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Forest carbon sequestration and China's potential: the rise of a nature-based solution for climate change mitigation

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ABSTRACT

A growing interest has recently been placed on the potential of nature-based solutions to help mitigate climate change, reflecting the importance of natural ecosystems as sources and sinks for greenhouse gases. Forests are of the hot debate – that sequester and also emit carbon dioxide (CO_2). In this paper, we estimate the forest carbon sequestration potential for China. We show that, as the government plans, by 2020, the size of China's forest carbon stock will reach 12.87 billion tons, among which 5.73 billion tons will be from afforestation and reforestation (A/R). From the up-to-date data on AR activities (by 2018), we find that only 80% of the target sinks have been met. Scenario analysis shows that the carbon sequestered by the forests in 2020 is equivalent to 13%-17% of the industrial CO_2 emission that year, with 6%-8% by A/R, 4%-6% by forest-management, 3%-4% by reduced-deforestation-and-forest-degradation, and 1% by wood-product-sink.

KEYWORDS

Forest; carbon dioxide; sequestration; sink; carbon dioxide emission reduction; nature-based solution

1. Introduction

The increase of greenhouse gases (GHGs) emissions can lead to global warming and climate change, will thus have serious consequences on the sustainability of the economy and society. The Intergovernmental Panel on Climate Change (IPCC)'s *Fourth Climate Change Assessment Report* in 2007 pointed out that the rise in the global average temperature over the past 50 years is related to the increase in GHGs emissions from combustion of fossil fuels (IPCC 2007). Mitigating and adapting to climate change can focus on solutions in reducing the sources of GHG emissions and increasing sinks for GHGs.[1] In the past 10 years, a growing interest has been placed on the potential of nature-based solutions (NbS) to help and protect human beings from climate change impacts while slowing further warming, supporting biodiversity and securing ecosystem services (Cohen-Shacham et al. 2016; Nature 2017). By definition, NbS involve working with and enhancing nature to help address societal challenges, reflecting the importance of natural ecosystems that provide services on which we depend on – ranging from storing carbon, controlling floods and stabilizing shorelines and slopes to clean air and water, food, fuel, medicines and genetic resources (Millennium Ecosystem Assessment 2005).

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Forests, in addition to the services as mentioned earlier, sequester carbon as trees grow and have potential to mitigate climate change because: trees absorb carbon dioxide (CO2) from the atmosphere, and wood substitutes for fossil fuels and carbon-intensive materials such as concrete and steel (Bellassen and Luyssaert 2014). The latest special report by the IPCC suggests that an increase of 950 million ha of the forest will be necessary to limit global warming to 1.5°C by 2050 (IPCC 2019). However, mature forests can become carbon sources if decomposing harvest residues and roots add to the CO2 emissions, as well as fires, infestations, droughts and storms occurring to forests (Bellassen and Luyssaert 2014). For these reasons, the potential of forests as a carbon sink, and how to best cultivate forest to store carbon and mitigate climate change is still a hot debate.

A recent widely cited study in *Science* identified nearly a billion ha of the Earth's surface as having the biophysical conditions, thus the great potential to increase tree cover (Bastin et al. 2019). Also, as reflected in the concept of NbS, models estimating the carbon sequestration potential of forests should not neglect forest management activities, and these activities – based upon the rules of the international climate agreement – must include afforestation and reforestation, forest-management techniques, reduction of deforestation and degradation, and the carbon in wood product sink (Cohen-Shacham et al. 2016; IPCC 2019). Putting together, as the IPCC report (2007) pointed out, forest has the outstanding advantage in mitigating global warming due to its low cost and being economically feasible in the next 30 to 50 years.

Forests can limit CO2 emissions in the following four group of activities. First, afforestation and reforestation increase tree cover, with more CO2 from the atmosphere and more carbon absorbed. Second, forest-management techniques that prioritize the increase of both the amount of wood produced (with increased vegetation volume) and the carbon stock retained in the forest increase the carbon density of the existing forests. Third, reduction in deforestation and forest degradation reduces the emission of CO2. The fourth is to develop wood products as a substitute for fossil fuels and reduce CO2 emissions from fossil-fuel burning (Canadell and Raupach 2008).

These activities, by far, have been promoted by, for example, the Clean Development Mechanism (CDM) of the Kyoto Protocol that approved the use of afforestation and reforestation (A/R) as CDM certified projects in the first commitment period. Namely, the methodology allows emission-reduction projects in developing countries to earn certified emission reduction credits to obtain carbon credits by developed countries, whose costs of reducing emission are greatly lowered. As deforestation and forest degradation in developing countries have contributed to one-fifth of global CO2 emissions, the issue (i.e., Reducing Emissions from Deforestation and Forest Degradation, REDD) in developing countries has become another hot spot for international climate negotiations. During the 2009 Copenhagen Climate Summit and the 2011 Durban Climate Conference, the REDD+, standing for 'reducing emissions from deforestation and forest degradation, conservation of existing forest carbon stocks, sustainable forest management and enhancement of forest carbon stocks', have made unique progress in widely recognizing the vital role of carbon sequestration of forests and the exertion of forests to play an important role in the post-Kyoto era.

In this background, this paper exploits a unique case, by estimating the forest carbon sequestration potential for China. China is an interesting case because of, firstly, her achievements in forest management that have endued her with an advantage in using forests as a carbon sink. And secondly, China at the UN Climate Change Summit in 2009 has made the commitment of an increase of forest reserves for forest carbon sinks by 40 million ha by 2020 (*cf.* 2005). Our exercise further extends to a comparison between the model-estimated amount of carbon sink and achieved carbon sink estimated from the actual increase of forests, using a period from 2010 to 2020. To the difference, if found, between the two, what implications will be elicited from the perspective of a nature-based solution?

As the world's largest CO2 emitter, China has been faced with increasing pressures from the international community to reduce GHGs emissions. In November 2009, the Chinese government announced its target of a reduction in CO2 emissions per unit of gross domestic product (GDP) by 40% to 45% by 2020 (*cf.* 2005). In accordance, during China's 'Twelfth Five-Year Plan' period (i.e., 2011–2015), the national CO2 emissions per 10,000 yuan of GDP aims to be down by 17% by 2015 than in 2010, and the energy consumption per 10,000 yuan of GDP decline by 16% than 2010 and by 32% than 2005 (State Council, 2012). In addition, China has currently the largest area of planted forests in the world and has shown unique advantages in forest management. The *Seventh National Forest Resources Inventory Investigation* (2004–2008) shows that China had a total forest area of 195.45 million ha, and its forest cover increased from 8.6% in early the 1950s to 20.4% in 2008. The global forest resources are on the decline, except the forests in the Asia-Pacific region, where China is a major driver of the increase (FAO 2015). The annual increase exceeds 3 million ha of forests, which offsets the high deforestation caused by harvests in other regions (Li, Yang, and He 2009).

The overall forest increase in China, has contributed to the protection of ecological environment and the mitigation of global warming. It is estimated that from 1980 to 2005, continuous afforestation and management activities has accumulatively absorbed CO2 of 4.68 billion tons, and the avoided deforestation reduced CO2 emissions of 430 million tons, and altogether 5.11 billion tons. Taking 2004, the net absorption of CO2 by China's forests is approximately 500 million tons, equivalent to 8% of industrial emissions in the year (NDRC 2007). China's total forest carbon stock has reached 7.811 billion tons, based on the assessment by the Chinese Academy of Forestry using the data from the Seventh Inventory Investigation and from the Positioned Forest Monitoring.

In the State Council's *National Climate Change Program* in 2007, China has prioritized forests in its strategic plans to sustainable growth including the economy, society and environment, using forest carbon sinks as a means of climate change mitigation and adaptation, and has made corresponding action plans and development goals. In November 2009, the *Forestry Action Plan for Climate Change*, issued by the State Forestry Administration and National Development and Reform Commission (NDRC), has put forward three phases of target and 22 main actions. The earlier-mentioned target – of 40 million ha increase of forest reserves for forest carbon sinks by 2020 – was announced by President Hu Jintao at the UN Climate Change Summit on 22 September 2009, committing to the increases of forest area by 40 million ha and of forest stock by 1.3 billion cubic meters, compared to those of 2005. Further, the *Twelfth Five-Year Plan's Work plan for Controlling Greenhouse Gas Emissions* sets a target to increase forest area by 12.5 million ha which will lead to a national forest cover of 21.66%, and to increase forest column by 600 million cubic meters (State Council, 2012).

However, what is missing from these plans and actions is on the uses of forests as the means to achieve carbon reduction goals. In other words, given that the policymakers acknowledged the role of forests in climate strategies, the role of forests as carbon sinks have not yet included, as a policy tool, in specific national emission reduction policies. In addition, converting its carbon intensity reduction target into the total amount of carbon emissions, one can find that the total emissions by China will not be reduced as expected. But, if we consider the amount of carbon sequestered by the increased forests, that offsets part of the rising amount of CO2 emissions, the actual amount of carbon emissions in 2020 will decrease compared to the level of 2005. Therefore, this estimation will be more convincing as China has been questioned for being the largest carbon emitter.

Therefore, forest carbon sinks, as a low-cost and multi-benefit means of emission reduction, if included into the policy instruments set for the reduction of GHGs emissions, will greatly reduce the emission mitigation costs. More attention should be paid to this role. What are the strategic implications of forest carbon sinks for China's climate change mitigation actions? And what roles has it played to meeting the 2020 CO2 emission reduction target? Answers to these questions will provide some guidelines for China to make effective and flexible policies in emissions reduction and climate change mitigation, and to prepare strategies for international negotiations.

2. A review on forest carbon sequestration estimates

A few studies focus on the capacity of the forests in China to store carbon and total carbon stock (see Table 1). Fang, Guo, and Piao (2007) found that from 1981 to 2000, the terrestrial carbon sequestration by vegetation – of which forests are the major component – offsets 14.6% to 16.1% of CO2 emitted by industry in China. Hou (2010) found that the country's increase of forests from afforestation and reforestation in the past two decades, absorbed a total amount of carbon of 1.089 billion ton. Of this amount, the biomass sink stored 818 million tons and soil captured 271 million tons. These findings are in strong support of the role of large-scale afforestation and reforestation in increasing forest cover and vegetation volume, which absorb CO2 and store carbon, and in turn, contributes to slowing global warming.

A number of studies have recognized the great potential of carbon sequestration of the forests in China (see, for example, Wei 2006; Wu et al. 2008; Li 2007; Li, Yang, and He 2009). In spite of the carbon sinks potential, there is a large room for the increase of forest cover and biomass through the scale-up of afforestation and reforestation activities in China (Wei 2006). Moreover, the supervision of deforestation, rationality in wood harvests and uses, substitution for steel and concreate (and etc.), and techniques to extend wood service life should be prioritized such that the overall carbon sequestration capacity of the forests can be strengthened. Xu et al. (2010) showed that China has currently overall young forests, the majority of which are plantation forests and increasing, so the carbon sink intensity is low on average at present but has a potential.

However, there are some concerns over the current studies that have estimations on the carbon sink potential of the forests in China, e.g., Li (2006), Gu, Zhang, and Zhang (2008), Xu et al. (2010), Hou (2010). First of all, due to the variety of data and methods used in the estimations, the studies have different conclusions as shown in Columns (3) and (4) of

Table 1. The carbon sequestration estimates for forests in China.

Source	Study period	Carbon stock (Pg C)	Carbon sequestration (Tg C yr^{-1})
Fang, Guo, and Piao 2007	The Second to Sixth Forest Inventory Investigations (From 1977–1981 to 1999–2003)	4.911	276
Wu et al. 2008	1989–1993	4.22	—
	1999– 2003	5.517	—
Li 2005	1999–2003	5.92	—
The People's Republic of China Initial National Communication on Climate Change, 1994	1994	—	433
Wu et al. 2008	The Fourth to Sixth Forest Inventory Investigations (From 1989–1994 to 1999–2003)	—	313–374
The Seventh Forest Inventory Investigation	2004–2008	7.811	—
Wang, Wang, and Niu 2013	2004–2008	—	1,190
The People's Republic of China Second National Communication on Climate Change, 2013 (NDRC, 2013)	2004–2008	—	411
Economic Development Research Center, State Forestry Administration, China	2004–2008	—	623–664
FAO 2015	2000–2005	—	433

Source: Authors' own compilation based on the review of existing works.
Pg C represents petagrams of carbon (10^{15} C) and Tg C means teragrams of carbon.

Table 1. Furthermore, the existing works only focus on the increase in forests by afforestation and reforestation, but the estimation on the potential of the other two important components of NbS – forest-management techniques and reduced deforestation and forest degradation – to limit the rise of CO2 concentration is missing. In addition, on carbon pools that are taken for the estimations, most of the studies use the aboveground biomass based on standing timber, and other carbon pools are excluded.

Therefore, based on the review of the methodology and results from the existing studies, it is necessary to improve the estimation on forest carbon sequestration potential by addressing the above concerns. More importantly, from the NbS perspective, the estimation should add the carbon sequestration effect from forest management and reduced emissions from the reduction of deforestation and forest degradation.

3. Estimation framework

3.1. Activities related to forest sequestration

As described by Li (2006), forests sequester carbon from the direct (absorption of carbon by trees) and indirect (by wood harvests and products that act as a temporary carbon sink) ways, and via substituting wood products for more carbon-intensive fuels and materials they contribute to limiting the rise of CO2 concentration in the atmosphere. Our estimation approach stands on these aspects as a foundation and consider the forest carbon sequestration framework that composes forest carbon-related activities described as follows.

3.1.1. Forest's carbon sequestration activities

At present, the forest carbon sink that has been involved in the international climate negotiations is in the sense, as defined by Articles 3.3 and 3.4 of the Kyoto Protocol, that focus on the estimate of carbon sink from the following forest-related activities such as afforestation, reforestation, forest management and protection, and deforestation. The role of deforestation and forest degradation in reducing CO2 emissions was not valued until the inclusion of the REDD mechanism to the UNFCCC's dual-track negotiation framework.

*1)**Afforestation and reforestation***

According to the definitions in the Kyoto Protocol (UNFCCC 1992): 'Afforestation' is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. And 'Reforestation' is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands since 1 January 1990. Therefore, to differ afforestation from reforestation is the length of time that the plots remain unforested, and this difference is marginal in the estimation of carbon sinks and monitoring (Zhang and Hou 2009). Also, given the unavailability of data on them separately, it is difficult to distinguish afforestation from reforestation. For these reasons, when estimating the carbon sink potential, we do not differentiate the two, but combine them into one, namely, forestation. We also attempt to consider the distribution of forestation across regions, forest species and forestation methods, taking the differences in forest growth and the resulted difference in carbon absorption into account.

2)***Forest management***

The Article 3.4 of the Kyoto Protocol stipulates that the individual targets for Annex I Parties can be offset by the amount of anthropogenic GHGs emissions that are absorbed by forests due to man-made activities such as forest management after 1990. Forest management, as defined in the Marrakesh Accords (COP7 in 2001), is a forest land utilization and management system whose purpose is to achieve sustainable forest-related ecological (including biodiversity), economic and social functions. Forest management involves plantation and natural forests, and also the land that has not yet with closed canopy (depending on the definition of forest). In other words, the Marrakesh Accords gave a very vague and broad definition on forest-management activities, and they can be any activity such as fertilization, fire control, pest control, forest regeneration, and young forest tending (e.g., weeding, soil loosening, etc.), pruning, thinning, fertilization, irrigation, drainage, harvesting modes selection, rotation, management of harvest residues and dead wood, and so on. If all forests in a country are managed in a sustainable way, to put it another way, the forests under forest management activities are managed, and the carbon sequestration estimate of these forests are of the carbon sink estimate of forest management activities (Hou 2010). The same is true in empirical applications: almost all the developed countries claim that their forests are managed, thus relevant activities are qualified forest management activities (Zhang and Hou 2009).

On the estimate approach on forest management activities, the UNFCCC proposes the use of broad measure based on land. To be specific, this measure estimates the carbon stock changes on land that is affected by any kind of forest management activities, without distinction on any specific activity. This estimate approach takes two forms: the 'Total-Net' and the 'Net-Net'. The 'Total-Net' estimate shows the aggregate carbon amount of the managed forest in the specific year when management is carried out; the 'Net-Net' estimate reflects the net change in carbon sinks in the target year relative to the base year (period, or baseline scenario).[2]

*3)**Reduced deforestation and forest degradation***

The main forestry activities in the Articles 3.3 and 3.4 of the Kyoto Protocol include deforestation in addition to afforestation, reforestation and forest management. On developing countries, the focus is greatly placed on the reduction of deforestation and forest degradation and their contributions in carbon emissions reduction, and this contribution should be included in the estimation of forest carbon sequestration. Indeed, as in REDD+, the '+' reflects forest carbon stocks and the changes.

3.1.2. Wood product sink

Wood products act as a temporary carbon sink, that is regarded as the indirect carbon sequestration of forests, because, various forest products such as timber products, synthetic boards, furniture, etc. store carbon in the products from trees after being harvested. Therefore, prolonging the service life of wood products and recycling them can be an effective way to reduce carbon emissions. To calculate the length of carbon that is stored in forest products is difficult and is not considered by the existing studies (Li 2006).

By 'indirect carbon sequestration' it means the reduced amount of CO2 emissions measured by the amount of carbon stored in wood products. Therefore, the increase in the uses of wood products stores more carbon and thus can offset GHGs emissions. The assessment of carbon storage by wood products was firstly proposed at the fourth meeting of the UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) in March 1996. The carbon stored by wood products was neglected in the first commitment period of the Kyoto Protocol, it receives more attention and has become an important issue in international climate change negotiations.

3.1.3. Reduction of CO2 emissions from forest uses

The reduction of CO2 emissions from forest uses refers to the process that the increase in uses of forest products to substitute for higher-carbon energy can reduce CO2 emissions, which is of a great potential to amplify forest sequestration to a larger extent (Li 2006). For example, wood products can substitute for steel, cement, aluminum, plastics, bricks, etc., so that the amount of CO2 emitted in the production processes of these energy-intensive materials is avoided. Moreover, wood fuel is a renewable green energy, so that substituting for fossil fuels reduces CO2 emissions. However, the carbon sink estimate by forest uses has not yet considered by the existing studies.

3.2. Forest types and the differences in carbon sequestration

The estimation of carbon sink relies on forest types and tree species that can be assessed, and this depends on whether the plant communities and their components belong to the forest. According to the Kyoto Protocol, forest is defined as having: a minimum canopy density of 0.1–0.3; a minimum area of 0.05–1.0 ha; a minimum tree height of 2–5 m. According to China's CDM project of forest carbon sink, bamboo forests and shrubs can be included in carbon sink estimate. However, it is often not recommended to include bamboo forests and shrubs in empirical estimation. As for economic forests, in principle, it is possible to apply for the A/R CDM projects for arbor economic tree species including oil, nuts and fruits. However, due to the same methodological issues, it is difficult to have a carbon sink estimate for economic forests.

Based on the above issues, the estimation of forest carbon sinks should aim at the forest stand. And for economic forests and bamboo forests, special attention needs to be paid to the impact on the carbon sinks and carbon stocks of them due to various activities related to carbon sequestration. Also, the aggregation of carbon sinks from different forest sequestration activities should be aware of the comprehensiveness of forest types and the sensitivity of the estimate.

3.3. Carbon pools and the differences

The proportion of carbon stock by different carbon pools varies greatly. Carbon sequestration by forest stock biomass accounts for 41% of the overall forest sequestration, non-forest plants accounts for 8%, and soil carbon sequestration accounts for 51% (Li 2006). According to the Resolution 11 of the Marrakesh Accords on IPCC (2000)'s LULUCF (Land use, land use change and forestry), the aboveground and belowground biomass (living biomass), liter, coarse wood residues and soil organic carbon are the carbon pools selected for estimation.[3]

Different carbon sink activities have different impacts on each carbon pool, and the estimation difficulty is accordingly. The question on which carbon pools should be selected and monitored during project implementation is complex and depends on many factors. At present, the forest carbon sinks that are traded in the global market only consider the aboveground biomass as the carbon pool for estimation. However, from the scientific perspective, the selection of carbon pools should be based on the actual importance of the carbon sequestration activities of each carbon pool. Zhang, Chen, and Wu (2004) provide a set of choices on carbon pools for each of the LULUCF activities. Similar references on carbon pools choices can be found in Ravindranath and Ostwald (2008).

3.4. Estimate approaches

Table 2 summarizes a number of approaches on forest carbon sinks by method classifications.

Among the works that estimate the forest carbon sinks in China, most apply a static approach to calculate or project carbon sequestration (carbon stock) of forests. The dynamic studies, e.g., Xu et al. (2010) and Hou (2010) estimate the change in carbon stock, that is, on the basis of the static approach, the annual average of carbon sequestration of the forest is calculated for a certain year.

On the scope of estimation, most studies are of the micro-level research, by focusing only the direct forest carbon sequestration. On the nature of the estimate approach, the current estimates of forest carbon sinks are mostly in the field of natural sciences. The natural sciences approaches vary at large given the procedure differences. The

Table 2. Estimate approaches.

Classification	Approach	Procedures	Comments
Timing	**Static**	Measure the carbon sequestration (carbon storage) of the forest during a certain period, by kg, ton, etc.	This is the basis of the economic evaluation on forest carbon sinks and forest carbon trade.
	Dynamic	Measure the carbon that is sequestered by the forest during a certain period, by ton/year, for example.	It is more accurate, reflecting the offset of the CO_2 concentration in the atmosphere by forest carbon sinks.
Measuring range	**Macro level**	Estimate direct and indirect carbon sequestration by forests, and the CO_2 emission reduction through wood products substituting other raw materials (that emit CO_2 during their productions).	This provides the estimate on the contribution of forest carbon sinks to reduce the CO_2 concentration in the atmosphere.
	Micro level	Estimate only the direct forest carbon sequestration (various carbon pools).	
Nature of method	**Natural sciences**	Natural science-based measurement on forest carbon sequestration.	The purpose is to provide an actual estimate on the amount of carbon that is sequestered in the forest.
	Social sciences	With the natural science-based measurement, the feasibility of estimation is given priority, for an economic evaluation purpose.	The focus is to provide a basis for policymaking in forestry carbon sink, for economic evaluation, and for carbon trade in forestry, etc.
Procedure	**Carbon flux**	Estimate the gains and losses, and the accumulation of carbon stock for each carbon pool in a given period of time. Incl. the sample-plot inventory approach, the flux measurement approach, the model simulation approach, and the carbon flux measurement based on remote sensing.	Adopted by IPCC (2007).
	Change in carbon stock	Based on the listing of all the changes in a given carbon pool, estimate the difference in carbon stock between two time points (e.g., years), and the difference divided by the inter-annual interval (e.g., number of years) to provide an estimate of annual average.	This approach is of more accuracy.

Source: Authors' own compilation based on the review of existing works.

approaches have their own caveats due to the difficulty of measuring and obtaining the baseline data as well as the scope of application of the estimation.

4. Data, method, and estimates

In this article, we firstly conduct a scenario analysis by estimating the carbon sinks potential of the forests in China to meet its 2020 CO2 emission reduction target, taking into account the main carbon sequestration activities under the international climate regulations and the wood product sink, that are discussed earlier (see Section 3.1). Secondly, the potential estimate is compared with the result using the available up-to-date data, to provide an estimate on China's potential to meet its CO2 emission target.

Data for this exercise are based on *China Forestry Statistical Yearbooks* and the *National Forest Resources Inventory Investigations* and the forestry development goals announced by the Chinese government. To conduct the scenario analysis, the goals specified in the *Research on China's Sustainable Development: Forestry Strategy* (RCSDFS Task Force 2002) are selected as the baseline scenario when climate change concerns were not tackled. The *Forestry Action Plan for Climate Change* (SFA 2009) proposed the forestry development goals in the three phases that China plans to mitigate and adapt to climate change. The difference in forestation area between the climate target and the baseline target is regarded as additional forest increase because of the climate change concerns.

To be specific, the targets established by the above policy documents are listed below.

Research on China's Sustainable Development: Forestry Strategy (RCSDFS Task Force 2002):

By 2010 – Forest area increases by 36.66 million ha compared to that in the Fifth National Forest Resources Inventory Investigation, and forest cover increases to 20.3%;

By 2020 – Forest area increases by 29.6 million ha *cf.* 2010, and forest cover increases to 23.4%;

By 2030 – Forest area increases by 19.82 million ha *cf.* 2020, and forest cover increases to 25.5%;

By 2050 – Forest area increases by 27.25 million ha *cf.* 2030, and forest cover increases to 28%.

Forestry Action Plan for Climate Change (SFA 2009):

Phase 1: By 2010 – Forest area increases by 4 million ha annually, forest cover reaches 20% and stock volume reaches 13.2 billion cubic meters, forest carbon sink capacity increases greatly;

Phase 2: By 2020 – Forest area increases by 5 million ha annually, forest cover reaches 23% and stock volume reaches 14 billion cubic meters, forest carbon sink capacity continues to increase;

Phase 3: By 2050 – Forest area increases by 47 million ha *cf.* 2020, forest cover maintains at 26% or higher, and the forest carbon sequestration capacity is stable.

The UNFCCC Climate Summit announcement (2009):

By 2020 – China will vigorously increase forest carbon sinks and strive to increase forest area by 40 million hectares and forest stocks by 1.3 billion cubic meters *cf.* 2005.

Next, for specific estimations based on the above targets, all the parameters are from published literature, and the estimation procedures are discussed below.

4.1. By afforestation and reforestation

To estimate the amount of carbon sequestration of forests that are increased by afforestation and reforestation, we use the carbon density parameters developed by Xu et al. (2010), that establishes the relationship between biomass density and forest age for 36 forest types, and provide a projected estimate of the carbon sink potential of the forests in China for 2050, based on the biomass predicted from the forestry development goals. This research has a solid natural science foundation, studying the differences across regions, forest species, and planting methods. The carbon pools selected for estimate include the above ground, below ground, and soil carbon pools, following Zhang et al. (2004). On forest type, we use the overall measure of forest stands. The estimating procedures are described as follows.

First, the new stand area is estimated for 2020, as well as the additional part over the baseline target.

Given the targets on the increase of forest area set by the *Research on China's Sustainable Development: Forestry Strategy* (the *Forestry Strategy*, hereinafter) and the *Forestry Action Plan for Climate Change* (the *Forestry Action*), we use Equation (1) to calculate the total area increase of living forest, to be used for carbon sink estimation:

$$Area^F = Area^P \times S^P + Area^A \times S^A \quad (1)$$

where $Area^F$ represents the total area of living forest by afforestation and reforestation activities; $Area^P$ and $Area^A$ define the area that is forested by manual planting (with superscript P) and by aerial seeding (with superscript A), with S^P and S^A defining the respective survival rate.

It is assumed that the shares of plantation area and aerial seeding area remain constant: i.e., 95.33% and 4.67%, taking 2010. The survival rates are 75% (S^P) and 25% (S^A), respectively (Hou 2010); Forest stand is assumed to be 87.5% of the total area of living forest and not changing with time (Xu et al. 2010). And, the additional forest area increase over the baseline target can be calculated by the difference in $Area^F$ between the *Forestry Strategy* and the *Forestry Action.*

Second, for the estimated increase of forest area (RAEL_A_1757027) from 2000 to 2020, the carbon stock of the aboveground biomass is calculated. The same calculation applies to the carbon stock of the additional above-baseline forests. With this, we calculate the annual amount of carbon sinks for the increased forests. On the basis of all carbon pools of the increased forests, the total amount of carbon stock, the carbon stock increment, annual carbon sink and annual carbon sink increment is estimated.

For example, to estimate the carbon sequestration by the aboveground biomass, the equation is shown below:

$$Carbon\ stock^{above} = Area^F \times Cdensity^{above} \quad (2)$$

The amount of carbon sequestration by the aboveground biomass ($Carbon\ stock^{above}$) is determined by the increase of (successfully) forested area ($Area^{F}$) and the carbon density parameter ($Cdensity^{above}$). For other carbon pools, the ratio amongst the belowground biomass, soil, and the aboveground biomass carbon pools is 41: 8: 51 Li's (2006). Following Fang et al. (2001), we adopt the carbon density parameter of 44.91 t.C/ha (ton carbon per hectare) for the existing forests and 31.11 ton C/ha for the (young) planted forests.

Third, it is of note that the above procedures have measurement errors that refinement may be required. Possible refinements are discussed in two aspects: 1) The above procedures take forests as an overall stand, ignoring the difference in carbon sequestration by economic forests or bamboo forests from the others. Therefore, it would be an underestimate. According to the estimates in Xu et al. (2010), if taking these differences into account, the estimate of the total carbon sinks of all forests will increase by 20% to 30% compared to the estimate taking forest as a simple stand.

2) The above procedures may produce an overestimated amount of forest carbon sink because of the implicit assumption on that no felling or death of the newly planted forests during the target period. As Xu et al. (2010) find, assuming the forests have the same withering rate as for the period during the Sixth National Forestry Inventory Investigation, the carbon sequestration estimate for the next 50 years would be reduced by about 25% from the predicted value.

Altogether, considering both the over and under-estimation on total carbon sequestration, the procedures will provide a rough estimate on the total amount of carbon sequestration of the forests in question.

4.2. By forest management

The carbon sequestration estimate on forest management involves the following choices:

Carbon pools – The main activities of forest management include sustainable logging, fertilizer application and thinning, regardless of any land-use change or disturbance to the soil. Therefore, the forest-management's carbon sequestration should focus on the carbon pools of the above and belowground biomass, rather than soil.

Forest types – Forest management activities have an impact on the living stand's growth and volume per unit area (Hou 2010). In other words, in the presence or absence of forest management, there should be little difference in bamboo (economic) forest's natural growth rate or volume per unit area of living stand. Therefore, the area of managed forests takes the stand area (Hou 2010).

Area of forest management (i.e., 'managed' forests) – The managed forests are limited to the land that was forested before the base year (2000) and remain as forest in the target year (2020), excluding the land that is converted to forest via afforestation, reforestation and deforestation (ARD). In other words, the area of managed forests in a certain year is determined by the area of forest stand in the base year net of the accumulated area of deforestation during the base year and the target year. However, due to the lack of data of accurate measures on deforestation, we use the area of managed forests as Hou (2010) estimated for a specific year with 2000 as the base year.

Carbon stock – To estimate the increase in carbon stock due to forest management, we use the carbon density in Xu et al. (2010) and the changes in carbon density of the existing forests in different periods. The changes in carbon density will reflect any change in managed forests, is thus an improvement to Xu et al. (2010).

Estimate approach on the forest management carbon sinks – The 'Total-Net' method is applied. The estimate of forest-management carbon sinks can be roughly calculated given the carbon density and the forest stand excluding afforested area (e.g., 87.5% of the total forest area net of newly forested area, $Area^F$).

4.3. By reducing deforestation and forest degradation

The estimation of how much the reduction in deforestation and forest degradation contributes to carbon sequestration depends on how the reference level and the future deforestation rates are determined. Taking REDD, the estimate on how much emission reduction will be caused by the implementation of REDD is determined by what reference level is chosen. The determination of reference is very different among countries.[4] And how to define the future deforestation rate should be in accordance with national policies and regulations related to deforestation, land use planning and so on. In China, the deforestation has been driven by economic development needs, including road expansions, urbanization and agricultural expansion that have taken large amounts of forestland. To fight against deforestation, the national policies include, for example, the Ecological Construction Projects in National Key Areas and the Natural Forest Protection Projects (NFPP), that had – and will continue to have – impacts on deforestation. Estimated by Hu and Liu (2006), within the first five years since implementation in 1998, the NFPP sequestered carbon of 44.107 billion tons, with an annual sequestration of 8.181 billion tons, which is equivalent to 1.2% of the total CO2 emission in that period.

Importantly, the definition on deforestation varies. The Kyoto Protocol defines deforestation as that has occurred on land that was defined as forestland in 1989. Yet, in China, the National Forest Resource Inventory Investigations take deforestation as it has happened on the land defined as forestland in the previous inventory. So, for China, deforestation land contains both the 1989 forestland and the afforested land since 1990. Therefore, the estimation of carbon emissions from deforestation, in order to be consistent with the Kyoto Protocol definition, the latter should be dropped. Additionally, due to the unavailability of official data on deforestation and forest degradation in China, associated with the complexity of the determination on the reference level (thus no rule-of-thumb way to determine), and most studies believe that the contribution of reduced deforestation and forest degradation to carbon sinks is much lower than that of afforestation and reforestation in China, this study will apply a simplified approach for this part of estimate.

To do so, we use the average measure of annual deforestation of 2.5033 million ha[5] as the reference level, using the period before the NFPP was implemented. Since the NFPP started in 1998, the reduction in a natural forest area that was converted to other land uses has an annual average of 85,700 ha – this figure is determined by the difference between the Sixth and the previous Inventory Investigation. We use this figure as a simplified measure for the annual reduction in deforestation. Next, the total amount of CO2 emission due to deforestation during 1980–2000 in China is 830 million tons, estimated by Li (2007). Based on this figure, a rough estimate of the emission coefficient per unit area of deforestation is 16.58 t.C ha^{-1}.[6]

Based on these data, from 2000 to 2020, China is expected to have a total reduction in deforestation of 1.714 million ha (i.e., 85,700 ha times 20 years), which is estimated to reduce CO2 emissions up to 28.42 million tons in total, and 1.9 million tons per year. Compared to the estimates by Hou (2010) who shows the deforestation in 2000 emitted 35.8 million tons of carbon in that year, and the projected annual carbon emissions reduction reaches to 13 million tons per year, our estimate is a very conservative one.

4.4. By wood product sink

The estimate of wood product sink focuses on the carbon storage in wood. Following Li (2006), our estimate of the amount of carbon sequestered in wood is determined by the harvesting efficiency and wood yield. The equation to estimate carbon storage in wood is shown below:

$$CW = \lambda \sum \left(S_{IJ} \times V_j\right) \times \rho \times \delta = \lambda \times Q \times \rho \times \delta \tag{3}$$

where CW represents the amount of carbon stored in wood products; λ represents the conversion factor of wood carbon sequestration, and $\lambda = \gamma_1\gamma_2$, on which γ_1 as the efficiency of wood processing and γ_2 defining wood yield of logging; ρ defines the bulk density, on which we use the IPCC default value of 0.50; and δ is carbon content rate, we use the IPCC default of 0.50 (t.C/m^3) as the average of the carbon content for the wood product species.

For instance, assuming the overall utilization rate of wood in terms of wood products is 80% (λ), and in Q we take the total amount of wood consumption of a certain year in China net of the imported amount. According to the SFA (2010a)'s the *Planning Outline on National Forest Land Conservation and Utilization (2010–2020)*, China's wood consumption (computed from consumption of forest products) in 2007 amounts to approximately 371 million cubic meters, of which 202 million was from the domestic market. By 2020, the consumption will increase to 457 to 477 million cubic meters, with a timeless gap of wood supply of about 100 to 150 million cubic meters. Based on this data, the carbon storage in wood products (CW) in 2007 is given by: $CW = 0.8 \times (371 - 202) \times 0.5 \times 0.5 = 33.8$ (million tons of carbon); and the same estimate for 2020 ranges from 61.4 to 75.4 million tons. Comparing these estimates to those by Bai, Jiang, and Zhang (2009) whose estimate is based on the change in the carbon stock, the production method, and the atmospheric flow method, that in 1990, the carbon storage of wood products is between 285 and 347 million tons in 1990, between 394 and 532 million tons in 2004, our estimates are conservative.

5. Results and discussion

5.1. Carbon sequestration potential estimates

5.1.1. Carbon sink potential at the baseline target

The baseline target for forestry development would be only due to the sustainability concerns by a government, thus it would not reflect any action to mitigate and adapt climate change impacts. At this baseline level of growth, forests and the planted forests sequester carbon. We estimate that, the forests in China, if by 2020 planned in accordance with the *Research on China's Sustainable Development: Forestry Strategy*, will sequester a total amount of carbon up to 9.71 billion tons in the year of 2020. This estimate will represent an increase of 2.57 billion tons compared to that in 2000 (Table 3).

5.1.2. Carbon sink potential under the climate-action target

Next, based on the action plans by the *Forestry Action Plan for Climate Change* (SFA 2009) and the government's announcement of the 40 million ha increase of forest reserves, the total amount of forests at this target will be estimated to sequester 12.87 billion tons of carbon in 2020, which will increase by 5.73 billion ton compared to the level of forest sequestration quantity in 2000 (Table 4).

5.131. How much has been met?

In the next step, we show the estimate of forest carbon sequestration based on the up-to-date data on real changes in China's forests (Table 5). Taking into account the survival rates of planting modes, by 2018, a total of 85.12 million ha of land has been successfully afforested or reforested. Although this number is above the baseline target by 18.84 million ha, it is a bit far to reach the climate-change forestation goal: the total forest area increase requires an amount of 164.28 million ha, and only a half of this target has been met by 2018. The associated carbon sequestration that has been met estimates as 10.4 billion ton, which implies that over 80% of the climate-change target potential in carbon sequestration has been met.

Table 6 shows the estimates of carbon sequestration through the set of activities discussed earlier. Taking 2020, in case the climate-change target being met, the forest area increase will mainly be through afforestation and reforestation (i.e., forestation), that sequester a total amount of carbon up to 3.72 billion tons. And the managed forests – taking

Table 3. Potential of carbon sequestration (CS) of China's forests: baseline target.

Year	Area (mn. ha)	Increase (mn. ha)	CS (Pg.C)	CS increase *cf.* 2000 (Pg.C)
2000	158.94		7.14	
2005	174.91	15.97	7.63	0.50
2010	195.62	20.71	8.50	1.36
2020	225.22	29.60	9.71	2.57

Data on forest area comes from the *2006 China Forestry Statistical Yearbook* (SFA 2006) and the Fifth National Forest Resources Inventory Investigations (SFA 1994–1998). For 2010 and 2020, data on planned increase is from the *Research on China's Sustainable Development: Forestry Strategy* (RCSDFS Task Force 2002).

Table 4. Potential of carbon sequestration (CS) of China's forests: the climate-change target.

Year	Area (mn. ha)	Increase (mn. ha)		Increase (mn. ha)	CS (Pg.C)	CS increase *cf.* 2000 (Pg.C)
		Strategy	*C.C. Action*			
2000	158.94				7.14	
2005	174.91	15.97		15.97	7.63	0.50
2010	203.62	20.71	8	28.71	8.75	1.61
2020	323.22	29.6	90	119.6	12.87	5.73

Data on forest area comes from the *2006 China Forestry Statistical Yearbook* (SFA 2006) and the Fifth National Forest Resources Inventory Investigations (SFA 1994–1998). For 2010 and 2020, data on planned increase is from the *Research on China's Sustainable Development: Forestry Strategy* (RCSDFS Task Force 2002) – the 'Strategy' and the *Forestry Action Plan for Climate Change* (SFA 2009) – the 'C.C. Action'. For 2020, the C.C. Action adds the 40 million ha target announced by the Chinese government in 2009.

Table 5. Potential of carbon sequestration (CS) of China's forests: the real changes by 2018.

Year	Area (mn. ha)	Increase (mn. ha)	CS (Pg.C)	CS increase *cf.* 2000 (Pg.C)
2000	158.94		7.14	
2005	181.91	22.97	7.85	
2010	203.64	21.73	8.85	1.71
2018	244.06	40.42	10.40	3.26

Data on forest area comes from the *2019 China Forestry Statistical Yearbook* (SFA 2019) and the Fifth National Forest Resources Inventory Investigations (SFA 1994–1998). The increase of the forested area is a total of the areas by a variety of planting models in that year, taking the respective survival rates into account.

the forest-management activities into account – will store some 9.15 million tons. By comparing the estimates under the climate-change target (Table 4) with that of the baseline target (Table 3), we show that the above-baseline increase of carbon sequestration reaches 3.16 billion tons (Column 1), implying that indeed, the potential of forests in meeting such carbon emission targets is considerable. Given that Column (2) shows the estimates of what has happened by the time of 2018, only 45% of the carbon sink target has been met.

Additionally, the carbon sinks of reduced deforestation and forest degradation, of wood products, together have a sizable contribution: they will be equivalent to 9% of the carbon sink by forestation, and 4% of the carbon sinks of the managed forests. More recently, the rapid growth in eucalyptus plantations in the provinces of Fujian, Guangdong and Guangxi has contributed to one-third of wood production in China. Taking this into account, wood product sink will be 0.08 Pg C.[7]

5.2. Scenario analysis: CO2 emission targets and forest carbon sinks

Our scenario analysis builds upon Zou, Teng, and Fu (2014)'s prediction on the 2020 carbon intensity in China given a set of scenarios on carbon emission reductions. To take a further step, we show, in Table 7, how forest carbon sinks contribute to meeting these targets.

Afforestation and reforestation increase forests and these forests sequester the amount of carbon equivalent to 6% to 8% of the CO2 emissions of the year. The incremental amount of carbon sequestration by afforestation and reforestation accounts for 3% to 4%. The annual increase of carbon sinks with forest management activities accounts for 4% to 6%. The potential for reducing carbon sinks in deforestation and forest degradation is medium, 3% to 4%. In total, the carbon sinks of the existing forest in the year will be

Table 6. Carbon sequestration estimates of China's forests in 2020 and 2018 (Pg C).

	Climate Change target	What's happened
CS activities	(1)	(2)
Increment from forestation	3.72	1.26
By the managed forests	9.15	9.14
Total CS estimate:	12.87	10.40
Other CS activities:		
Increment from REDD (*cf.* 2000)	0.28	0.26
Wood product sink	0.07	0.08
Versus 2000:		
Total increment (cf. 2000)	5.73	2.55
Increment of managed forests (*cf.* 2000)	2.05	2.00
The above-baseline incremental (cf. 2000)	3.16	0.70

Table 7. The 2020 CO2 emission scenarios and forest carbon sinks.

Sink	CO2 emission and reduction target scenarios:	33%	40%	45%	50%
	CO2 emission	10.9	9.5	8.7	8
	The business-as-usual level	16.3	16.3	16.3	16.3
	Amount of reduction	5.369	6.333	7.118	8
1 Forestation	**CS (Pg C yr^{-1})**	0.643	0.643	0.643	0.643
	CS/CO2 emission	6%	7%	7%	8%
2 Forestation incremental	**CS (Pg C yr^{-1})**	0.286	0.286	0.286	0.286
	CS/CO2 emission	3%	3%	3%	4%
3 Managed forests	**CS (Pg C yr^{-1})**	0.458	0.458	0.458	0.458
	CS/CO2 emission	4%	5%	5%	6%
4 Reduction in deforestation and forest degradation	**CS (Pg C yr^{-1})**	0.284	0.284	0.284	0.284
	CS/CO2 emission	3%	3%	3%	4%
5 Wood products	**CS (Pg C yr^{-1})**	0.068	0.068	0.068	0.068
	CS/CO2 emission	1%	1%	1%	1%
Total forest CS estimate (1,3,4)	**CS (Pg C yr^{-1})**	1.385	1.385	1.385	1.385
	CS/CO2 emission	13%	15%	16%	17%
Indirect sinks (2,3,4)	**CS (Pg C yr^{-1})**	1.028	1.028	1.028	1.028
	CS (Pg C yr^{-1})	9%	11%	12%	13%
Indirect sinks incl. wood product sink (2,3,4,5)	**CS (Pg C yr^{-1})**	1.096	1.096	1.096	1.096
	CS/CO2 emission	10%	12%	13%	14%

CS is abbreviation for carbon sequestration. The annual CS estimates for different sinks are based on the results of Tables 4 and 6.

equivalent to 13% to 17% of CO2 emissions that year. This finding reassures the forests' potential in meeting the CO2 emissions reduction target.

Put it another way, the direct sequestration, that the forests store carbon up to an amount equivalent to 6% to 8% of the year's industrial CO2 emissions. In addition, indirectly, taking the wood products sink, for example, the carbon sink potential through the consumption of wood will be another 1%. The indirect sinks can sequester some carbon equivalent to 10% to 14% of the CO2 emission. This sizable potential to the mitigation of global warming, will help us understand better the role of forests, from the NbS perspective, can exert powerful ways to fight against climate change. The following example is thus a simple one, as of an NbS. In the cases that mature forests become carbon sources, harvesting should be increased and this may become the best mitigation option from that these fell can have additional carbon sink value in terms of wood product.

It is worth noting that we our estimates do not include the reduced amount of CO2 emissions caused by the substitution of wood for fossil fuels and other high-carbon materials. So, they are currently underestimating the carbon sink potential, given the very rich variety of biomass energy resources in the forests in China. According to the *National Forestry Biomass Energy Development Plan (2011–2020)*, energy forests aim to reach 13.34 million ha by 2020, providing 6 million tons of biodiesel to meet the fuel need of 15 million kilowatts for power plants. Specifically, using 1 cubic meter of wood to replace cement and bricks is estimated to reduce emissions of 0.8 tons of CO2 equivalent (Abergel, Dean, and Dulac 2017). As a result, the potential of wood uses in the construction sector in reducing carbon emissions are enormous.

Taking the net CO2 emissions of 2.669 Pg C equivalent in 1994, the wood structure substituting the reinforced concrete structure and the reinforced prefabricated plate structure, respectively, contributed to 13% and 8%, by construction area; and 5.4% and 3.2% by the completed area: implying that in the future, the potential has a large room for the substitutions (Bai, Jiang, and Zhang 2009). Besides the construction sector, substitutes of wood products for other high energy-consuming products such as aluminum, plastics and so on have similar potential.

Moreover, such potential can be enhanced by prolonging the service life of wood or wooden products. As of 2005, antiseptic treatment was found less than 1% of the Chinese wood products, which is far below the world average ratio of 15%.[8] Applying antiseptic treatment can prolong the time of service of the treated wood by 3 to 5 times. Also, as shown in Bai et al. (2009), a 10% prolongation of use is estimated to reduce carbon emission from the wood product sink by 0.81% to 0.9%. A doubling of service life will reduce carbon emission by 8% to 9%, suggesting a large potential to fight against global warming.

5.3. Comparisons of carbon sequestration with previous estimates

Table 8 compares our estimates with those in other studies that also provide an estimate on the potential of China's forest carbon sequestration.

Our estimate of the total carbon stock by all the forests, and that of the incremental sink by afforested and reforested area, are both higher than the results in Xu et al. (2010) and Li (2005). Xu et al. (2010) has a lower estimated area for newly planted forests and thus overestimate the managed forests. Also, only the aboveground biomass is taken by the estimate. The two aspects result in an overall underestimate. Li (2005) underestimates the total area of forests. Our results overestimate the carbon sinks because emissions from possible deforestation is not yet deducted.

China's forests as a big carbon sink of 12.87 Pg C in 2020, and compared to the estimate of 7.81 Pg C by the Seventh National Forest Inventory (2004–2008), have excellent potential in the near future. In 2004, the forests net absorption of CO2 is 0.5 Pg C, equivalent to 8% of the industrial CO2 emissions (NDRC 2007), and our findings in the scenario analysis suggest a larger potential, i.e., to be 13% to 17% in 2020.

6. Conclusion

The estimation on the potential of forest carbon sequestration should consider all the activities such as afforestation and reforestation, forest management, reduction of deforestation and forest degradation, and wood product sinks. Based on a vigorous review of the methodology in estimating forest carbon sinks, this paper estimates the carbon sequestration potential of China's forests. The results show that by 2020, China will have a carbon stock of 12.87 Pg C in its forests. By planting in accordance with the action plans to mitigate climate change, the increase of forests – through afforestation and reforestation – will have an overall increase in carbon sink by 5.73 Pg C from 2000. In the year of 2020, total forest CS estimate will be 1.35 Pg C, equivalent to 13% to 17% of the CO2 emissions in that year. Of this potential, 6% to 8% percent is contributed by afforestation and reforestation; forest management contributes 4% to 6%; reduced deforestation and forest degradation by 3% to 4%; and wood product sink contributes to 1%. Altogether, the potential is even bigger when deforestation and forest degradation is considered, as well as wood's substitution effect for fossil fuel and other carbon-intensive materials, and the plausibility of extend the service life of wood products.

Table 8. Estimates comparison with other studies.

	Total C	Sinks (Tg C)					Carbon pools			Forests	
Source	(Pg C)	Total CS	Planted	Managed	REDD	Wood product	Planted forests	Managed forests	REDD	Af(re)forestation	Managed
Our estimate	12.87	368.01	176.59	121.6	1.42	68.4	Above, below, soil	Above, below	Above, below, soil	Stand, economic forests, bamboo forests	
Hou (2010)	-	160	99.4	83.4	13 Deforestation: –22.8	-	Above, soil	Above, soil	Y (deforestation)	Economic forest, bamboo, timber, shelter forest, firewood forest	Stand
Xu et al. (2010)	9.417	177.72	44.02	133.7	-	-	Above	Above	-	Stand	Stand
Li (2005)	8.89–10.5	-	-	-	-	Y	Above, below, soil	Above, below, soil	-	Unspecified[a]	Unspecified[a]
Wu (2010)	21.69–25.6	-	-	-	-	-	Above, below, soil	Above, below, soil	-	Unspecified[a]	Unspecified[a]*
Gu, Zhang, and Zhang (2008)	5.956	-	-	-	-	-	No distinction by carbon sink activities, by forest type. Only aboveground biomass considered.				

[a]Given the data source in these studies, the forest inventory data on forest total area, contain all forest types including economics forests and bamboo forests.

China's climate strategies should value all these activities and use forest carbon sinks as a policy tool to achieve its 2020 target on carbon intensity reduction.

Notes

1. By 'Sink', the United Nations Framework Convention on Climate Change defines as any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere. The concept of 'carbon sink' means the process, activity or mechanism that removes CO2 from the atmosphere; and vice versa, the process, activity or mechanism that emits CO2 to the atmosphere is called 'Carbon Sources' (UN 1992). Forest carbon sink, from the natural sciences perspective, means the process, activity, or mechanism in which forest ecosystems absorb CO2 from the atmosphere and store in vegetation or soil, thereby reducing the concentration of CO2 in the atmosphere; from the social sciences perspective, it refers to, via afforestation and reforestation and forest management, the reduction of deforestation and other processes, activities, and mechanisms that absorb (or reduce) atmospheric CO2, which also be interacted with relevant policy, management, and carbon trade (Li 2007).

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2. As specified in the first commitment period, the carbon sink estimate of forest management in developed countries adopts the 'Total-Net' method. The 'Total-Net' estimate of annual carbon sequestration of all forests = total forest area × carbon sequestration rate (ton C/ha/year); the 'Net-Net' estimates the annual carbon sequestration in newly planted forests = area of afforestation × carbon sequestration rate (ton C/ha/year).

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3. COP9 adopted the same carbon stock classification in its decision on the methods and procedures of A/R CDM projects (UNFCCC 2003). See the UNFCCC report of *Ninth session of the Conference of the Parties (COP 9)*. (Quoted by Zhang, Chen, and Wu 2004, report available via link: https://unfccc.int/news/ninth-session-of-the-conference-of-the-parties-cop-9.)

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4. Most of the NGO proposals and some government proposals (Brazil, India and Indonesia) base on historical emission levels to determine the reference level. Most governments use the historical reference associated with adjustment factors (small island National Union, Canada, Union of Rainforest Nations, Colombia, COMIFAC, European Union, Japan,

Malaysia, Mexico, Norway and Panama) or expected reference (Australia, Indonesia). Some adopt more complex methods (Parker et al. 2009).

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5. This annual deforestation is calculated using the data from the Second to Fifth National Forest Resources Inventory Investigations, between 1977 and 1998.

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6. 830 million tons carbon/20 years/2.5033 million ha = 16.58 tons carbon per year (t.C yr^{-1}).

830 million tons carbon/20 years/2.5033 million ha = 16.58 tons carbon per year (t.C yr^{-1}).

7. This result is estimated by Equation (3) in Section 4.4, taking the carbon content rate of 0.5253 given by Li, Zhang, and Li (2017).

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8. The notice sent by State Council on the NDRC's '*Opinions on the Promotion of Wood Saving and Substitution*' in 2005 (http://www.gov.cn/jrzg/2005-12/24/content_136256.htm).

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Disclosure statement

No potential conflict of interest was reported by the authors

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