that this 'thought experiment' only considers a certain amount space; it does not define how the allocated space is distributed. I.e., a 2% of total global space may also be distributed to different percentages on a country basis in order to address the planting on available degraded land only, and therein at different locations as opposed to one single location.

To avoid land use conflicts, there is the idea of bamboo intercropping in agroforestry systems, combining the two major conflicting agricultural and forest spaces. Given the ecosystem altering properties bamboos can have, bamboos for agroforestry may suppress crop growth. There are applications of bamboos in agroforestry with mixed results, either improving or limiting crop growth (see Acharya et al., 2016; Akoto et al., 2020; Kittur et al., 2016b; Shangmughavel and Francis, 2001), seemingly related to spacing of bamboo versus crops and the ecological interactions resulting from shading, evapotranspiration, water infiltration and flow as well as nutrients competition and addition. However, no radical invasiveness and crop suppression has been identified. This may have well to do with management of the plant.

Local inclusion required

The displacement of local populations due to labour skills mismatches, despite believing forest plantations to reduce poverty, has been a major critique. In order to account for social development and poverty reduction under the Paris Agreement, Agenda 2030 and other frameworks, the management of bamboo plantations needs to employ local communities in combination with ensuring the acquisition of the skills necessary to manage specifically bamboo plantations (e.g. Acharya et al., 2016: pp. 30). As bamboos have been regarded as poor man's timber due to being a central resource in rural and considered poor communities (Lobovikov et al., 2009), they may not require highly skilled labour, specialised knowledge nor high technology (Lobovikov et al., 2007, Mera and Xu, 2014), which are likely to be lacking in many developing regions in the first place.

The regraded low skills for the management of bamboos may also favour making bamboo plantations part of local farming, which may be further benefited by serving as food source. The spatial conflict may be mitigated when bamboos serve as part of agricultural livelihoods, as opposed to being a competition to it. Forest plantations were side-lined and neglected in the past due to missing silviculture skills, while bamboo forest plantations constitute indeed part of farmers' income which is apparently contributed to a lesser skills demand (Ly et al., 2012; Mera and Xu, 2014).

Even though, bamboos are advertised as low skills demand, their rapid growth and oppressive spread, different from trees, will require relevant knowledge for optimal bamboo management. For example, in agroforestry applications with intercropping, bamboos require the removal of the extensive leaf litter in order to allow other crops to grow in between bamboo stands (Mera and Xu, 2014: 5; Nath et al., 2009: 1). Some training on bamboo silviculture will be required.

Investment to be incentivised

Bamboo plantations will require an initial investment by local implementors of the plantation, which is accompanied with initial risk, just like their tree counter parts. Large initial investments with uncertain outcomes are not attractive (Honegger, 2013: 49). Direct or indirect incentives are able to bridge initial cost arising from equipment and labour, and the missing financial gains until future harvest are compensated (compare Enters, Durst and Brown, 2003). However, instances of incentive abuses in forest plantation establishment have been documented as being exploited or plantations not being managed to expectations after receiving monetary incentives (Enters, Durst and Brown, 2003; FAO, 2004; FAO, 2016). Government-provided resources were re-sold and loans used for other purposes for short-term gains by private individuals and companies (Enters, Durst and Brown, 2003: 7). Furthermore, those incentives can stand in direct competition with incentives for alternative land use (Danso-Addo, Bulkan and Innes, 2019: 144), which would require adjusting alternative incentives to not discourage or disfavour bamboo plantations. But it should be noted at this point that "studies dealing with the incentive schemes that are needed to stimulate investment in bamboo plantations are scarce." (Addo-Danso, Bulkan and Innes, 2019: 133) In consequence, little experience around investment and risk related to bamboo can be found. It can be remarked, however, that a singular incentive may not be sufficient to yield the needed results, but requires a combination of incentives for bamboo plantations as there are different private stakeholder groups comprised of large-scale companies, to individual small-holders or a combination of both as well as public or community owned lands. (ibid.: 145). One of such incentive needed is clarification around land tenure.

Local land ownership

Clear rights to land by means of legal regulations were positively related to plantation investment and management by private entities (Enters, Brown and Durst, 2003). Blurred land tenure in many developing countries led to land use collisions, mismanagement or the disregard of forest plantations all together (Enters, Brown and Durst, 2003: 7; FAO, 2001: 7).

Typically, forests and forest plantations are state-administered in developing countries with use rights granted to individual or private sector companies (e.g. Chokkalingam and Phanvilay, 2014). To ensure optimal carbon sequestration, land ownership, tenure and benefits must be clarified while operating under established forest policies (Addo-Danso, Bulkan and Innes, 2019; Enters, Brown and Durst, 2003; FAO, 2001).

In that regard, ensuring local stakeholders' ownership and benefits is considered crucial in North-South-cooperated carbon projects as to avoid what is called 'carbon colonialism' (Bäckstrand and Lövbrand, 2016: 65). The management and administration must remain under an implementing country's sovereignty. Furthermore, bamboo plantations for agroforestry may serve local land owners to become part of carbon sink projects in addition to agricultural activities, while serving them as short- and long-term investment incentives with lower financial risks due to yield diversification (Nath et al., 2009: 1).

Market product opportunities

Even though bamboos may be used in over 1250 applications, the reality is that on a country basis, there is only residual knowledge of using bamboos and their application due to research focusing on other agricultural and/or timber resources (Abbas and Manabo, 2017; van der Lugt, 2005). The edible bamboo shoots add a valuable use of the plant for household income contribution (Hogarth and Belcher, 2013). But more important is that the harvested bamboo biomass is converted into wood products, which otherwise would be made from non-renewable tropical timber and can thus take pressure off tropical forest resources. Tall-grown bamboos with woody stems can be processed into durable wood products, furniture material and other small appliances, which are estimated to preserve 90% of its carbon biomass (Jijeesh, 2009; Widmer, 1990). In order to take advantage of bamboo timber products, the market demand for bamboo and thus the availability of the resource needs to grow (Acharya et al., 2016; Widmer, 1990; Wiseman, 2015). Making bamboo a common timber source for manufacturing and trade requires adapting it on a larger scale, which in turn requires forest policy changes in order to promote it as a timber resource (Buckingham et al., 2007).

Turning bamboo into marketable products furthers the local or national income opportunities by providing additional employment in bamboo manufacturing depending on the farming scale in particular in developing countries' rural areas (Akwada and Akinlabi, 2018; Lobovikov et al., 2007). This would be important for developing countries where resource generation is scarce due to missing technologies. Attention must be paid not to fall in the same trap of converting jobs, as opposed to creating additional ones, and as was criticised with tree plantations before (section 5.2.4.).

Lifespan to consider

Converting bamboo into durable products is a promising approach to increase the potential of bamboo carbon sinks under REDD+ by continuously regrowing harvested bamboo culms and while retaining the sequestered carbon within the manufactured end-products. However, the lifespans of many of these products may turn out short and depend on the processing standard (Lobovikov et al. 2007; Kuehl, Kuehl and Castillo, 2018). Depending on the purpose of the product, it may last up to several decades, such as in the case of bamboo hardwood flooring (Gu et al., 2019): 10. However, where the bamboo product decay lasts only a couple of years, the re-growth of bamboos (of the same couple of years) for the creation of that product may be a zero-sum game when carbon intake and release are equal. In that case, increasing the carbon capturing capacity to the extents exemplified in this paper would require increasing the product amount, preferably by substituting non-bamboo wood products, and altering the lifetime of the products. The latter would also include end-consumer behaviour change.

Even if the lifespan is limited, capturing carbon in bamboo timber products is still significant, because at the least it gains time for developing 'cleaner' energy and transportation technologies and help avoid accumulating carbon dioxide the atmosphere (Karsenty, Blanco and Dufour, 2003: 7).

Processing causes emissions

To carbon dioxide emissions along the production chain also accounts the processing itself. Carbon dioxide release after or while processing is considered 'leakage' in the sense that the emissions take place outside the intended use (Bäckstrand and Lövbrand, 2006: 63). From harvesting machinery, to transportation, drying, heating and preserving, or any other machinery requiring some form of fuel is subject to carbon dioxide emissions (e.g. Gu et al., 2019), unless it was substituted with renewable energy sources. On a country basis, inadequate technology exists in farming and cultivation activities, and bamboo is no exception (Abbas and Manabo, 2017; Acharya et al., 2016). Appropriate technology to transform bamboo into different finished products is either lacking or insufficient (ibid.). It can be expected that outdated machinery will contribute negatively to the emissions which bamboo plantations are supposed to absorb and therewith be counterproductive.

Alternative carbon storage via bamboo

An alternative to lasting bamboo products is biochar; a state in which wood retains carbon through a process of pyrolysis to up to 50% while releasing it only gradually over time (Lou et al. 2010: 36). While this application seems counterintuitive at first, because it releases carbon dioxide, biochar is used in agriculture as a natural fertilizer to regenerate degraded and nutrient deficient soils to spur the growth of other plants, which in return can help with crops and/or absorbing carbon dioxide emissions (Hall, 2013; Lehmann and Joseph, 2015; Whitman and

Lehmann, 2009, Xu et al., 2020 Yanai et al. 2007). Bamboo charcoal could replace the wood consumption for charcoal production (Sileshi and Nath, 2017: 7) which again would support conserving natural forests as carbon sinks. In times were agricultural soils become nutrient poor due to over use, inserting charcoal has shown to be of benefit (e.g. Hua, Chen and Wu, 2012). Nevertheless, the decomposition time with which biochar degrades and the velocity with which surrounding plants sequester carbon dioxide will influence how much carbon remains sequestered in the soil and plants. The in the decay process released carbon may equate to zero, if and when surrounding plants, such as crops, sequester the released carbon at the same velocity. Theoretically, bamboo-based biochar would add another economic good that would allow for market participation, including of smallholders in developing countries (e.g. Scheba, Blanchard and Mayeki, 2017).

At last, carbon capture and storage (CSS), specifically permanent underground storage, is an essential part of the solution for reducing carbon dioxide emissions in the 2 °C the beyond scenario (IEA, 2016). Bamboo in its dry mass can be stored underground, which would retain the sequestered carbon in or below the soil and prevent it from atmospheric-accelerated decomposition (Holloway, 2005). This may include processed products, such as furniture (Zeng, 2008). However, in contrast to above market goods, the underground storage would provide only further offset of the carbon to another location without any added functionality that could add consumer demand and thus only incur cost on the side of the carbon emitter (Holloway, 2005). As with any additional inputs, carbon burial will incur cost. But the cost for burial of naturally sequestered carbon (as opposed to chemically) is said to be low, because carbon dioxide is removed from the atmosphere by photosynthesis at little cost, making it low tech, easy to monitor, biologically safe and reversible if needed (Zeng, 2008). Thus, not only an attractive option for large-scale implementation in a world-wide carbon market but in line with cost-effectiveness argumentation of REDD+ and definitions of the Paris Agreement as well as country or regional development goals. Nevertheless, as with other underground storage discussions, it has yet to be verified how secure the underground storage of bamboo as well as identified where such large-scale underground storage facilities would result from (Holloway, 2005; Zeng, 2008).

There are yet more applications for bamboo, such as biofuel substitute and animal fodder, which cannot be elaborated on in this paper but expand the economic integration of cultivating bamboos.

7.3. Bamboos' Fit in International Political Frameworks

After understanding the global potential of bamboos forest plantations for carbon sequestration, and an overview over the viability of that idea from social, economic and environmental perspectives, the international policy contexts need re-addressing. The final sections will re-contextualise and, therewith, summarise bamboo forest plantations into the initially discussed policy frameworks and mechanisms, and which overarching issues remain.

It may not have been surprising from the beginning. Given the scope of the attempted estimations, carbon sequestration via bamboo forest plantations will have some positive carbon intake effect. With regards to the Agenda 2030, it set out a specific timeline for 2030, but also to go up to 2050 with the aim of reducing greenhouse gas emissions. Depending on the scale, species and whether or not bamboos are harvested and processed, the effect can be impressively large or at least not negligibly small. As per the exemplary requirements of the Kyoto Protocol to reduce emissions to 18% of the levels of 1990 (5.59 GtC per year), bamboo forest plantations would only have come close to such a target if the most promising species would be planted in preferably large space. Higher reduction targets, as set out by the European Union with 40% (perhaps 55% by June 2021), would not be achievable with bamboos alone. Yet, bamboo forest plantations may be able to curb emissions from certain sectors, like transportation, or the biggest polluters on a country basis. Given the fast growth of the plant, with its versatile economic applications and role in local livelihoods, it may yet be a considerable option for climate change mitigation strategies.

As per the Paris Agreement, countries' primary aim is to contribute to staying below the 2 °C threshold by means of nationally determined contributions, depending on a country's socio-economic circumstances. Bamboo forest plantations, as a means to capture carbon dioxide and store it in form of organic carbon in their biomass, are enabled by the Agreement in the sense that they can serve as carbon sinks; always provided they are managed and their biomass is processed into durable products.

Another critical condition has been with not to threaten food security. Given the comparatively low space consumption required by bamboos as well as being edible and also qualifying as an agricultural and potential agroforestry product, bamboo forest plantations may be unlikely to threaten food production. This would address individual development agendas which specifically seek for agricultural and forest solution as integral part of carbon sequestration. A common aspect in the climate change, international development and forestry frameworks has been to improve social conditions (reduce poverty) by means of climate change and forestry initiatives. Bamboo forest plantations appear to require relatively low skills for the management of these plantations, while at the same time providing multiple livelihood options. Specifically, agroforestry finds attention in development frameworks, which would offer integration in agriculture-based economies where large population do not have access to high skills and/or technology and if bamboos are confirmed suitable for agroforestry. This circumstance would speak in favour of bamboo plantations versus tree plantations; the latter of which showed to be neglected due to missing skills but also other labour unfavourable conditions. Whether under ASEAN, African Union or individual country strategies in Latin America, bamboo forest plantations would address sought after forestry and agricultural opportunities. It remains to ensure decent work conditions.

Bamboos' known use as "poor man's timber" also feeds into discouraging from tropical logging for local communities; bamboos re-grow faster than most trees and provide timber for livelihood purposes at a faster pace and in the developing regions of concern. "[T]wo-thirds of the deforestation continues to occur in the tropical forests of South America, Africa and Southeast Asia" (Whitehead, 2011: 894). Coupled with agricultural use, providing a fast-growing timber alternative that supplements the re-growth precisely in those regions has the potential to replace tropical wood products and, thereby, slowing if not halting tropical deforestation. Bamboo planting may be able to avoid or at least reduce the deforestation of tropical forests and the related carbon releases, as well as to store carbon on the condition that bamboos are embedded and expanded upon as food and timber resources in economic activities (Kuehl, Kuehl and Castillo, 2018; Nath et al., 2008; Nath and Das, 2011).

The Kyoto Protocol opened up the principle that carbon dioxide should be mitigated where it is least expensive, with carbon sinks to be implemented by industrialised countries in developing countries (North-South relationships) (Bäckstrand and Lövbrand, 2006: 58). Investment cost is considered low in developing countries, which is framed as carbon trade, carbon credit or carbon payment (ibid.). The same principle has been carried forward in the Paris Agreement, and which instrumentalises the Adaptation Fund to provide the necessary finances for the planting of carbon sinks in developing countries. As bamboos are accounted for in international forestry, bamboo forest plantations can be financed under the Paris Agreement by means of the Fund and fall under North-South relationships. As per the economic principle, national or local governments can draw from the international fund to create direct or indirect incentives for the planting of bamboos. To mention it, the issue of exploitation of the financing remains, however, due to individual stakeholders abusing incentives, as mentioned previously.

When included as part of a larger greenhouse gas emissions reduction programmes, forest carbon offsets provide low-cost opportunities for greenhouse gas mitigation (Galik and Jackson, 2009). Being able to be financed by the industrialised countries of the North, while offering low-cost plantations growth in the countries of the South, coupled with a number of socio-economic benefits through livelihood income opportunities, bamboo plantations fit the concept of co-benefits through carbon offsets under the Paris Agreement (compare UN, 2015: 7). In consequences, they also feed into the Agreement-related development aims, such as in particular the Agenda 2030.

Fitting into REDD+ becomes somewhat less straightforward. REDD+ laid out the preconditions for activities recognised under the Paris Agreement. By serving as timber substitute in local or industrial processing and by revegetating landscapes, bamboo forest plantations can reduce emissions from deforestation; they can reduce emissions from forest degradation; they can conserve (natural) forest carbon stocks; they can be sustainably managed; and they can enhance other forest carbon stocks; and thus, address the eligibility criteria of REDD+ (UNFCCC, 2016: 8). But REDD+ also requires taking into account an array of perspectives from not only from environmental sustainability, but also economic profitability, land values, competitive land use, land resources, employment opportunities, and other social and cultural conditions (Whitehead, 2011: 899).

A general condition that remains to be clarified in many developing countries is land tenure and the resulting decision-making over and receiving benefits from the land. REDD+ requires transparent forestry practices (UNFCCC, 2016: 6), which cannot happen with obscured land rights. Bamboos can theoretically be planted despite uncertain land right conditions. However, that these uncertain plantations represent a stable, long-term investment with stable, long-term benefits for carbon offsetting may result as a concern and, thus, disincentivise growing bamboos.

It also remains to be clarified whether bamboos are a benefactor or a detriment to biodiversity, which has shown to qualify for both. Bamboos forest plantations may count as monoculture plantations and, thus, be a theoretical threat to biodiversity. However, the latter depends on the landscape where the plantations are established and whether bamboos invasiveness and spread into adjacent areas are controlled for.

On a positive note, REDD+ seeks to include the participation of local stakeholders for knowledge exchange on sustainable management practices (UNFCCC, 2016: 6). Due to the under-researched nature and lack of awareness on bamboos, involving local communities in the management of bamboo plantations may turn out a necessity as to make use of existing human capital – at least until bamboo management is exported into other countries and makes local knowledge redundant.[45]

Bamboo species and forest plantations can have environmental consequences and cause social and economic complications, which need to be safeguarded against as required by REDD+. It would appear logical to agree to uniformly defined policies for bamboo plantations. It appears, however, that most countries do not wish to participate in internationally governed forestry initiatives due to stakeholders in the country wanting to pursue their own material interests without financial burdens from sustainability measures (Dimitrov, 2005: 14). On the

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[45] E.g., INBAR, 2018: Press Release: New China-Africa Centre in Addis Ababa Promotes Bamboo for Sustainable Development. INBAR, 3 September 2018. Available at: https://www.inbar.int/pressrelease_chinaafricacentre/ (last accessed 14 February 2021).

presumption that additional forest cover can be established (according to Bastin et al., 2019), adding fast-replenishable bamboo forestry resources should be in the interest of any financially incentivised stakeholder, as bamboos would provide relatively quick harvestable resources. To supplement complying with REDD+ safeguards, FLEGT and FSC or other resembling mechanisms can offer some solution.

While FLEGT can only hold stakeholders accountable with regulations on legal cultivation that exist in a stakeholder's country, in the short-term it could serve as a common operational basis in different countries. FLEGT seeks to establish a minimum common ground by mapping national laws, identifying gaps and driving reforms (European Commission, 2012: 61). FLEGT encourages social and environmental sustainability of timber by involving the country of origin in holding local timber producers accountable in exchange for the opportunity to export their timber into other countries (here EU). FLEGT includes bamboos as well as the participation of local stakeholders in the negotiation process. Social and environmental conditions must be met in exchange for economic rewards. In line with Honegger's (2013: 49) requirements for a regulatory decision frame, a FLEGT-approach can provide the needed guidance for local deployment, mechanisms for oversight and safety requirements. A major disadvantage is that FLEGT requires years of intergovernmental- negotiation before implementation.

Sustainability certifications serve as an alternative where there is a lack of intergovernmental agreements to address legality of timber supplies (Buckingham et al., 2014: 774). The FSC certification is the most notably, internationally recognised standard in timber management (Buckingham et al., 2011: 547). Similar to the FLEGT approach, forest management for FSC certification must consider not only environmental but social conditions and impacts. The FSC provides a checklist for these conditions to be met in order to be certified. The difference to FLEGT is that the initiative rests with a local plantation owner but does not find enforcement by any authority. An FSC certification can also open up export opportunities, where sustainability is a requirement.

A drawback is that the FSC certification was found as inappropriate for bamboo cultivation as it applies regulations relevant for tree ecology, specifically on timeframes and extents of allowed versus non-allowed logging (Buckingham and Jepson, 2015; Buckingham et al., 2011; Buckingham, 2014). Though bamboos are recognised by the FSC, their cultivation (and harvest) must conform to complex FSC standards based on trees, which can counter the incentivisation for bamboo plantations due to reluctance by the institution to integrate new resources into its existing framework (Bucking and Jepson, 2015: 575). Specifically, it is criticised that the removal of carbon sinks (harvesting of trees) releases the once-sequestered carbon as part of their decay process. However, bamboos would not serve as standing carbon stocks in the sense that they can be established once and remain for decades. Contrary to trees, after bamboos were harvested, the "lost biomass is usually replaced within a year [and therefore] classified as highly renewable" (Kuehl, Kuehl and Castillo, 2018: 49).

The harvesting issue stems from defining forests as carbon sinks not only under FSC but national forest policies. The unregulated removal of forest biomass is banned and punished under such policies (Kuehl, Kuehl and Castillo, 2018: 52). Although bamboos can be regularly harvested and quickly regrown unlike most trees, they are unnecessarily affected by harvesting bans and remain unavailable as a timber resource and, therefore, tropical timber substitute (ibid.). Sustainability regulation and certification mechanisms may yet be an obstacle to bamboos, in particular when harvesting is regulated under inappropriate definitions. Pursuing sustainable origins to fit REDD+ and other forestry standards come at a high cost for plantation owners, which collide with bamboo-inappropriate requirements (Buckingham and Jepson, 2015; Buckingham et al., 2014). If such a cost barrier occurs, it may be non-conducive to the locally inclusive, cost-effective requirements under the Paris Agreement.

In order to take advantage of bamboo timber products, the market demand for bamboo and the availability of the resource needs to grow (Acharya et al., 2016; Widmer, 1990; Wiseman, 2015). Making bamboo a common timber source for manufacturing and trade requires adapting it on a larger scale, which in turn requires forest policy changes in order to promote it as a timber resource (Buckingham et al., 2007). But unless there is an enabling institutional forestry framework specifically supporting bamboos, commercialisation may be impeded by unfitting sustainability requirements (Buckingham et al., 2014: 778). Inadequate requirements may risk losing the initial investment in bamboo plantations, when the timber product cannot be sold without compliance to certain standards and achieving the verification comes at a too high financial cost. This would become problematic, given that bamboo forest plantations' effectiveness for the purpose of carbon sequestration hinges on utilising the wooden culms for industrial and manufacturing applications.

An international exchange on sustainable bamboo management practices has already been called for by Kuehl, Kuehl and Castillo (2018), in particular "involving China and India and other southern countries" (ibid.: 54) due their history with bamboo. As according to Dimitrov (2005) only consequences of global dimensions instigate governments to assemble and develop common governance frameworks, highlighting the socio-economic benefits of bamboos as silviculture product (see e.g. Mera and Xu, 2014) may be more in line with the financial motivations that tended to withhold countries from participating (Dimitrov, 2005).

7.4. Overarching Obstacles

A primary issue with bamboos arises from a lack of awareness on the resource among policymakers who could steer socio-economic and environmental attentions. This may come as no surprise, given the general under-researched nature and discriminatory labelling (poor man's timber) of the plant. It was documented that only three out of 27 REDD+ partner countries mentioned bamboo as a forest resource, indicating a lack of inclusion in socio-economic applications (Kuehl, Kuehl and Castillo, 2018: 51). It may not be entirely disregarded as a resource but instead lumped together with trees (ibid.); but due to being different from trees, bamboos require different forestry practices. To utilise bamboos under REDD+ or the Paris Agreement for the purpose of carbon sequestration, it remains a pre-condition that national forest definitions recognise bamboos as part of the forestry sector and at the same time uniquely define them (Kuehl, Kuehl and Castillo, 2018: 51, 53). A previous misclassification and general neglect due to not resembling a tree caused the missing awareness and inclusion of bamboos in the forestry sector (Buckingham et al, 2011; Buckingham et al., 2014).

In further consequence, this lack of awareness hampers the application of bamboos as a tropical and sustainable timber alternative. For example, Abbas and Manabo (2017) pinpointed to the missing specification of bamboo usage in the Nigerian national agroforestry policies, and the country would lose out on "huge economic and environmental benefits" (ibid.: 46). This example is contrasted by the 2019 Kenyan National Bamboo Policy which, as the title suggested, promotes the specific use of bamboo, including species specification and applicability, for economic purposes (see Ministry of Environment and Forestry, 2019). In other words, national forest and forest-related policies must address bamboos specifically for cultivation, silviculture management and harvest repurposing, and at best outline sustainability safeguards. With differing national forest definitions and differing national forestry practices, it is currently unlikely that all countries would apply the same standards in bamboo cultivation.

In order to overcome unavailable, uncertain, if not contradictory, knowledge on bamboo species, it remains yet to increase research and combine existing knowledge to reduce systemic risks in the implementation of bamboo plantations which could potentially alter the climate. It begins with registering existing bamboo forests on a global scale. If similar issues from establishing bamboo plantations worldwide can be expected, an internationally uniform bamboo forestry framework would benefit dealing with environmental, social and economic consequences by serving as guidance for operations. A global regulatory frame may be needed to provide decision-making capacity on the global level, to create incentives and to inspire trust on the local level (Honegger, 2013: 49).

It has been criticised by developing countries that carbon storage on their territory would allow industrialized countries to continue emitting greenhouse gases domestically (Bäckstrand and Lövbrand, 2006: 59). While many industrialized countries welcome carbon sequestration in the South, such plantations do not further fundamental changes in consumption and production to reduce carbon dioxide emissions (ibid.: 65). In order for countries where bamboo cultivation is suitable to participate in such scenario, the plantations would have to create added values for the countries, and in particular economic ones.

Missing behaviour change would be reflected in outdated machinery, to which then not only developed but also developing countries count. Greenhouse gas emitting technologies from harvest to transportation are a concern for adding carbon dioxide emissions (and other pollutants) that were supposed to be curbed in the first place. Updating technologies as a means of behaviour change becomes an indispensable part of mitigating emissions, including in developing countries. At the same time, replacing such technologies will add cost and require additional time.

It remains to acknowledge that establishing bamboo plantations alone will not solve curbing carbon dioxide emissions. Bamboo plantations can be one solution in order to buy time and initiate behaviour and technology change for the reduction of emissions at the source.

8. Conclusion

Climate change and greenhouse gas reductions have been widely embedded in international policy frameworks, and mitigation actions and participation vary by region and country. Re- and afforestation is regarded as essential in sustainable development, preceding the Paris Agreement and other frameworks. Owed to the increased emphasis in the such frameworks, carbon sequestration via re-/afforestation as a means to intervene in the atmospheric carbon dioxide accumulation was and is debated regarding its environmental, social and economic impacts. Bamboo forest plantations can support forest restoration and prevent deforestation when using degraded land for fast-growing sustainable bamboo timber production, instead of tropical timber. By providing bamboo timber, they take the pressure of tropical forests. Bamboo plantations may support restoration goals "by using degraded and deforested land to restore critical ecosystem functions, while producing a sustainable source of fibre" (Rebelo and Buckingham, 2015: 92).

Bamboo forest plantations and their carbon stock can be monitored regarding their management and productivity to each country's own cost-effective solutions. Therewith, they are relevant in countries which struggle with stable socio-economic conditions and seek international development finance leading to economic opportunities. With wood serving as construction and manufacturing material worldwide, and also being a source of income for local communities in developing countries, bamboos may serve as an alternative to traditional timber sources all the while regrowing fast (Kuehl, Kuehl and Castillo, 2018: 47).

Bamboo forest plantations can be a response to the threat of climate change by conserving and enhancing natural carbon sinks and serving as sustainable reservoirs of carbon themselves. They also contribute to eradicating poverty, and consequently can serve as an economic strategy as encouraged under several political frameworks. With potential environmental, social and economic benefits, bamboo forest plantations can be made to fit into the essential components required under REDD+, concerning the sustainable management of forest, reduction of emissions from forest degradation and deforestation, conservation of forest carbon sinks, and monitoring carbon stock (Kuehl, Kuehl and Castillo, 2018). Addressing REDD+ subsequently feeds into addressing other development agendas, and in particular the Paris Agreement on climate as they have been built upon the REDD+ principles. But socio-economic conditions need safeguarding, too.

In order to make bamboos fit, a central condition is that bamboos require bamboo-specific and sustainability-crosscutting policy-making in order to find optimal utilization; especially with regards to bamboos' ability to be regularly extracted (Kuehl, Kuehl and Castillo, 2018). Setting politically-steered environmental safeguards against the potential invasiveness and biodiversity alterations, water and soil benefits and detriments, as well as restrictions to degraded landscapes for ecological protection appear as the most needed considerations. Establishing bamboo plantations must also include local actors in managing the plantations to provide employment and skills training, and thus contribute to poverty alleviation. To local benefits relates that land access rights must be defined for the purpose of incentivising investments in bamboo plantations as well as ensuring economic benefits from ongoing and efficient management of the plantations.

Varying incentives must be developed to promote and replace traditional tropical timber with bamboo timber. These incentives need to be appropriate for the different stakeholders along the market value chain as changing to bamboo timber will require technological change, which is again accompanied with investment. The REDD+ mechanism of developed countries financing carbon offsets in developing countries (North-South relations) can bolster the initial investment costs at the national level to encourage industries and smallholders to adopt and manage bamboos as timber resource. The local distribution of the international finances is yet another issue.

All the concerns would have to be recognised and implemented universally, for which an international framework on bamboo management would seem logical. But since countries are reluctant to join internationally regulated forestry frameworks due to fearing economic losses (Dimitrov, 2005), an international bamboo silviculture framework may be difficult to realise. This can be countered with existing validation and certification schemes (e.g. FSC, FLEGT), which have included - although not been adequately redefined for - bamboos in their sustainability verification schemes. Inadequate certification standards appear to be an impediment in the harvest of bamboos, because bamboos are often set equal to trees or not distinguishingly mentioned in national forest protection regulations. Overcoming the certification and regulation obstacles by private actors may incur high cost as well as the risk of not being allowed to harvest the bamboos. Provided that certification regulations are amended, countries would be able to operate under common guidelines with equal access to knowledge to implement safeguards at their best knowledge, but also retain their autonomy in decision-making and means of implementation.

The many encountered issues highlight the need for intensified research to fill critical knowledge gaps first, which then would grant adequate classifications and definitions as required for adequate bamboo policy-making (Kuehl, Kuehl and Castillo, 2018). If more conclusive research was conducted, political decision-making can be based on better knowledge, which is inconsistent on bamboos. This would especially account for collecting carbon sequestration data from bamboos for the monitoring and evaluation as required by REDD+ projects (ibid.). International exchanges have been encouraged with countries which have the experience in managing bamboos in order to increase awareness across private and public actors and develop a common knowledge base.

There is a limit to the amount of carbon dioxide bamboos or any plant can sequester in a given space, but the sequestration effect is not negligible. Also, carbon sequestration on a global scale must be accompanied by carbon emission reductions on a global scale. This also avoids understanding carbon offsets as a tool to grant any public or private actor an easy way out of carbon emission adaptation strategies as they are required by some international frameworks to mitigate climate change. Without accompanying emission reductions in form of behaviour and technology change, carbon sequestration would only alleviate the consequences but not remove the underlying cause; in the sense of a 'painkiller effect' that alleviates the pain but does not cure the cause of it. Reducing other greenhouse gases must not be neglected either.

It is out of the question to argue that bamboo forest plantations would suffice as one single approach to climate change mitigation, just like there is not one single source of carbon dioxide emissions. Criticising that trees cannot save the climate because we cannot plant enough, and discarding the idea altogether, is short-sighted. The debate of planting enough trees (or bamboos) to recapture all released carbon dioxide appears as the wrong logic from the start. The criticism against plantations for carbon sequestration should not be the space it consumes. A better logic is to estimate how much carbon can be sequestered in an available amount of space and to use that space as one supplementary method alongside other methods, and in particular emission reductions.

We could decide not to plant trees – or bamboos -, but it will not prevent from tropical forests being cut down nor prevent the suffering of current carbon stocks from greenhouse effects in the near future. At the very least, bamboos as carbon sinks can be a political tool to bring industries closer to taking initial measures to tackle their emissions with socio-economic value-added approaches and possible environmental benefits while buying valuable time for technological adaptation strategies. Planting bamboo on a large scale would resemble a sponge effect, soaking up carbon dioxide fast and perhaps mitigate the greenhouse effect to some extent.

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10. Annex

Table 16: Estimated carbon sequestration rates by allocated space (initial five-years growth)

Region	Countries	Country size (km^2)	Size allocated for bamboo plantation (km^2)				Minimum estimated BOC per allocated space (GtC)				Maximum estimated BOC per allocated space (GtC)			
			1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
Asia and the Pacific	Australia	769,200	7,692	15,384	38,460	53,844	0.044	0.087	0.218	0.305	0.137	0.275	0.687	0.962
	Bangladesh	130,170	1,302	2,603	6,509	9,112	0.007	0.015	0.037	0.052	0.023	0.047	0.116	0.163
	Bhutan	38,394	384	768	1,920	2,688	0.002	0.004	0.011	0.015	0.007	0.014	0.034	0.048
	Brunei Darussalam	5,765	58	115	288	404	0.000	0.001	0.002	0.002	0.001	0.002	0.005	0.007
	Cambodia	176,520	1,765	3,530	8,826	12,356	0.010	0.020	0.050	0.070	0.032	0.063	0.158	0.221
	China	3,098,109	30,981	61,962	154,905	216,868	0.175	0.350	0.876	1.227	0.553	1.107	2.767	3.874
	India	2,973,190	29,732	59,464	148,660	208,123	0.168	0.336	0.841	1.177	0.531	1.062	2.656	3.718
	Indonesia	1,811,570	18,116	36,231	90,579	126,810	0.102	0.205	0.512	0.717	0.324	0.647	1.618	2.265
	Japan	364,560	3,646	7,291	18,228	25,519	0.021	0.041	0.103	0.144	0.065	0.130	0.326	0.456
	Lao People's Democratic Republic	230,800	2,308	4,616	11,540	16,156	0.013	0.026	0.065	0.091	0.041	0.082	0.206	0.289
	Malaysia	328,550	3,286	6,571	16,428	22,999	0.019	0.037	0.093	0.130	0.059	0.117	0.293	0.411
	Myanmar	653,080	6,531	13,062	32,654	45,716	0.037	0.074	0.185	0.259	0.117	0.233	0.583	0.817
	Nepal	147,516	1,475	2,950	7,376	10,326	0.008	0.017	0.042	0.058	0.026	0.053	0.132	0.184
	Pakistan	770,880	7,709	15,418	38,544	53,962	0.044	0.087	0.218	0.305	0.138	0.275	0.689	0.964
	Papua New Guinea	452,860	4,529	9,057	22,643	31,700	0.026	0.051	0.128	0.179	0.081	0.162	0.404	0.566
	Philippines	298,170	2,982	5,963	14,909	20,872	0.017	0.034	0.084	0.118	0.053	0.107	0.266	0.373
	Sri Lanka	62,710	627	1,254	3,136	4,390	0.004	0.007	0.018	0.025	0.011	0.022	0.056	0.078
	Thailand	510,890	5,109	10,218	25,545	35,762	0.029	0.058	0.144	0.202	0.091	0.183	0.456	0.639
	Viet Nam	310,070	3,101	6,201	15,504	21,705	0.018	0.035	0.088	0.123	0.055	0.111	0.277	0.388
Africa	Angola	1,247,000	12,470	24,940	62,350	87,290	0.071	0.141	0.353	0.494	0.223	0.446	1.114	1.559
	Benin	114,763	1,148	2,295	5,738	8,033	0.006	0.013	0.032	0.045	0.021	0.041	0.103	0.144
	Burundi	27,834	278	557	1,392	1,948	0.002	0.003	0.008	0.011	0.005	0.010	0.025	0.035
	Cameroon	475,442	4,754	9,509	23,772	33,281	0.027	0.054	0.134	0.188	0.085	0.170	0.425	0.595
	Central African Republic	622,984	6,230	12,460	31,149	43,609	0.035	0.070	0.176	0.247	0.111	0.223	0.556	0.779
	Côte d'Ivoire	322,463	3,225	6,449	16,123	22,572	0.018	0.036	0.091	0.128	0.058	0.115	0.288	0.403
	Democratic Republic of the Congo	2,345,000	23,450	46,900	117,250	164,150	0.133	0.265	0.663	0.929	0.419	0.838	2.095	2.932
	Equatorial Guinea	28,050	281	561	1,403	1,964	0.002	0.003	0.008	0.011	0.005	0.010	0.025	0.035
	Eswatini	17,364	174	347	868	1,215	0.001	0.002	0.005	0.007	0.003	0.006	0.016	0.022
	Ethiopia	1,000,000	10,000	20,000	50,000	70,000	0.057	0.113	0.283	0.396	0.179	0.357	0.893	1.250
	Gabon	267,667	2,677	5,353	13,383	18,737	0.015	0.030	0.076	0.106	0.048	0.096	0.239	0.335
	Ghana	238,535	2,385	4,771	11,927	16,697	0.013	0.027	0.067	0.094	0.043	0.085	0.213	0.298
	Guinea-Bissau	36,125	361	723	1,806	2,529	0.002	0.004	0.010	0.014	0.006	0.013	0.032	0.045
	Kenya	569,140	5,691	11,383	28,457	39,840	0.032	0.064	0.161	0.225	0.102	0.203	0.508	0.712
	Liberia	111,369	1,114	2,227	5,568	7,796	0.006	0.013	0.031	0.044	0.020	0.040	0.099	0.139
	Madagascar	587,041	5,870	11,741	29,352	41,093	0.033	0.066	0.166	0.232	0.105	0.210	0.524	0.734
	Malawi	118,484	1,185	2,370	5,924	8,294	0.007	0.013	0.034	0.047	0.021	0.042	0.106	0.148
	Mozambique	801,590	8,016	16,032	40,080	56,111	0.045	0.091	0.227	0.317	0.143	0.286	0.716	1.002
	Nigeria	910,770	9,108	18,215	45,539	63,754	0.052	0.103	0.258	0.361	0.163	0.325	0.813	1.139
	Republic of the Congo	342,000	3,420	6,840	17,100	23,940	0.019	0.039	0.097	0.135	0.061	0.122	0.305	0.428

Region	Countries	Country size (km²)	Size allocated for bamboo plantation (km²)				Minimum estimated BOC per allocated space (GtC)				Maximum estimated BOC per allocated space (GtC)			
			1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
	Rwanda	26,338	263	527	1,317	1,844	0.001	0.003	0.007	0.010	0.005	0.009	0.024	0.033
	Sierra Leone	71,740	717	1,435	3,587	5,022	0.004	0.008	0.020	0.028	0.013	0.026	0.064	0.090
	South Africa	1,220,000	12,200	24,400	61,000	85,400	0.069	0.138	0.345	0.483	0.218	0.436	1.090	1.526
	South Sudan	619,745	6,197	12,395	30,987	43,382	0.035	0.070	0.175	0.245	0.111	0.221	0.554	0.775
	Togo	56,785	568	1,136	2,839	3,975	0.003	0.006	0.016	0.022	0.010	0.020	0.051	0.071
	Uganda	200,520	2,005	4,010	10,026	14,036	0.011	0.023	0.057	0.079	0.036	0.072	0.179	0.251
	United Republic of Tanzania	885,800	8,858	17,716	44,290	62,006	0.050	0.100	0.251	0.351	0.158	0.316	0.791	1.108
	Zambia	752,618	7,526	15,052	37,631	52,683	0.043	0.085	0.213	0.298	0.134	0.269	0.672	0.941
	Zimbabwe	390,757	3,908	7,815	19,538	27,353	0.022	0.044	0.111	0.155	0.070	0.140	0.349	0.489
South and Central America	Argentina	1,390,000	13,900	27,800	69,500	97,300	0.079	0.157	0.393	0.550	0.248	0.497	1.242	1.738
	Belize	22,965	230	459	1,148	1,608	0.001	0.003	0.006	0.009	0.004	0.008	0.021	0.029
	Bolivia	1,098,581	10,986	21,972	54,929	76,901	0.062	0.124	0.311	0.435	0.196	0.393	0.981	1.374
	Brazil	8,358,140	83,581	167,163	417,907	585,070	0.473	0.946	2.364	3.309	1.493	2.986	7.465	10.452
	Colombia	1,143,000	11,430	22,860	57,150	80,010	0.065	0.129	0.323	0.453	0.204	0.408	1.021	1.429
	Costa Rica	51,100	511	1,022	2,555	3,577	0.003	0.006	0.014	0.020	0.009	0.018	0.046	0.064
	Cuba	109,884	1,099	2,198	5,494	7,692	0.006	0.012	0.031	0.044	0.020	0.039	0.098	0.137
	Dominican Republic	48,442	484	969	2,422	3,391	0.003	0.005	0.014	0.019	0.009	0.017	0.043	0.061
	Ecuador	248,360	2,484	4,967	12,418	17,385	0.014	0.028	0.070	0.098	0.044	0.089	0.222	0.311
	El Salvador	21,041	210	421	1,052	1,473	0.001	0.002	0.006	0.008	0.004	0.008	0.019	0.026
	French Guiana	83,534	835	1,671	4,177	5,847	0.005	0.009	0.024	0.033	0.015	0.030	0.075	0.104
	Guatemala	108,889	1,089	2,178	5,444	7,622	0.006	0.012	0.031	0.043	0.019	0.039	0.097	0.136
	Guyana	214,969	2,150	4,299	10,748	15,048	0.012	0.024	0.061	0.085	0.038	0.077	0.192	0.269
	Haiti	27,750	278	555	1,388	1,943	0.002	0.003	0.008	0.011	0.005	0.010	0.025	0.035
	Honduras	112,492	1,125	2,250	5,625	7,874	0.006	0.013	0.032	0.045	0.020	0.040	0.100	0.141
	Mexico	1,973,000	19,730	39,460	98,650	138,110	0.112	0.223	0.558	0.781	0.352	0.705	1.762	2.467
	Nicaragua	130,373	1,304	2,607	6,519	9,126	0.007	0.015	0.037	0.052	0.023	0.047	0.116	0.163
	Panama	75,517	755	1,510	3,776	5,286	0.004	0.009	0.021	0.030	0.013	0.027	0.067	0.094
	Paraguay	406,752	4,068	8,135	20,338	28,473	0.023	0.046	0.115	0.161	0.073	0.145	0.363	0.509
	Peru	1,280,000	12,800	25,600	64,000	89,600	0.072	0.145	0.362	0.507	0.229	0.457	1.143	1.601
	Puerto Rico	13,800	138	276	690	966	0.001	0.002	0.004	0.005	0.002	0.005	0.012	0.017
	Suriname	163,821	1,638	3,276	8,191	11,467	0.009	0.019	0.046	0.065	0.029	0.059	0.146	0.205
	Trinidad and Tobago	5,131	51	103	257	359	0.000	0.001	0.001	0.002	0.001	0.002	0.005	0.006
	Uruguay	176,215	1,762	3,524	8,811	12,335	0.010	0.020	0.050	0.070	0.031	0.063	0.157	0.220
	Venezuela (Bolivarian Rep. of)	916,445	9,164	18,329	45,822	64,151	0.052	0.104	0.259	0.363	0.164	0.327	0.819	1.146
North America	United States of America	2,458,500	24,585	49,170	122,925	172,095	0.139	0.278	0.695	0.973	0.439	0.878	2.196	3.074
Total		48,179,629	481,796	963,593	2,408,981	3,372,574	2.725	5.451	13.626	19.077	8.607	17.214	43.034	60.248

Note: The aforementioned country size reductions have been applied to Argentina with 50%, Australia with 10%, China with 33% and USA with 25% to account for potentially less or non-favourable geographically determined climate conditions.

Table 17: Country-wise estimated carbon sequestration rates by allocated space (2030, 2050, 2070)

Region	Countries	Minimum estimated BOC per allocated space (by 2030) (GtC)				Maximum estimated BOC per allocated space (by 2030) (GtC)				Minimum estimated BOC per allocated space (by 2050) (GtC)				Maximum estimated BOC per allocated space (by 2050) (GtC)				Minimum estimated BOC per allocated space (by 2070) (GtC)				Maximum estimated BOC per allocated space (by 2070) (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
Asia and the Pacific	Australia	0.086	0.171	0.428	0.599	0.270	0.541	1.351	1.892	0.254	0.508	1.269	1.777	0.802	1.604	4.009	5.613	0.422	0.844	2.111	2.955	1.333	2.667	6.666	9.333
	Bangladesh	0.014	0.029	0.072	0.101	0.046	0.091	0.229	0.320	0.043	0.086	0.215	0.301	0.136	0.271	0.678	0.950	0.071	0.143	0.357	0.500	0.226	0.451	1.128	1.579
	Bhutan	0.004	0.009	0.021	0.030	0.013	0.027	0.067	0.094	0.013	0.025	0.063	0.089	0.040	0.080	0.200	0.280	0.021	0.042	0.105	0.148	0.067	0.133	0.333	0.466
	Brunei Darussalam	0.001	0.001	0.003	0.004	0.002	0.004	0.010	0.014	0.002	0.004	0.010	0.013	0.006	0.012	0.030	0.042	0.003	0.006	0.016	0.022	0.010	0.020	0.050	0.070
	Cambodia	0.020	0.039	0.098	0.137	0.062	0.124	0.310	0.434	0.058	0.117	0.291	0.408	0.184	0.368	0.920	1.288	0.097	0.194	0.484	0.678	0.306	0.612	1.530	2.142
	China	0.345	0.689	1.724	2.413	1.089	2.177	5.443	7.620	1.023	2.045	5.113	7.158	3.229	6.459	16.147	22.605	1.700	3.401	8.502	11.903	5.370	10.740	26.850	37.591
	India	0.331	0.662	1.654	2.316	1.045	2.089	5.224	7.313	0.981	1.963	4.907	6.869	3.099	6.198	15.496	21.694	1.632	3.264	8.159	11.423	5.154	10.307	25.768	36.075
	Indonesia	0.202	0.403	1.008	1.411	0.637	1.273	3.183	4.456	0.598	1.196	2.990	4.185	1.888	3.777	9.442	13.218	0.994	1.989	4.971	6.960	3.140	6.280	15.700	21.980
	Japan	0.041	0.081	0.203	0.284	0.128	0.256	0.641	0.897	0.120	0.241	0.602	0.842	0.380	0.760	1.900	2.660	0.200	0.400	1.000	1.401	0.632	1.264	3.160	4.423
	Lao PDR	0.026	0.051	0.128	0.180	0.081	0.162	0.405	0.568	0.076	0.152	0.381	0.533	0.241	0.481	1.203	1.684	0.127	0.253	0.633	0.887	0.400	0.800	2.000	2.800
	Malaysia	0.037	0.073	0.183	0.256	0.115	0.231	0.577	0.808	0.108	0.217	0.542	0.759	0.342	0.685	1.712	2.397	0.180	0.361	0.902	1.262	0.569	1.139	2.847	3.986
	Myanmar	0.073	0.145	0.363	0.509	0.229	0.459	1.147	1.606	0.216	0.431	1.078	1.509	0.681	1.361	3.404	4.765	0.358	0.717	1.792	2.509	1.132	2.264	5.660	7.924
	Nepal	0.016	0.033	0.082	0.115	0.052	0.104	0.259	0.363	0.049	0.097	0.243	0.341	0.154	0.308	0.769	1.076	0.081	0.162	0.405	0.567	0.256	0.511	1.278	1.790
	Pakistan	0.086	0.172	0.429	0.600	0.271	0.542	1.354	1.896	0.254	0.509	1.272	1.781	0.804	1.607	4.018	5.625	0.423	0.846	2.115	2.962	1.336	2.672	6.681	9.353
	Papua New Guinea	0.050	0.101	0.252	0.353	0.159	0.318	0.796	1.114	0.149	0.299	0.747	1.046	0.472	0.944	2.360	3.304	0.249	0.497	1.243	1.740	0.785	1.570	3.925	5.495
	Philippines	0.033	0.066	0.166	0.232	0.105	0.210	0.524	0.733	0.098	0.197	0.492	0.689	0.311	0.622	1.554	2.176	0.164	0.327	0.818	1.146	0.517	1.034	2.584	3.618
	Sri Lanka	0.007	0.014	0.035	0.049	0.022	0.044	0.110	0.154	0.021	0.041	0.103	0.145	0.065	0.131	0.327	0.458	0.034	0.069	0.172	0.241	0.109	0.217	0.543	0.761
	Thailand	0.057	0.114	0.284	0.398	0.180	0.359	0.898	1.257	0.169	0.337	0.843	1.180	0.533	1.065	2.663	3.728	0.280	0.561	1.402	1.963	0.886	1.771	4.428	6.199
	Viet Nam	0.034	0.069	0.172	0.241	0.109	0.218	0.545	0.763	0.102	0.205	0.512	0.716	0.323	0.646	1.616	2.262	0.170	0.340	0.851	1.191	0.537	1.075	2.687	3.762
Africa	Angola	0.139	0.277	0.694	0.971	0.438	0.876	2.191	3.067	0.412	0.823	2.058	2.881	1.300	2.600	6.499	9.099	0.684	1.369	3.422	4.791	2.161	4.323	10.807	15.130
	Benin	0.013	0.026	0.064	0.089	0.040	0.081	0.202	0.282	0.038	0.076	0.189	0.265	0.120	0.239	0.598	0.837	0.063	0.126	0.315	0.441	0.199	0.398	0.995	1.392
	Burundi	0.003	0.006	0.015	0.022	0.010	0.020	0.049	0.068	0.009	0.018	0.046	0.064	0.029	0.058	0.145	0.203	0.015	0.031	0.076	0.107	0.048	0.096	0.241	0.338
	Cameroon	0.053	0.106	0.264	0.370	0.167	0.334	0.835	1.169	0.157	0.314	0.785	1.098	0.496	0.991	2.478	3.469	0.261	0.522	1.305	1.827	0.824	1.648	4.121	5.769
	Central African Republic	0.069	0.139	0.347	0.485	0.219	0.438	1.095	1.532	0.206	0.411	1.028	1.439	0.649	1.299	3.247	4.546	0.342	0.684	1.710	2.393	1.080	2.160	5.399	7.559
	Côte d'Ivoire	0.036	0.072	0.179	0.251	0.113	0.227	0.567	0.793	0.106	0.213	0.532	0.745	0.336	0.672	1.681	2.353	0.177	0.354	0.885	1.239	0.559	1.118	2.795	3.913
	Democratic Republic of the Congo	0.261	0.522	1.305	1.826	0.824	1.648	4.120	5.768	0.774	1.548	3.870	5.418	2.444	4.889	12.222	17.110	1.287	2.574	6.435	9.009	4.065	8.129	20.323	28.453
	Equatorial Guinea	0.003	0.006	0.016	0.022	0.010	0.020	0.049	0.069	0.009	0.019	0.046	0.065	0.029	0.058	0.146	0.205	0.015	0.031	0.077	0.108	0.049	0.097	0.243	0.340
	Eswatini	0.002	0.004	0.010	0.014	0.006	0.012	0.031	0.043	0.006	0.011	0.029	0.040	0.018	0.036	0.090	0.127	0.010	0.019	0.048	0.067	0.030	0.060	0.150	0.211

Region	Countries	Minimum estimated BOC per allocated space (by 2030) (GtC)				Maximum estimated BOC per allocated space (by 2030) (GtC)				Minimum estimated BOC per allocated space (by 2050) (GtC)				Maximum estimated BOC per allocated space (by 2050) (GtC)				Minimum estimated BOC per allocated space (by 2070) (GtC)				Maximum estimated BOC per allocated space (by 2070) (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
	Ethiopia	0.111	0.223	0.556	0.779	0.351	0.703	1.757	2.460	0.330	0.660	1.650	2.310	1.042	2.085	5.212	7.297	0.549	1.098	2.744	3.842	1.733	3.467	8.667	12.133
	Gabon	0.030	0.060	0.149	0.208	0.094	0.188	0.470	0.658	0.088	0.177	0.442	0.618	0.279	0.558	1.395	1.953	0.147	0.294	0.735	1.028	0.464	0.928	2.320	3.248
	Ghana	0.027	0.053	0.133	0.186	0.084	0.168	0.419	0.587	0.079	0.157	0.394	0.551	0.249	0.497	1.243	1.740	0.131	0.262	0.655	0.916	0.413	0.827	2.067	2.894
	Guinea-Bissau	0.004	0.008	0.020	0.028	0.013	0.025	0.063	0.089	0.012	0.024	0.060	0.083	0.038	0.075	0.188	0.264	0.020	0.040	0.099	0.139	0.063	0.125	0.313	0.438
	Kenya	0.063	0.127	0.317	0.443	0.200	0.400	1.000	1.400	0.188	0.376	0.939	1.315	0.593	1.187	2.966	4.153	0.312	0.625	1.562	2.187	0.987	1.973	4.933	6.906
	Liberia	0.012	0.025	0.062	0.087	0.039	0.078	0.196	0.274	0.037	0.074	0.184	0.257	0.116	0.232	0.580	0.813	0.061	0.122	0.306	0.428	0.193	0.386	0.965	1.351
	Madagascar	0.065	0.131	0.327	0.457	0.206	0.413	1.031	1.444	0.194	0.388	0.969	1.356	0.612	1.224	3.060	4.283	0.322	0.644	1.611	2.255	1.018	2.035	5.088	7.123
	Malawi	0.013	0.026	0.066	0.092	0.042	0.083	0.208	0.291	0.039	0.078	0.196	0.274	0.124	0.247	0.618	0.865	0.065	0.130	0.325	0.455	0.205	0.411	1.027	1.438
	Mozambique	0.089	0.178	0.446	0.624	0.282	0.563	1.408	1.972	0.265	0.529	1.323	1.852	0.836	1.671	4.178	5.849	0.440	0.880	2.200	3.080	1.389	2.779	6.947	9.726
	Nigeria	0.101	0.203	0.507	0.709	0.320	0.640	1.600	2.240	0.301	0.601	1.503	2.104	0.949	1.899	4.747	6.645	0.500	1.000	2.499	3.499	1.579	3.157	7.893	11.051
	Republic of the Congo	0.038	0.076	0.190	0.266	0.120	0.240	0.601	0.841	0.113	0.226	0.564	0.790	0.356	0.713	1.782	2.495	0.188	0.375	0.939	1.314	0.593	1.186	2.964	4.150
	Rwanda	0.003	0.006	0.015	0.021	0.009	0.019	0.046	0.065	0.009	0.017	0.043	0.061	0.027	0.055	0.137	0.192	0.014	0.029	0.072	0.101	0.046	0.091	0.228	0.320
	Sierra Leone	0.008	0.016	0.040	0.056	0.025	0.050	0.126	0.176	0.024	0.047	0.118	0.166	0.075	0.150	0.374	0.523	0.039	0.079	0.197	0.276	0.124	0.249	0.622	0.870
	South Africa	0.136	0.271	0.679	0.950	0.429	0.857	2.143	3.001	0.403	0.805	2.013	2.819	1.272	2.543	6.358	8.902	0.670	1.339	3.348	4.687	2.115	4.229	10.573	14.803
	South Sudan	0.069	0.138	0.345	0.483	0.218	0.436	1.089	1.524	0.205	0.409	1.023	1.432	0.646	1.292	3.230	4.522	0.340	0.680	1.701	2.381	1.074	2.148	5.371	7.520
	Togo	0.006	0.013	0.032	0.044	0.020	0.040	0.100	0.140	0.019	0.037	0.094	0.131	0.059	0.118	0.296	0.414	0.031	0.062	0.156	0.218	0.098	0.197	0.492	0.689
	Uganda	0.022	0.045	0.112	0.156	0.070	0.141	0.352	0.493	0.066	0.132	0.331	0.463	0.209	0.418	1.045	1.463	0.110	0.220	0.550	0.770	0.348	0.695	1.738	2.433
	United Republic of Tanzania	0.099	0.197	0.493	0.690	0.311	0.623	1.556	2.179	0.292	0.585	1.462	2.047	0.923	1.847	4.617	6.463	0.486	0.972	2.431	3.403	1.535	3.071	7.677	10.748
	Zambia	0.084	0.167	0.419	0.586	0.264	0.529	1.322	1.851	0.248	0.497	1.242	1.739	0.785	1.569	3.923	5.492	0.413	0.826	2.065	2.892	1.305	2.609	6.523	9.132
	Zimbabwe	0.043	0.087	0.217	0.304	0.137	0.275	0.687	0.961	0.129	0.258	0.645	0.903	0.407	0.815	2.037	2.851	0.214	0.429	1.072	1.501	0.677	1.355	3.387	4.741
South and Central America	Argentina	0.155	0.309	0.773	1.083	0.488	0.977	2.442	3.419	0.459	0.918	2.294	3.211	1.449	2.898	7.244	10.142	0.763	1.526	3.815	5.340	2.409	4.819	12.047	16.865
	Belize	0.003	0.005	0.013	0.018	0.008	0.016	0.040	0.056	0.008	0.015	0.038	0.053	0.024	0.048	0.120	0.168	0.013	0.025	0.063	0.088	0.040	0.080	0.199	0.279
	Bolivia	0.122	0.244	0.611	0.856	0.386	0.772	1.930	2.702	0.363	0.725	1.813	2.538	1.145	2.290	5.726	8.016	0.603	1.206	3.015	4.221	1.904	3.808	9.521	13.330
	Brazil	0.930	1.860	4.650	6.510	2.937	5.874	14.685	20.558	2.759	5.517	13.793	19.311	8.712	17.424	43.561	60.986	4.587	9.175	22.937	32.112	14.488	28.975	72.438	101.413
	Colombia	0.127	0.254	0.636	0.890	0.402	0.803	2.008	2.811	0.377	0.755	1.886	2.641	1.191	2.383	5.957	8.340	0.627	1.255	3.137	4.391	1.981	3.962	9.906	13.868
	Costa Rica	0.006	0.011	0.028	0.040	0.018	0.036	0.090	0.126	0.017	0.034	0.084	0.118	0.053	0.107	0.266	0.373	0.028	0.056	0.140	0.196	0.089	0.177	0.443	0.620
	Cuba	0.012	0.024	0.061	0.086	0.039	0.077	0.193	0.270	0.036	0.073	0.181	0.254	0.115	0.229	0.573	0.802	0.060	0.121	0.302	0.422	0.190	0.381	0.952	1.333
	Dominican Republic	0.005	0.011	0.027	0.038	0.017	0.034	0.085	0.119	0.016	0.032	0.080	0.112	0.050	0.101	0.252	0.353	0.027	0.053	0.133	0.186	0.084	0.168	0.420	0.588
	Ecuador	0.028	0.055	0.138	0.193	0.087	0.175	0.436	0.611	0.082	0.164	0.410	0.574	0.259	0.518	1.294	1.812	0.136	0.273	0.682	0.954	0.430	0.861	2.152	3.013
	El Salvador	0.002	0.005	0.012	0.016	0.007	0.015	0.037	0.052	0.007	0.014	0.035	0.049	0.022	0.044	0.110	0.154	0.012	0.023	0.058	0.081	0.036	0.073	0.182	0.255
	French Guiana	0.009	0.019	0.046	0.065	0.029	0.059	0.147	0.205	0.028	0.055	0.138	0.193	0.087	0.174	0.435	0.610	0.046	0.092	0.229	0.321	0.145	0.290	0.724	1.014
	Guatemala	0.012	0.024	0.061	0.085	0.038	0.077	0.191	0.268	0.036	0.072	0.180	0.252	0.114	0.227	0.568	0.795	0.060	0.120	0.299	0.418	0.189	0.377	0.944	1.321

Region	Countries	Minimum estimated BOC per allocated space (by 2030) (GtC)				Maximum estimated BOC per allocated space (by 2030) (GtC)				Minimum estimated BOC per allocated space (by 2050) (GtC)				Maximum estimated BOC per allocated space (by 2050) (GtC)				Minimum estimated BOC per allocated space (by 2070) (GtC)				Maximum estimated BOC per allocated space (by 2070) (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%	1%	2%	5%	7%
	Guyana	0.024	0.048	0.120	0.167	0.076	0.151	0.378	0.529	0.071	0.142	0.355	0.497	0.224	0.448	1.120	1.569	0.118	0.236	0.590	0.826	0.373	0.745	1.863	2.608
	Haiti	0.003	0.006	0.015	0.022	0.010	0.020	0.049	0.068	0.009	0.018	0.046	0.064	0.029	0.058	0.145	0.202	0.015	0.030	0.076	0.107	0.048	0.096	0.241	0.337
	Honduras	0.013	0.025	0.063	0.088	0.040	0.079	0.198	0.277	0.037	0.074	0.186	0.260	0.117	0.235	0.586	0.821	0.062	0.123	0.309	0.432	0.195	0.390	0.975	1.365
	Mexico	0.220	0.439	1.098	1.537	0.693	1.387	3.466	4.853	0.651	1.302	3.256	4.558	2.057	4.113	10.283	14.396	1.083	2.166	5.414	7.580	3.420	6.840	17.099	23.939
	Nicaragua	0.015	0.029	0.073	0.102	0.046	0.092	0.229	0.321	0.043	0.086	0.215	0.301	0.136	0.272	0.679	0.951	0.072	0.143	0.358	0.501	0.226	0.452	1.130	1.582
	Panama	0.008	0.017	0.042	0.059	0.027	0.053	0.133	0.186	0.025	0.050	0.125	0.174	0.079	0.157	0.394	0.551	0.041	0.083	0.207	0.290	0.131	0.262	0.654	0.916
	Paraguay	0.045	0.091	0.226	0.317	0.143	0.286	0.715	1.000	0.134	0.269	0.671	0.940	0.424	0.848	2.120	2.968	0.223	0.446	1.116	1.563	0.705	1.410	3.525	4.935
	Peru	0.142	0.285	0.712	0.997	0.450	0.900	2.249	3.148	0.422	0.845	2.112	2.957	1.334	2.668	6.671	9.340	0.703	1.405	3.513	4.918	2.219	4.437	11.093	15.531
	Puerto Rico	0.002	0.003	0.008	0.011	0.005	0.010	0.024	0.034	0.005	0.009	0.023	0.032	0.014	0.029	0.072	0.101	0.008	0.015	0.038	0.053	0.024	0.048	0.120	0.167
	Suriname	0.018	0.036	0.091	0.128	0.058	0.115	0.288	0.403	0.054	0.108	0.270	0.378	0.171	0.342	0.854	1.195	0.090	0.180	0.450	0.629	0.284	0.568	1.420	1.988
	Trinidad and Tobago	0.001	0.001	0.003	0.004	0.002	0.004	0.009	0.013	0.002	0.003	0.008	0.012	0.005	0.011	0.027	0.037	0.003	0.006	0.014	0.020	0.009	0.018	0.044	0.062
	Uruguay	0.020	0.039	0.098	0.137	0.062	0.124	0.310	0.433	0.058	0.116	0.291	0.407	0.184	0.367	0.918	1.286	0.097	0.193	0.484	0.677	0.305	0.611	1.527	2.138
	Venezuela (Bolivarian Rep. of)	0.102	0.204	0.510	0.714	0.322	0.644	1.610	2.254	0.302	0.605	1.512	2.117	0.955	1.911	4.776	6.687	0.503	1.006	2.515	3.521	1.589	3.177	7.943	11.120
North America	United States of America	0.274	0.547	1.368	1.915	0.864	1.728	4.319	6.047	0.811	1.623	4.057	5.680	2.563	5.125	12.813	17.939	1.349	2.699	6.747	9.445	4.261	8.523	21.307	29.830
Total		5.4	10.7	26.8	37.5	16.9	33.9	84.6	118.5	15.9	31.8	79.5	111.3	50.2	100.4	251.1	351.5	26.4	52.9	132.2	185.1	83.5	167.0	417.6	584.6

Note: The aforementioned country size reductions have been applied to Argentina with 50%, Australia with 10%, China with 33% and USA with 25% to account for potentially less or non-favourable geographically determined climate conditions.

Table 18: Country-wise allocation of 1/5th of the estimated carbon sequestration rates, less 3.3% yearly decay rate

Region	Countries	1/5th of minimum estimated BOC, less 3.3% yearly decay (GtC)				1/5th of maximum estimated BOC, less 3.3% yearly decay (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%
Asia and the Pacific	Australia	0.008	0.017	0.042	0.059	0.027	0.053	0.133	0.186
	Bangladesh	0.001	0.003	0.007	0.010	0.004	0.009	0.022	0.031
	Bhutan	0.000	0.001	0.002	0.003	0.001	0.003	0.007	0.009
	Brunei Darussalam	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
	Cambodia	0.002	0.004	0.010	0.014	0.006	0.012	0.030	0.043
	China	0.034	0.068	0.169	0.237	0.107	0.214	0.535	0.749
	India	0.033	0.065	0.163	0.228	0.103	0.205	0.514	0.719
	Indonesia	0.020	0.040	0.099	0.139	0.063	0.125	0.313	0.438
	Japan	0.004	0.008	0.020	0.028	0.013	0.025	0.063	0.088
	Lao People's Democratic Republic	0.003	0.005	0.013	0.018	0.008	0.016	0.040	0.056
	Malaysia	0.004	0.007	0.018	0.025	0.011	0.023	0.057	0.079
	Myanmar	0.007	0.014	0.036	0.050	0.023	0.045	0.113	0.158
	Nepal	0.002	0.003	0.008	0.011	0.005	0.010	0.025	0.036
	Pakistan	0.008	0.017	0.042	0.059	0.027	0.053	0.133	0.186
	Papua New Guinea	0.005	0.010	0.025	0.035	0.016	0.031	0.078	0.110
	Philippines	0.003	0.007	0.016	0.023	0.010	0.021	0.052	0.072
	Sri Lanka	0.001	0.001	0.003	0.005	0.002	0.004	0.011	0.015
	Thailand	0.006	0.011	0.028	0.039	0.018	0.035	0.088	0.124
	Viet Nam	0.003	0.007	0.017	0.024	0.011	0.021	0.054	0.075
Africa	Angola	0.014	0.027	0.068	0.095	0.043	0.086	0.215	0.302
	Benin	0.001	0.003	0.006	0.009	0.004	0.008	0.020	0.028
	Burundi	0.000	0.001	0.002	0.002	0.001	0.002	0.005	0.007
	Cameroon	0.005	0.010	0.026	0.036	0.016	0.033	0.082	0.115
	Central African Republic	0.007	0.014	0.034	0.048	0.022	0.043	0.108	0.151
	Côte d'Ivoire	0.004	0.007	0.018	0.025	0.011	0.022	0.056	0.078
	Democratic Republic of the Congo	0.026	0.051	0.128	0.180	0.081	0.162	0.405	0.567
	Equatorial Guinea	0.000	0.001	0.002	0.002	0.001	0.002	0.005	0.007
	Eswatini	0.000	0.000	0.001	0.001	0.001	0.001	0.003	0.004
	Ethiopia	0.011	0.022	0.055	0.077	0.035	0.069	0.173	0.242
	Gabon	0.003	0.006	0.015	0.020	0.009	0.018	0.046	0.065
	Ghana	0.003	0.005	0.013	0.018	0.008	0.016	0.041	0.058
	Guinea-Bissau	0.000	0.001	0.002	0.003	0.001	0.002	0.006	0.009
	Kenya	0.006	0.012	0.031	0.044	0.020	0.039	0.098	0.138
	Liberia	0.001	0.002	0.006	0.009	0.004	0.008	0.019	0.027
	Madagascar	0.006	0.013	0.032	0.045	0.020	0.041	0.101	0.142
	Malawi	0.001	0.003	0.006	0.009	0.004	0.008	0.020	0.029
	Mozambique	0.009	0.018	0.044	0.061	0.028	0.055	0.138	0.194
	Nigeria	0.010	0.020	0.050	0.070	0.031	0.063	0.157	0.220
	Republic of the Congo	0.004	0.007	0.019	0.026	0.012	0.024	0.059	0.083
	Rwanda	0.000	0.001	0.001	0.002	0.001	0.002	0.005	0.006
	Sierra Leone	0.001	0.002	0.004	0.005	0.002	0.005	0.012	0.017
	South Africa	0.013	0.027	0.067	0.093	0.042	0.084	0.211	0.295
	South Sudan	0.007	0.014	0.034	0.047	0.021	0.043	0.107	0.150
	Togo	0.001	0.001	0.003	0.004	0.002	0.004	0.010	0.014
	Uganda	0.002	0.004	0.011	0.015	0.007	0.014	0.035	0.048
	United Republic of Tanzania	0.010	0.019	0.048	0.068	0.031	0.061	0.153	0.214
	Zambia	0.008	0.016	0.041	0.058	0.026	0.052	0.130	0.182
	Zimbabwe	0.004	0.009	0.021	0.030	0.014	0.027	0.068	0.095
South and Central America	Argentina	0.015	0.030	0.076	0.106	0.048	0.096	0.240	0.336
	Belize	0.000	0.001	0.001	0.002	0.001	0.002	0.004	0.006
	Bolivia	0.012	0.024	0.060	0.084	0.038	0.076	0.190	0.266
	Brazil	0.091	0.183	0.457	0.640	0.289	0.578	1.444	2.021
	Colombia	0.013	0.025	0.063	0.088	0.039	0.079	0.197	0.276
	Costa Rica	0.001	0.001	0.003	0.004	0.002	0.004	0.009	0.012

Region	Countries	1/5th of minimum estimated BOC, less 3.3% yearly decay (GtC)				1/5th of maximum estimated BOC, less 3.3% yearly decay (GtC)			
		1%	2%	5%	7%	1%	2%	5%	7%
	Cuba	0.001	0.002	0.006	0.008	0.004	0.008	0.019	0.027
	Dominican Republic	0.001	0.001	0.003	0.004	0.002	0.003	0.008	0.012
	Ecuador	0.003	0.005	0.014	0.019	0.009	0.017	0.043	0.060
	El Salvador	0.000	0.000	0.001	0.002	0.001	0.001	0.004	0.005
	French Guiana	0.001	0.002	0.005	0.006	0.003	0.006	0.014	0.020
	Guatemala	0.001	0.002	0.006	0.008	0.004	0.008	0.019	0.026
	Guyana	0.002	0.005	0.012	0.016	0.007	0.015	0.037	0.052
	Haiti	0.000	0.001	0.002	0.002	0.001	0.002	0.005	0.007
	Honduras	0.001	0.002	0.006	0.009	0.004	0.008	0.019	0.027
	Mexico	0.022	0.043	0.108	0.151	0.068	0.136	0.341	0.477
	Nicaragua	0.001	0.003	0.007	0.010	0.005	0.009	0.023	0.032
	Panama	0.001	0.002	0.004	0.006	0.003	0.005	0.013	0.018
	Paraguay	0.004	0.009	0.022	0.031	0.014	0.028	0.070	0.098
	Peru	0.014	0.028	0.070	0.098	0.044	0.088	0.221	0.310
	Puerto Rico	0.000	0.000	0.001	0.001	0.000	0.001	0.002	0.003
	Suriname	0.002	0.004	0.009	0.013	0.006	0.011	0.028	0.040
	Trinidad and Tobago	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
	Uruguay	0.002	0.004	0.010	0.013	0.006	0.012	0.030	0.043
	Venezuela (Bolivarian Rep. of)	0.010	0.020	0.050	0.070	0.032	0.063	0.158	0.222
North America	United States of America	0.027	0.054	0.134	0.188	0.085	0.170	0.425	0.595
Total		0.527	1.054	2.635	3.689	1.665	3.329	8.323	11.652

Note: The aforementioned country size reductions have been applied to Argentina with 50%, Australia with 10%, China with 33% and USA with 25% to account for potentially less or non-favourable geographically determined climate conditions.

11. Eidesstattliche Erklärung zur Eigenständigkeit

*Hiermit erkläre ich, dass ich die vorliegende Masterarbeit mit dem Thema **„Bamboo**’s Global Carbon **Sequestration Potential for Climate Change Mitigation“** ohne fremde Hilfe erstellt habe. Alle verwendeten Quellen wurden angegeben. Ich versichere, dass ich bisher keine Studien- oder Prüfungsarbeit mit gleichem oder ähnlichem Thema an der FernUniversität oder an einer anderen Hochschule eingereicht habe.*

Bangkok, 8. März 2021