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The Chinese Grain for Green Program – assessment of the land reform’s carbon mitigation potential

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Abstract

Grain for Green Program or Sloping Land Conversion Program was launched in China as a national measure to control erosion and increase vegetation cover in 1999. With a budget of 40 billion USD dollars, the program that targets cropland and barren land has today converted over 20 million hectares of land into primarily tree-based plantations. Even though the design of the program includes a category of energy forest only a negligible part is planted as such (0.61%). The majority of the land converted is for protection (78%). The use of these plantations in the future is however unclear and a hypothesis of energy substitution is valid.

In this paper, we try to estimate the overall carbon that has been sequestered due to the program by using official statistics from the program and by calculating it according to mainly three different approaches; calculations made on I) net primary production, II) figures from IPCC's greenhouse gas inventory guidelines, and III) mean annual increment. We also highlight several of the uncertainties that are associated with the program and the estimations.

The result shows that conversion of cropland and barren land generated carbon sequestration over its 10 first years ranging from 222 to 468 million tonnes of carbon, with the IPCC approach yielding the highest estimate whereas the other two approaches had more similar outcome (around 250 million tonnes of carbon). Uncertainties associated with the assessment lies within the use of growth curves not designed for the particular species and their different locations, actual survival rate of the plantations, and discrepancies in figures concerning the program (e.g. area, type, survival rates) at different levels of authority (from national to local). The carbon sequestered in the biomass (above and below ground) from this program is equivalent to 14% (based on median of all three approaches) of China's carbon dioxide emissions due to fossil-fuel use and cement production.

Keywords*: Land-use change, Mitigations impact, Plantations, Carbon sink, Bioenergy*

摘要：为了控制水土流失并增加植被覆盖度，中国政府从1999年开始实施流了退耕还林工程（坡地治理项目）。该工程投入400亿美元，时至今日，已通人工种植的方式将2千万公顷的坡耕地和荒地转化为林地。尽管工程包含保护薪炭林的项目，但涉及薪炭林仅占全工程的0.61%，几乎可以忽略不计。其主要对象仍然为生态公益林，占78%。然而对于新增人工林的用途并无定论，将其作为一种能源替代品也是有可能的。

本研究基于官方公布的统计数据，利用三种方法尝试评估该工程产生的碳汇量：1）净初级生产力法、2）IPCC温室气体清单法、3）年均增量法。同时分析了方法差异及项目实施条件等因素对估算结果的影响。

结果表明：中国退耕还林工程十年间（1999-2009）产生的碳汇量为2.22到4.68亿吨；
其中净初级生产力法和年均增量法的估算结果较为接近（约为2.5亿吨），而IPCC温室气体清单法的估算结果则相对较高。

影响本研究碳汇量估算精度的主要因素包括：评估所用的生长曲线没有精确到不同的物种及其立地条件；林木实际存活率数据不可获得；官方（中央单位及地方单位）用于评估工程的指标（如面积、类型、存活率）在存在差异。

退耕还林产生的碳汇量（包括地上和地下部分的生物量）相当于中国因使用化石燃料及生产水泥而产生的二氧化碳总排放量的14%（三种方法估算结果的算数平均值）。

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List of Abbreviations and Acronyms

AGBG	Above ground biomass growth
CCFGP	Conversion of Cropland to Forest and Grassland Program
FAO	Food and Agriculture Organization
GGP	Grain for Green Program
GHG	Green House Gas
GNGGI	Guidelines for National Greenhouse Gas Inventories
IPCC	Intergovernmental Panel on Climate Change
MAI	Mean Annual Increment
NPP	Net Primary Productivity
SFA	State Forestry Administration
SLCP	Slope Land Conversion Program
SOC	Soil Organic Carbon
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

When the President of China, Hu Jintao, held his speech about climate change at the UN climate summit in New York 2009 he emphasized Chinas plan to increase the forest cover with 40 million hectares (ha) until 2020 (Guo et al. 2009; The New York Times 2009). China has since many years been trying to increase the forest cover through six different forestry programs and today China is one of the few countries in the world that has a growing forest cover (The World Bank 2010).

Atmospheric concentrations of greenhouse gases (GHG) have increased considerably since the industrial revolution and a growing concern for global climate change have recently been witnessed. According to Intergovernmental Panel on Climate Change (IPCC) (2007), increases in anthropogenic GHG concentrations is very likely to have caused most of the increase in global average temperature since the mid-1900s. The increase of atmospheric GHG concentration results to a large extent from human activities and agricultural activities contribute to a large percentage of these emissions (Guo and Zhou 2007). One of the main reasons for the increasing atmospheric GHG concentration is conversion of natural vegetation to farming which has led to a net loss in carbon from the terrestrial biosphere to the atmosphere (Zhang et al. 2009).

As China continues its rapid rate of development, dealing with the massive and growing emissions of anthropogenic GHG will be vital in the context of global climate change (Caldwell et al. 2007). Afforestation and reforestation have become important measures in China to slow down the wind and water erosion. In 1999 the Chinese government introduced the Grain for Green Program (GGP) also known as Slope Land Conversion Program (SLCP) (Ostwald et al. 2007) or The Conversion of Cropland to Forest and Grassland Program (CCFGP) (Bennet et al. 2008). The large-scale afforestation under the GGP will result in a large amount of new forest. Although it is not the primary target the GGP will enhance the carbon sequestration capacity in the terrestrial ecosystems and mitigate the increasing carbon dioxide concentration in the atmosphere.

Since the beginning of the GGP many studies have evaluated the socio-economic aspects of the program (Xu and Cao 2002; Uchida et al. 2007; Bennett 2008). Yet little research has been done on the carbon sequestration potential of the largest land retirement program in the developing world.

1.1. Background

During the mid-1990s the necessity for reducing environmental degradation in China became obvious through significant desertification and floods (Bennet et al. 2008). To cope with ecological concerns six national key forest programs was developed (Sylvie et al. 2007). The programs were launched in the end of the 1990s, aiming at restoring, conserving and expanding China´s forest, especially in ecologically sensitive areas such as Yangtze and Yellow rivers´ basins in the western region. The six national key forest programs include Natural Forest Protection Program, the Grain for Green Program, the Desertification and Dust Storms Control Program in the vicinity of Beijing and Tianjin Municipalities, the Forest Shelterbelt Development Program in key environmentally fragile regions, the Wildlife Conservation and Nature Reserves Development Program and the Fast-growing and High-yield Timber Plantations Program (Sylvie et al. 2007). GGP is distinct from China's other water and soil conservation and forestry programs since it is one of the first and certainly the most ambitious “payment for environmental services” program in China (Bennett 2008). The total area converted from 2001 to 2008 was 20 128 267 ha according to State Forestry Administration (1999-2008) at the same time Bennett (2008) claims that goal of total converted area from 1999 to 2010 is 32 million ha. The total budget of the GGP is 40 billion USD (Stokes et al. 2009).

The GGP is a nationwide program aimed at increasing the forest and grass cover to prevent soil erosion and flooding (Ostwald et al. 2007). This land-use policy featured the conversion of steep-sloped and degraded cropland and barren land to forest and grassland by millions of small landholders in 25 provinces, municipalities and autonomous regions (henceforth referred to as provinces) in China. When the program is finished in 2010 the area of forest converted from cropland is planned to be 14.76 million ha and the area of afforestation of non-agricultural land is planned to be 17.33 million hectares. This sum up to a net increases of forest or grass vegetation of 32 million hectares (Bennet et al. 2008), about the same as the area of Norway. The total area of China according to United Nations Statistics Division (1984) is 960 million hectare, which means that the area converted amounts for 3% of the total area. The GGP involves the world's second largest expenditure on a single environmental services program after the Conservation Reserve Program in the United States (Bennet et al. 2008). To compensate the farmers, the program provided compensation in terms of money and food grains for up to eight years to farmers that convert their land (Ostwald and Chen 2006).

The GGP was initiated to increase the vegetation and reduce erosion and sedimentation, which is the primary cause of the degradation in China's Yellow River and Yangtze River Basin (WWF 2003). According to the WWF (2003) records show that the annual soil loss in the two rivers in 2003 was 4 billion tons. Many environmental experts believe that soil erosion is the primary cause of the devastating floods that have been occurring late 1990 (WWF 2003). In addition to reducing the degradation of China's two largest rivers the GGP has increased the terrestrial carbon, since the forest absorbs carbon when it is growing (Li Shun-long 2006). Although this was not the primary target of GGP, Shun-long mentions the importance of increasing the reforestation as one way of controlling the carbon dioxide level.

1.2. Introduction to the problem

China accounts for the largest carbon dioxide emissions in the world. According to United Nations (2006), China's emissions accounted for 6.1 Gt carbon dioxide in 2006 which was 21.5% of the global annual carbon dioxide emissions. According to Canadell (2007), the conversion from natural vegetation to croplands worldwide has reduced global net primary productivity by about 5% and released 182–199 Gt carbon (C) to the atmosphere. Changes in land use since 1850 are responsible for 33% of the increased concentrations of carbon dioxide observed in the atmosphere, 68% of which are due to conversion to cropland (Houghton 1999).

China has long been experiencing intense land use/cover changes. During the mid-1900s, China underwent a period of widespread deforestation. China's relative lack of reforestation during and after this period left the country exposed to severe environmental problems, including widespread soil erosion, flooding and dust storms (Wang 2004). Forest degradation reached a peak during the ''Great Leap Forward'' (1958–1960) (Chen et al. 2007). Current land degradation in China is mainly caused by too intensive agriculture, including overgrazing of steppes and excessive cutting of trees and shrubs for fuelwood (Zhang et al. 2007). It is estimated that, in 1999, land degradation in China caused a direct loss of 7.7 billion USD (4% of GDP[1]); indirect losses are estimated at 31 billion USD (Bai and Dent 2009). Because of the intensive use, China's agricultural soil have relatively low carbon content level, hence it may have a great potential for carbon sequestration through improved land management. In recent years China's croplands have lost 1.6% of their soil organic carbon (SOC) per year compared to U.S. croplands that have only lost 0.1% (Yan et al. 2007).

As a response to the severe Yellow River drought in 1997 and devastating floods in 1998 in the Yangtze River Basin the central government initiated the Grain for Green program in 1999 (Xu et al. 2006). The aim of the GGP is to bring problems with soil erosion and desertification to a halt. According to Xu (2006), a proper forest coverage in the Yangtze and Yellow River basins could reduce the soil erosion by 80–90%.

Large-scale vegetation cover in China has increased due to the land-use change that the GGP have introduced. The program has been successful in reducing the soil erosion. The land-use conversions on the Chinese Loess Plateau between 1990 and 2005 have resulted in reduced soil erosion (Feng et al. 2010). As the area under the GGP increased, sediment concentration and sediment discharge into the upper reaches of the Yangtze River both decreased (Zhou et al. 2009). According to the concept of carbon sink the increase in vegetation cover has also resulted in an increase of terrestrial carbon. Even though carbon sequestration has not been a major objective of China's reforestation and forest protection programs, there is a growing interest in this additional benefit. The objective of this study is to estimate the carbon sequestration potential under GGP and the research question of this study is therefore:

- How much carbon has been and can be sequestrated under the Grain for Green Program?

Bioenergy is a renewable resource and it is argued that it is one of the solutions to the world's severe energy crisis. Bioenergy might meet the requirements of sustainable development and is needed if China and the World should cope with the ongoing environmental deterioration. Li (2009) have studied the development of bioenergy resources in China and mention that species such as Salix, Tamarix, Sea-Buckthorn, and Caragana show immense potential to be planted as energy plants in marginal lands. These species are among the most common planted under the GGP. Another widely used species is Black Locust which is the main species in Shaanxi province (Ostwald and Chen 2006). Black Locust ideally suited for woody biomass plantings (Barrett 1990). Barret (1990) claims that commercial energy production may eventually become one of its primary uses. This leads to the sub question of this study:

- What is the potential for bio-energy from the forest planted due to the Grain for Green Program?

1.3. Purpose

The purpose of this paper is to quantify the amount of carbon that has been mitigated through the conversion of cropland to forestland under the GGP. The analysis aims to discuss the possible additional benefits of the GGP. The authors also hope to inspire for further research in this area.

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[1] GDP – Gross domestic product

1.4. Delimitations

In order to estimate the carbon sequestration under the Grain for Green program a number of delimitations was needed.

1.4.1. No rotation

In a study about carbon sequestration under the GGP in Yunnan Chen (2009) lists the minimum rotation for different species, none being less than 26 years. In another study Niu and Duiker (2006) uses two management schemes: Permanent forest without harvesting and short-rotation with trees harvested every 20 years. Because the time frame of this study only is a 10-year period it is reasonable to assume that the period is too short for any rotation to occur with bamboo as an exception. For bamboo a growth rate that assumes harvest after 5 years has been used. For all other species it is assumed that the only three factors affecting the standing volume per area are growth rate, survival rate and replanting rate.

1.4.2. Grassland

The total area of converted land into grassland from 2002 until 2009 is 638 761 ha, in relation to the area converted into forestland this is about 3%. Because the converted area in 1999, 2000 and 2001 was not available and that the area converted to grassland is marginal compared to conversion to forestland grassland was not included in this study.

2. Method and materials

This section presents material used in the study and describes the choice of method. The first part describes carbon sequestration, the Grain for Green program and other concepts that are essential to this study. Thereafter the model and the calculations are presented.

2.1. Carbon sequestration

Carbon dioxide is released into our atmosphere when combusting carbon-containing fuels such as oil, natural gas, coal and biomass or by clearing natural vegetation. Technological options for reducing anthropogenic emissions of carbon dioxide include reducing the use of fossil fuels, substituting fossil fuels and enhancing the absorption of atmospheric carbon dioxide by natural systems.

Carbon sequestration is the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes. Carbon accumulates in trees, grasses, and other plants through photosynthesis. The carbon sink in forests and wood products helps to offset sources of carbon dioxide to the atmosphere, such as deforestation, forest fires, and fossil fuel emissions. Increasing net carbon sequestration by afforestation/reforestation is one way of mitigating the greenhouse effect.

2.1.1. Afforestation/Reforestation

Afforestation and reforestation both refer to planting of trees on non-treed land. Reforestation refers to planting of forest on land that had recent tree cover, whereas afforestation refers plantations on land that has been without forest for a long time (IPCC 2000). United Nations Framework Convention on Climate Change (UNFCCC) defines afforestation as the establishment of trees on land that has not had forest on it the last 50 years and reforestation as the establishment of trees on land that has had forest on it within the last 50 years, but is not currently forested (Zomer et al. 2008).

2.1.2. Bioenergy

Bioenergy is renewable energy made from the biomass. As long as biomass is produced sustainably, with only as much used as is grown, it will not increase the atmospheric carbon dioxide. With China's growing dependence on imported fossil fuel energy security has become a key driver in renewable energy development, in addition to concerns to reduce the environmental consequences of economic development. The Government has committed to increase the share of renewable energies in 2020 to 16% of the total energy supply (Greenpeace International 2007). Renewable energy sources include hydropower, solar energy, wind power and also bioenergy. Biomass is the most abundant renewable energy resource in China and the government has set up a 30 000 MW by biomass in electricity generation target by 2020 (Greenpeace International 2007). A problem with biomass is that some biomass resources are already being used for non-energy purposes, such as those being used as raw materials in the paper-making industry (Gan and Yu 2008).

2.2. Carbon inventory and carbon stock

A carbon inventory involves estimation of changes in the carbon stock in biomass and in soil, normally expressed in tonnes of carbon per hectare for a given land-use system and time

(Ravindranath and Ostwald 2008). The IPCC defines five carbon pools for carbon inventory (IPCC 2003): above-ground biomass and below-ground biomass, litter, deadwood and soil organic carbon. To estimate the terrestrial carbon stock many methods have been developed throughout the years, including several methods for each carbon pool. A description of the various methods is presented by Ravindranath and Ostwald (2008). The choice of method used to estimate each carbon pool depends on several factors such as project area, needed accuracy and available information.

The forestry carbon stock in China has been estimated in several studies. Zhao and Zhou (2006) estimate the Chinese forestry carbon stock to be 3.8 Gt C, Zhou (2000) estimated it to be 6.2 Gt C, Fang and Wang (2001) estimated it to be 4.2 Gt C and 3.2 Gt C was estimated by Wang (2001). Guo (2009) estimates China's forestry carbon stock with three different methods (4.0–5.9 Gt C, 5.7–7.7 Gt C and 4.2–6.2 Gt C) and conclude that the discrepancy between different estimates may be largely attributed to the methods used. It can be concluded that the forestry carbon stock in China should be between 3.2 and 7.7 Gt C. This can be compared with Brazil 54.7–82.7 Gt C, which has the largest carbon stock in the world (Gibbs et al. 2007). A few regional carbon sequestration studies of the GGP have been made, but no study has been made of the entire program. The GGP carbon forestry stock have been estimated for example in Yunnan Province (Chen et al. 2009), Chongqing municipality (Chen et al. 2009) and Liping County (Caldwell et al. 2007).

Chen (2009) calculates the carbon sequestration under the GGP in Yunnan and Chongqing with the use of area, empirical growth curves, basic wood density, biomass expansion factors and carbon fraction while Caldwell (2007) uses a GIS (Geographic information system) based integrated assessment model for Liping county. The model uses both remotely sensed data and ground-collected data.

Although only a few studies on carbon sequestration potential by afforestation have been done in China, carbon sequestration potential by afforestation is a well studied subject around the world, studied by Tassone (2004) in Italy, in United States by Niu and Duiker (2006) and in Chile by Palo (1999) among many others. Several models have been developed that analyze and simulate carbon stocks and fluxes at the level of the forest stands, for example CO2FIX (Masera et al. 2003), InTEC (Chen et al. 2000) and CENTURY (Parton et al. 2005). In addition to the many models developed for general use many countries have developed models to calculate the national forest carbon stock. One example is CBM-CFS3, which is the operational-scale Carbon Budget Model of the Canadian Forest Sector (Hagemann et al. 2010). It is used to calculate the Canadian forest carbon stocks and stock changes and simulate and compare various forest management scenarios in order to assess impacts on carbon. It is compliant with requirements under the Kyoto Protocol and with the Good Practice Guidance for Land Use, Land-Use Change and Forestry. Because the described models are very extensive and require a lot of data these models cannot be used in this study therefore a simplified model suited for the information attained was developed.

Since the first commitment period of the Kyoto Protocol came into force in 2008, afforestation projects planned for the period 2008–2012, and prior to 2008, can be certified under the Clean Development Mechanism (CDM) (Thomas et al. 2007). In 2006 reforestation projects in Pearl River Watershed in Guangxi was the first in the world to be registered under Kyoto Protocol regulations (Li and Yang 2009). Although the carbon dioxide reductions due to the GGP do not fall under the CDM since the reductions must be additional to what would have been the baseline and since the GGP would have been implemented anyway the reductions are not additional.

2.3. The Grain for Green Program

The pilot phase began in 120 counties in Sichuan in the second half of 1999. Experiments followed in Gansu and Shaanxi before the GGP was expanded nationwide in 2001 (Xu et al. 2006). In 2008 the program was implemented in more than 2000 counties across 25 provinces containing large ecological and economic heterogeneity and involved tens of millions of rural households (Bennett 2008). The goal of the GGP is to increase vegetative cover by 32 million hectare by 2010 affecting 40–60 million rural households. The provinces included in the GGP are presented in Figure 1.

Figure 1. Included provinces, municipalities and autonomous regions. Source: The authors

The primary targeted area of the GGP was the basins of the Yellow and Yangtze River, seen in Figure 1. The Loess plateau located in the upper and middle reaches of the Yellow River is a part of this area. It is well known for severe soil erosion and degraded land. Over 60% of the land suffers from various degrees of soil erosion as a consequence of unsustainable use and degraded vegetation cover, as well as the presence of deep, loose yellow soils (Li et al. 2009). The GGP mainly focuses on steep slopes that seriously threaten to degrade the water quality in the rivers. The steepness criterion means that the program in Southwest China targets land with 25 degrees of slope or more for participation. In Northwest China, the program targets land with 15 degrees of slope or more (Xu et al. 2006).

The land converted under the GGP can be divided into to two different systems, either by type of land or by type of plantations (State Forestry Administration 1999-2008). The categories when dividing the area by type of land are:

1. Cropland converted to forestland
2. Barren land converted to forestland

Figure 2 and Figure 3 shows examples of the two different land categories described above.

Figure 2 Example of cropland converted to forestland using Walnut (*Juglans regia*) Source: The authors

Figure 3 Example of Barren land coverted to forestland using Chinese fur (*Cunninghamia lanceolata*) Source: The authors

Table 1. Converted land divided into type of land. Source: State Forestry Administration (1999-2008)

Land converted 2001-2008		
Type	Area (ha)	Share (%)
Cropland	**8 227 786**	40.88
Barren land	**11 900 481**	59.12
Total	**20 128 267**	100

When dividing the area converted under the GGP by types of plantations the categories are:

1. Environmental protection forest: The main purpose of protection of forests is water and soil conservation, to create wind-breaking forests for farmland and grassland protection (State Forestry Administration 1999-2008).

2. Wood for material use: The main purpose is timber production, including the production of bamboo both for constructions and for the pulp and paper industry (State Forestry Administration 1999-2008).

3. Economical forest: The production of fruits, edible oils, beverages, spices, industrial raw materials and medicinal herbs is the main aim of economical forests (State Forestry Administration 1999-2008).

4. Energy forest: The production of fuel is the main purpose (State Forestry Administration 1999-2008).

5. Forest for special use: The purpose of this type of forest is environmental protection, scientific experiments, scenic forests, monuments and revolutionary memorial places (State Forestry Administration 1999-2008).

Table 2. Converted land per plantation category. Source: State Forestry Administration (1999-2008)

Plantation categories 2001-2008				
Timber	Economy	Protection	Firewood	Special use
2 497 449 Ha	1 641 823 Ha	15 147 756 Ha	118 808 Ha	32 072 Ha
12.6%	8.5%	77.9%	0.6%	0.2%

For the planned retired area 75% must be designated as ecological forests for ecological protection purposes, while 25% is classed as economical forests, which refer to orchard crops or trees with medicinal value. Economical species can also be used for ecological plantings. For ecological plantations the planting density is generally higher, this means that tree species used for ecological plantings may also yield commercial gain as long as the planting density is high enough. The main feature of the GGP is that the Chinese government provides free grain and cash payments for the participating farmers. The annual grain (that is unprocessed grain for human consumption) payment made to participants in the Yangtze River Basin and other southern regions is 2250 kg per year per hectare of converted land. In the northern regions and in the Yellow River Basin, the payment amounts to 1500 kg per annum per hectare. The amount of cash payment is 300 Chinese Yuan (CNY) per annum per hectare of cropland converted. The payment of grain and cash for cropland to grassland is made for two years, whilst for the conversion of cropland to forest comprising commercial species the period of payment is five years. For cropland converted to ecological forests the payment is eight years (Bennet et al. 2008).

For barren land converted to forestland the species planted may, as well as for cropland, have commercial value even though they are designated as providing ecological benefits. The central government provides funds to the provincial authorities that in turn provide the farmers with samplings to a value of CNY 50 per mu[2] converted barren land (Bennet et al. 2008).

The farmer who contracts with the village to convert croplands to forest and grassland owns the related use rights. In other words, the farmers who plant trees or grass hold the property right to the trees or grass (Bennett et al. 2008). The county government issues the tenure certificate after the registration of the land use change as well as the ownership certificate of the trees or grass. The duration of the tenure extends to 70 years (Bennet et al. 2008). Even though the farmers holds the rights to the trees the forest under the GGP are not allowed to be harvested until over mature according to the legislations set up by the State forestry administration (Chen et al. 2009).

2.3.1.Species

A very small fraction of China's 2500 tree species are currently planted in reforestation efforts, with Larch (*Larix sp.*) predominant in northern China, hybrid Poplar (populus) along the eastern seaboard,

[2] 1 ha equals 15 mu

and Chinese-fir (*Cunninghamia lanceolata*) and Masson pine (*Pinus massoniana*) in southern China (Chen et al. 2007).

Although the vegetative cover and forested area have increased, the diversity of tree species chosen for the GGP is typically low, and the tree species planted may not be the same as the native species. A single or a few tree species often dominate the land affected by the GGP in many places. For instance, in Jiangxi Province, 60% of the converted land in 2006 was planted with Tea bush (Oil camellia). In Henan province during 2000–2005, Poplar accounted for 40% of the reforested area, whereas other species accounted for <2% and fruit trees were planted on the remaining area (Liu et al. 2008). From a case study by Li et al. (2001) it has been conducted that Seabuckthorm (*Hippophaerhamnoides rhamnoides*), Black Locust (*Robinia pseudocacia*), and Chinese Pine (*Pinus tabulaeformis*) are the main tree species used in Shaanxi province. Shaanxi province is the province with the largest area affected by the GGP. It accounts for 10% of the total area under the GGP. According to Ge (2001) the common species for Gansu province are Caragana (*Caragana intermedia*), Sea buckthorn (*Hippophae rhamnoides*), *Tamarix austromongolica*, Siberian elm (*Ulmus pumila*), Apricot (*Prunus armeniaca*), and Lavender milk-vetch (*Astragalus adsurgens*).

The number of species planted per hectare must comply with state regulations standards Planting Density Standard for Economical Forestry (GBT15776-1995) and the Planting Density Standard for Ecological Forest (GBT18337,3-2001). The Planting Density Standard for Economical Forestry includes planting densities for 30 different orchard crops where intercropping is possible for 5 out of the 30 species. The planting density for intercropping is lower than orchard planting without intercropping. Planting Density Standard for Ecological Forest covers all ecological species included in the GGP. The standard covers planting densities for 108 species.

2.3.2. Survival rate

Many argue that one of the greatest challenges faced by the GGP is a low survival rate on the plantations (Li et al. 2001; Uchida et al. 2007; Wang et al. 2007). A wide range of survival rates have been recorded (Shen et al. 2003); (Bennett 2008). Some reasons, such as geographical differences, can seem to be obvious while others are more complex. An example of geographical differences is the Loess plateau where the survival rates are generally lower because of water shortage (Wang et al. 2007).

A more complex reason is that forest management activities ensuring tree planting and regeneration have not been well incorporated into the program (Yin and Yin 2009). Many places that received the assignment to implement the GGP were not traditional forest areas and lacked experience in afforestation and the necessary technologies, for example in Yunnan province (Zuo 2002). The program's lack of forest management activities such as tending and thinning resulted in lower survival rates (Yin and Yin 2009). However there is also some evidence of successful implementation of technical support. In Hancheng, Shaanxi province, technical staff increased the survival rate of Chinese prickly Ash (*Zanthoxylum*) from 52% to 95%. In Suide County, also Shaanxi province, farmers implemented a technique that enabled a survival rate of 95% even in serious drought year (Yao et al. 2001).

The survival rate criteria for both cropland and barren land converted during the pilot period divided the converted land into two regions: arid or semi-arid regions and general regions. The arid and semi-arid regions are found in the north and the acceptance survival rate is 70% (high plateaus, mountainous areas, uplands or barren) while the general regions are located in the south with an acceptance survival rate of 85%. As mentioned by Bennett (2008) this was later revised to a nationwide standard of 75% for both cropland and barren land. If the requirement were not fulfilled the township authority may suspend that year's compensation and only renew it when the survival rates meet the established criteria (Sylvie et al. 2007). According to Zuo (2002) and Bennet (2008) low survival rates have generally not resulted in significant withholding of subsidies. As Zuo (2002) observed, the main reason for this would appear to be that the dual goals of environmental improvement and poverty reduction, withholding subsidies based on low survival rates can significantly dampen enthusiasm for the program and potentially harm participant welfare. When the trees planted failed to survive, both farmers and the local governments have attributed this to "uncontrollable factors" such as issues related to water sources and rabbit and rat prevention (Zuo 2002).

An additional stipulation during the pilot phase was that, in conjunction with retirement of cropland, a set proportion of barren land was to be afforested. The barren land could be afforested without any survival rate criteria (Bennett 2008).

A literature study of available survival rate data has been performed and 24 samples were found in 12 different references. The study included searching online databases in English as well as in Chinese. Survival rates for different regions have been summarized and are presented in Table 1. The regions are located in nine provinces all located in central China, lacking samples from the most western and eastern parts of China. Most of the sources were found in Gansu province and Shaanxi province which is not that surprising since both these provinces were included in the pilot phase, 1999-2001. The summary has a good coverage from north to south, Zhuozi County, Inner Mongolia, in the north to Luquan County, Yunnan in the south. Most samples are mean values for a county and only three of the studies have been performed after 2003.

Table 3. Survival rates of selected GGP affected provinces.

	Province	Area	Year	Survival rate	Reference
1	Gansu	40 key counties	2000-2002	83,1%	(Wang 2003)
2	Gansu	Tongwei County	2003-2005	85,0%	(Liu and Li 2007)
3	Gansu	Jingning County	2003	73,3%	(Bennett 2008)
4	Gansu	Linxia County	2003	68,4%	(Bennett 2008)
5	Gansu	Dingxi County	2001	23,8%	(Xu and Cao 2002)
6	Guizhou	Liping County	2001	90.0%	(Pan 2007)
7	Guizhou	Dafang County	2001	90,0%	(Xu and Cao 2002)
8	Inner Mongolia	Zhuozi County	2001	80,0%	(Xu and Cao 2002)
9	Ningxia	Pengyang County	2001	85,0%	(Xu and Cao 2002)
10	Qinghai	Huangyuan County	2001	72,1%	(Jin 2002)
11	Qinghai	15 counties	2003	66% - 88%	(Min et al. 2003)
12	Shaanxi	Suide County	2001	95%	(Yao et al. 2001)
13	Shaanxi	Yanchuan County	2003	89,8%	(Bennett 2008)
14	Shaanxi	Liquan County	2003	66%	(Bennett 2008)
15	Shaanxi	Jingbian County	1999-2000	26,8%	(Jiao 2005)
16	Shaanxi	Ansai County	2001	52,4%	(Xu and Cao 2002)
17	Shaanxi	Along the Great Wall in Northern China	2001	20% - 40%	(Yao et al. 2001)
18	Shaanxi	Northern Shaanxi Province	2005	49%	(Shixiong et al. 2009)
19	Shanxi	Luliang Mountains,Taihang Mountains	2008	30%	(Han and Li 2008)
20	Sichuan	Chaotian County	2003	68,2%	(Bennett 2008)
21	Sichuan	Li County	2003	79,7%	(Bennett 2008)
22	Sichuan	Tianquan County	2001	90,0%	(Xu and Cao 2002)
23	Yunnan	Luquan County Sayingpan Town	2003	85%	(Yang 2004)
24	Yunnan	Heqing County	2001	70,1%	(Xu and Cao 2002)

1. After trees were replanted a total survival rate of 90.14% was achieved; 2. Average of mountain peaches survival rate of 76.7%; Sophora japonica survival rate of 91.4%; Sea buckthorn survival rate of 84.8%; Caragana survival rate of 87.2%; 3. Average of three township: Zhigan, Gangou, Lingzhi. Three inspections for each township; 4. Average of three township: Zhangzigou, Tiezhai, Hexi. Three inspections for each township; 7. Second-time planting was needed in order to reach the acceptance rate; 8. Second-time planting was needed in order to reach the acceptance rate; 9. Second-time planting was needed in order to reach the acceptance rate; 10. Average of Sea buckthorn, Populus, Wolfberry, Birch, Elm; 12. There is water shortage in most parts of Shaanxi, droughts, forest (grass) and low survival rate are serious problems; 13. Average of three township: Yanshuiguan, Majiahe, Yuji. Three inspections for each township; 14. Average of three township: Yanxia, Jianling, Chigan. Three inspections for each township; 15. The survival rate improved in 2001-2002, a result of replanting; 16. Second-time planting was needed in order to reach the acceptance rate; 18. Five randomly selected counties (Jingbian, Ansai, Baota, Yanchang, Luochuan) out of the 25 counties in northern Shaanxi Province; 20. Average of three township: Datan, Zhongzi, Shahe. Three inspections fot each township; 21. Average of three township: Shangmeng, Puxi, Guergo. Three inspections fot each township; 22. Second-time planting was needed in order to reach the acceptance rate; 23. Returning farmland to forest completion rate of 100%;24. Second-time planting was needed in order to reach the acceptance rate;

The survival rate in the samples range from 23.8% up to 90%, which indicate great diversity and it can be concluded that survival rate can have a great impact on the carbon sequestration under the GGP. An analysis found the following reasons for the diversified survival rates:

- Geographical differences

- Some samples are success cases
- Replanting resulting in higher survival rates
- Low survival rates during pilot phase

Geographical differences

The lowest survival rates are found in the arid areas of Shaanxi province and Gansu province while samples in the southern provinces of China, Yunnan and Guizhou, show perceivably higher survival rates.

Some samples are success cases

Suide County, Shaanxi province has exceptionally high survival rate. The reason for this was implementation of forest management activities. This is a rare case and the survival rate of this sample should not be interpreted as a mean value of the Shaanxi province. Yin (2009) questions the accuracy and reliability of the survival rate surveys, especially the ones based on State Forestry Administration (SFA) monitoring reports.

"Again, the SFA monitoring reports portray a rosy picture: the survival rate of the tree planting efforts was at least 85%, the forest coverage has been increasing steadily, and the tree and grass stocking level has improved markedly. However, it should be said that these reports were based on information provided by the local government agencies. Without independent validation and assessment, their accuracy and reliability may be questionable." (Yin et al. 2009)

Bennet (2008) describes how some areas have been chosen though they are not the most exposed. He explains that in some cases plots closer to roads have been targeted to "showcase" implementation to higher-level authorities.

Replanting resulting in higher survival rates

In order to receive subsidies, farmers have usually replanted the areas where trees have failed to survive. In many places, converted cropland has had to be replanted repeatedly in order to raise the survival rates (Zuo 2002). In the counties analysed by Xu and Cao (2002), the first survival rates were very low, ranging from 20 to 50%. Second-time planting was needed in order to reach the acceptance rate. The survival rates shown in Table 3 were after the second-time planting, with the exception of Dingxi of Gansu.

A field study in Baiwu Township, Yanyuan County, Sichuan, presents high survival rates but it also states that there has been a high demand for seedling replanting due to planting on arid and water deficient land (Trac et al. 2007).

Low survival rates during pilot phase

The summary shows that lowest survival rates have been noted during the pilot phase. The reasons for this included lack of adequate tree nurseries, water supplies, pest control, and farmer education (Davis 2006).

2.3.3. Grassland

Wang (2007) points out that only a limited area with good water conditions is suitable for tree plantation in north China. Area that has an arid or semi-arid climate with an annual precipitation less than 400 mm is only suitable for grass or scrub growth according to Wang. Wang describes how local people call the trees as ‘Xiao Lao Tou Shu’’ (small old men trees). The trees don’t grow tall because of water shortage. SFA has been enthusiastic about tree planting and regeneration, but not necessarily so with restoring grass coverage or natural re-vegetation (Yin et al. 2009).

2.3.4. Intercropping

Intercropping is generally regarded as a better way for ecological conservation and economic development but the encouragement of tree-crop intercropping likely makes local farmers only pay attention to grain production in pursuit of high income, leading to large-scale land degradation (Wang et al. 2007).

2.4. Field trip

The area concerned by the GGP is large and has great variations in the landscape, climate and species in various parts of China. Therefore it is very difficult to get a good picture of the program from a literature study. In order to get a better picture of the implementation of the GGP and to evaluate parameters and issues that affect the carbon sequestration a field trip to Shaanxi, Sichuan and Yunnan provinces were organized. One of the main purposes with the study visit was to assess the different species used in the GGP. This was due to classified data on national level regarding the species used in various provinces. The provinces chosen to visit were Shaanxi, Sichuan and Yunnan province. These provinces were chosen for the reasons mentioned below. Figure 4 shows the research group with local farmers in Shiyuan village in Sunyuan Town in Tongchuan City in Shaanxi Province.

- Both Shaanxi province and Sichuan province were part of the pilot project that started in 1999.
- Shaanxi province has the largest area of cropland converted, 1 001 000 ha or 10%, of all provinces concerned by the GGP.
- Shaanxi province is part of the Loess plateau where the erosion is extensive.
- Yunnan province is located in the south of China and has a different climate.

Figure 4. The research group with local farmers in Shiyuan village in Sunyuan Town in Tongchuan City in Shaanxi Province Source: The authors

2.4.1.Shaanxi province

Shiyuan village in Sunyuan Town in Tongchuan City in Shaanxi Province is situated north of Xian city on the south part of the Loess plateau. In this area, which belongs to the middle reaches of the Yellow river, erosion is severe and therefore large areas of cropland have been converted. During the field trip to Tongchuan City plantations with Chinese prickly ash (*Zanthoxylum simulans*)*,* Persimmon (*Diospyros virginiana*), Black locust (*Robinia pseudoacacia*) and Walnut (*Juglans regia*) was visited. All the plantations were from 1999, which is when the program started. The local farmers stated that the Walnut trees had grown especially big due to fertilization and irrigation. According to Shaanxi forestry department Black Locust (*Robinia pseudoacacia*) is the most commonly used species for barren land converted to forestland in this province. The overall survival rate of the plants for Shiyuan village was 85-90% with the highest for Chinese prickly ash (*Zanthoxylum simulans*), which is a very drought resistant plant. The survival rate of the persimmon was slightly lower. The commercial gain from the plantations was only in terms of pepper or fruits, since no harvesting occur. One of the observations made when travelling through the landscape outside Tongchuan City is the lack of natural forests.

Figure 5. Plantations with Chinese prickly ash (*Zanthoxylum simulans*). Tongchuan City, Shaanxi Province. Source: The authors

2.4.2.Sichuan province

Hongya County is situated south of Chengdu city south west of Meishan city. Minjiang and Qingyi rivers which flows through Hongya county are both branches of the Yangtze river and therefore makes this area an important part of the GGP. The plantations visited in Hongya county included Chinese cedar (*Cyptomeria fortunei Hooibrenk ex Otto et Dietr*), Bamboo (*Neosinocalamus affinis keng f*.), Bamboo (*Siobambusa tootsik Mekino*), Bamboo (*Phyllostachys pubescens*), Dawn Redwood (*Metasequoia glyptostroboides*) and Tea (*Camellia sinensis*). The Chinese cedar was planted in 2001 and the bamboo was planted around 2004-2007. The Dawn redwood and the Tea were planted in 2005. According to the local staff at Hongya forestry department the overall survival rate in Hongya County was between 85-90%. The Bamboo here is harvested with a few years interval and used in construction and the pulp and paper industry for example. This is done in order to keep the yield as high as possible. Hongya County is known for its dense forest cover and that is a well-deserved reputation. The most common species in the natural forests seemed to be various conifers.

Figure 6. Plantation with Bamboo (*Phyllostachys pubescens)* in Hongya County.

2.4.3. Yunnan province

Xinping County is situated south of Kunming city where the upper reaches of the Yangtze river has its southern branches. The plantations visited in Xinping included Bamboo (*Neosinocalamus affinis keng f.*) and Walnut (*Juglans regia*). According to Xinping forestry department the most commonly used species in Xinping are Walnut and Bamboo because of its economical benefits. The visited plantation of Walnut as well as the Bamboo was planted in 2003 and the survival rate was between 85-90% in Xinping County. For the visited plantations of Walnut (*Juglans regia*) intercropping with either Tobacco plants (*Nicotiana tabacum*) or crops was very popular. According to the local staff at Xingping forestry department this resulted in faster growth of the Walnut trees (*Juglans regia*). The local staff also explained that it has to be a certain amount of Walnut trees per mu for the land to be considered converted and as long as that criterion is fulfilled intercropping is possible. Also in Xinping County the Bamboo was harvested every year in order to keep the yield as high as possible. The general observation made when travelling through Xinping County is that forest mainly consists of mixed deciduous and coniferous wood with a relatively low amount of natural forest.

Figure 7. Walnut intercropping with Tobacco plants. Xinping County, Yunnan.

2.4.4. Data collected

The forestry statistics collected at the visited provincial forestry departments in Shaanxi Sichuan and Yunnan was the planted area for each species under the GGP. The planted area under the GGP program is divided into several categories presented in section 2.3. When meeting with the local forestry department's statistics covering all these five categories was asked for but only cropland converted to forestland was available. This means that categories 4 and 5, see section 2.3, were left out in the provincial data collected. When asking the local forestry departments about categories 4 and 5 they seemed very surprised and answered that these categories not were included in the GGP even though they are included in the program at national level.

The reported survival rate from the farmers was always around 85-90% for all plantations in the visited areas. All farmers described that in order to be economically compensated from the government the survival rate must be higher than 85%. This information deviates from information found in literature. The legislation behind the program also states that if some of the plants die new ones should replace them.

2.5. The model

As mentioned earlier there are many different methods and models for estimating the carbon pools. A first version of the model used in this study was set up after making an overview of the accessible material. The development of the method became an iterative process and adjustments in the model were required due to lack of data. The model calculates the carbon stock for an area divided into a number of regions. Data used in the model is:

- Area cropland converted to forestland per year for each region, see section 2.6.3.

- Carbon increment per area and year, see section 2.6.4.
- Time frame for the study, see section 2.6.1.

The model used in this report is influenced by the articles presented in the section above, especially the article by Chen (2009) about carbon sequestration under the GGP in Yunnan. The model, as for the article about Yunnan, is based on area and carbon increment per area and year. Although the model is similar to the one used by Chen there are some significant differences. The main difference between the article by Chen (2009) and this study is the use of area planted for each tree species. Data for each species was not available for most regions therefore a model with an average carbon increment fitted for the conditions of each region were developed.

Because of limited information it was needed to simplify the carbon inventory and to select the most critical carbon pools. IPCC (IPCC 2006) provides an approach called "key category analysis" that has been used in this study. The carbon pools that are recommended for afforestation and used in this study are:

- Above-ground biomass and below-ground biomass.

The carbon pools litter and deadwood will not be estimated because the accumulation of these pools is unlikely to be significant in the short period that will be analyzed (Ravindranath and Ostwald 2008). Ravindranath and Ostwald (2008) also mentions that in short-term projects, such as afforestation or reforestation projects of 2–5 years, soil carbon can be excluded as a key carbon pool. For example, in degraded lands considered for afforestation and reforestation, the stock of carbon in soil at the time of planting could be 30–60 tonnes C (ha yr)$^{-1}$, and annual incremental addition due to afforestation is likely to be low at 0.25–1 tonnes C (ha yr)$^{-1}$. Because of the small change it could be argued that the change in soil carbon also can be neglected and therefore soil carbon is not included in this study.

The total carbon stock for the different regions, i.e. provinces, is calculated according to equation 1,

$$C_{Total} = \sum_{j}\left[\sum_{i}(A_{i,j} \times C_{j} \times (Y - i))\right] \qquad \text{Equation 1}$$

where $A_{i,j}$ (ha) is the converted cropland for region *j* in year *i*. *Y* is the year the study was conducted, i.e. 2009. This means that the trees planted in year i=2008 has been growing for 1 year. C_j (tonnes C (ha yr)$^{-1}$) is the carbon increment per hectare and year fitted for the climate conditions of each for region *j*.

When the area planted for each tree species was available, i.e. in the province specific analysis, equation 2 was used to calculate the carbon stock for a specific region.

$$C_{Total} = \sum_{k}\left[\sum_{i}(A_{i,k} \times C_{k} \times (Y - i))\right] \qquad \text{Equation 2}$$

where $A_{i,k}$ (ha) is the planted area for specie *k* in year *i.* Y is the year the study was conducted, i.e. 2009. C_k (tonnes C (ha yr)$^{-1}$) is the carbon increment per hectare and year for specie *k*.

2.6. Data and calculations

This section gives a more detailed description of how the model has been used and which calculations that has been carried out. First an analysis regarding only cropland converted to forestland was carried out. This was done for two reasons: The first reason was that the provincial specific data for Shaanxi and Sichuan contained no information regarding barren land converted to forestland which ruled out the possibility to compare national results for barren land with provincial results for barren land. The second reason was that there is no barren land data for the years before 2001. Therefore barren land was excluded from the first analysis and analyzed separately. Second, an analysis including both cropland and barren land has been done and last the analysis for cropland and barren land including survival rate is presented.

2.6.1. Time frame

The time frame of this study is from 1999 until 2009. That means that the trees planted in 1999 has been growing for 10 years. The pilot phase of the GGP was initiated in 1999 in Shaanxi, Sichuan and Gansu and in 2001 the program was expanded to include 25 provinces (Bennett et al. 2008). The duration of the program in all of the 25 affected provinces is from 2001 to 2010, but because no data for 2009 and 2010 existed when this study was carried out the trees planted during these years were not included in the analysis. The time step used in the calculations was carbon sequestration per year. A smaller time step was not possible due to lack of information regarding the exact date of plantation for the various species.

2.6.2. Baseline

The baseline is what plausible could happen in the absence of the GPP. Bennett (2008) writes that the SFA Sloping Land Conversion Program Plan of 2003 does not include a baseline scenario and it is unclear what would happen in absence of the GPP. According to (Liu et al. 2005), during 1990–2000 cropland increased by 2.79 million hectare, including 0.25 million hectare of paddy land and 2.53 million hectare of dry farming land. The north-east and north-west regions of China gained cropland area while the north and south-east regions showed a loss of cropland area. Increasing cropland area is a possible baseline scenario.

The GGP was initiated with an aim to control soil erosion and combat desertification by restoring forest vegetation on degraded and decertified land, thus the program was mainly carried out at sites with degraded soil. Zhang (2009) describes serious land degradation and erosion with decreasing soil organic carbon. Assuming continued agriculture on degraded land as a business-as-usual scenario it can be assumed that the carbon sequestration would be equal to zero or negative.

The carbon sequestration baseline of this study is approximated to be zero assuming that the included croplands and barren lands would continue to degrade or at least be in a steady state.

2.6.3. Area

The area of cropland and barren land converted to forestland was collected from China Forestry Yearbook (1999-2008) (State Forestry Administration 1999-2008). In the yearbook the converted area of cropland and barren land is presented per province and per year. According to Bennett (2008) 25 provinces are included in the GGP but only data for 23 are presented in China Forestry Yearbook (1999-2008), there is no data for Beijing and Tianjin. The total area of only cropland converted in each province is presented in Figure 8. The largest converted regions can be found among the provinces that where included in the pilot phase, Shaanxi, Sichuan and Gansu whereas in

Hainan and Tibet very small areas have been converted. By the end of 2008 the accumulated converted cropland under the GGP was 8.23 million ha. Shaanxi stands for 12% of the total converted area and together with the two other pilot provinces, Sichuan and Gansu, they stand for 30%.

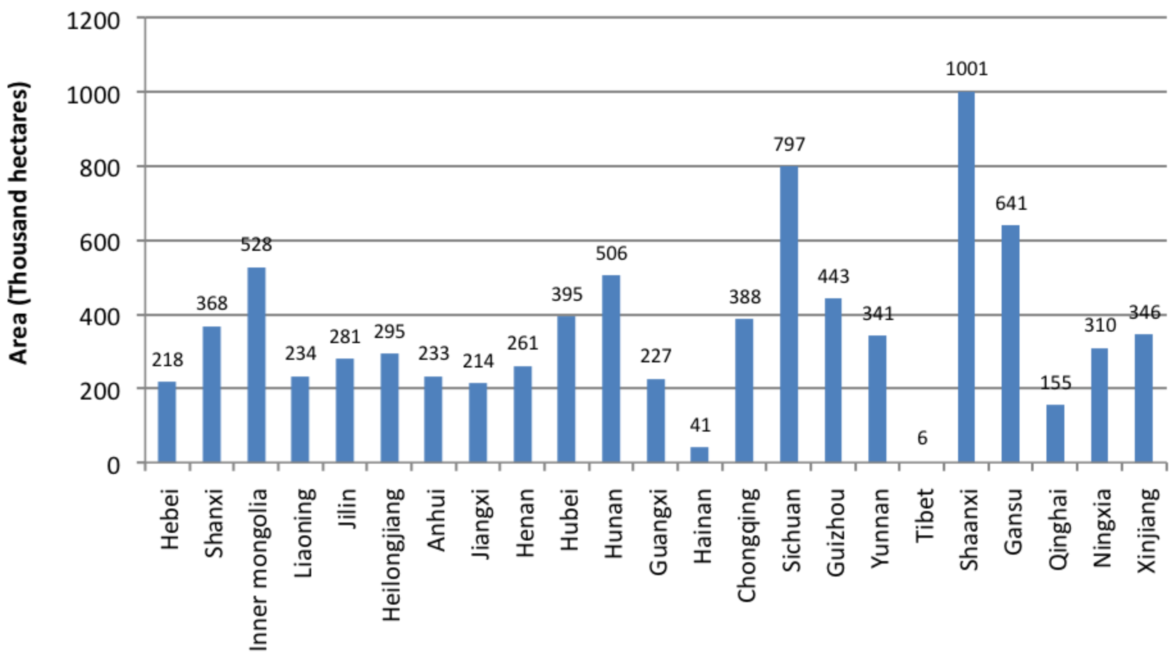

Figure 8. Converted cropland area (ha) per province 1999-2008 (State Forestry Administration 1999-2008).

Figure 9 shows the area of cropland, barren land as well as the total area converted to forestland in China since 1999 to 2008. From 2002-2003 a rapid increase in converted cropland can be seen and then it levels out in 2004. 72% of the converted cropland is converted between 2002 and 2004. The converted cropland in the earlier years is mainly in the pilot provinces while the Hebei, Heilongjiang and Jilin have converted large areas in last two years.

By the end of 2008 the accumulated converted barren land under the GGP was 11.9 million hectares. China forestry yearbook lacks data of barren land converted to forestland during 1999-2000 (State Forestry Administration 1999-2008). These years been left out of the analysis. From 2002-2003 a rapid increase similar to the cropland conversion per year can be seen but after 2003 the area of cropland converted per year levels out much faster than barren land converted per year.

The area of cropland and barrenland converted in each province each year was used for A_{ij} in Equation 1 where index i represents year and index j represents the region of study. Here the different regions are the 23 provinces included in China forestry yearbook (1999-2008) (State Forestry Administration 1999-2008).

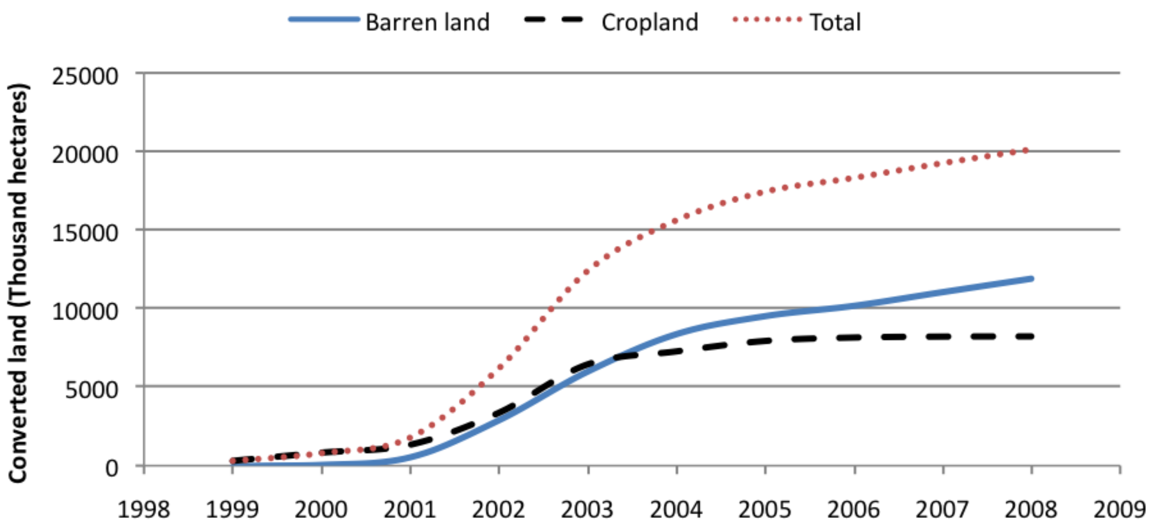

Figure 9. Total accumulated converted cropland and barren land area 1999-2008, data missing for barren land 1999-2000 (State Forestry Administration 1999-2008).

For the area converted from barren land to forestland there are several factors contributing to a more unsecure estimation. Those are:

- Barren land is originally not suitable for cropping due to low fertility and steep slopes.
- Farmers tend manage, fertilization and irrigation, the forest on former barren land less than forest on former cropland.
- Lower survival rate

2.6.4. Carbon increment

Further a measurement of the carbon increment fitted for the conditions in each region was needed, C_j in Equation 1. Three different types of values have been used: (1) First C_j values compiled from the Intergovernmental panel on climate change (IPCC) Guidelines for National Greenhouse Gas Inventories (GNGGI) was used. (2) Second, Net Primary Productivity (NPP) for different forest types and climates in China compiled from scientific articles was used as C_j values. (3) As a third way of estimating the carbon increment Mean Annual Increment (MAI) was used. In order to use the carbon increment values an analysis of the climate in each included province was needed.

China is one of the few nations to encompass nearly the earth's entire range of climate zones, with temperature regimes ranging from tropical to alpine/boreal, and precipitation regimes from humid to arid (Chen et al. 2007). Table 4 presents average yearly temperature, yearly precipitation and general climate in the affected provinces. The data is collected from the governmental homepage of each province. To validate the result of the climate study it was compared to a climate study of China by Shaohong et al. (2009). A map of the various climates in China from the study by Shaohong et al. (2009) can be seen in Figure 10. From Figure 10 it can be seen that some provinces, like Yunnan, have several different climate zones. For those provinces with various climate regions but where the areas of some climate zones are not substantially large, like Yunnan, the most common climate has been used in the analysis. For the provinces where substantially large areas have different climates the climate corresponding to the lowest carbon increment has been chosen in the analysis.

Table 4. Average yearly temperature, yearly precipitation and general climate of each province included in the GGP.

Province	Temp. [°C]	Precipitation [mm]	Climate	Humidity	GNGGI Def	Reference
Anhui	15	800-1800	Warm temperate/Subtropical	Semi-humid/Humid	Temperate continental forest/Subtropical humid	(Anhui Goverment 2006)
Chongqing	18	1000-1400	Subtropical	Humid	Subtropical humid forest	(Chongqing government 2007)
Gansu	7	50-500	Temperate continental	Dry	Temperate continental	(Gansu government 2004)
Guangxi	20	1000-2800	Subtropical	Humid	Subtropical humid forest	(Guangxi government 2008)
Guizhou	15	1100-1400	Subtropical	Humid	Subtropical humid forest	(Guizhou government 2005)
Hainan	24	>1600	Tropical	Humid	Tropical moist deciduous forest	(Hainan government)
Hebei	7	400-800	Temperate continental		Temperate continental forest	(Hebei government 2009)
Heilongjiang	1	400-650	Cold temperate continental	Semi-humid/Humid	Temperate continental forest	(Heilongjiang government)
Henan	14	500-900	Warm temperate/Subtropical	Semi-humid/Humid	Temperate continental forest/Subtropical humid	(Henan government)
Hubei	16	800-1600	Subtropical	Humid	Subtropical humid forest	(Hubei government 2008)
Hunan	18	1200-1700	Subtropical	Humid	Subtropical humid forest	(Hunan government)
Inner mongolia	7	100-500	Temperate continental	Arid/Semi-humid/Humid	Temperate continental forest	(China Culture 2003)
Jiangxi	18	1200-1900	Subtropical	Humid	Subtropical humid forest	(Jiangxi government 2008)
Jilin	4	400-600	Temperate continental	Humid/Semi-humid/Dry	Temperate continental forest	(Jilin Government 2008)
Liaoning	7	700	Temperate continental	Humid/Semi-humid	Temperate continental forest/Subtropical humid	(Liaoning government)
Ningxia	7	200-700	Temperate continental		Temperate continental	(Ningxia government)
Qinghai	4	<300	Highland continental	Arid/Semi-arid	Temperate mountain system	(Qinghai government 2010)
Shaanxi	13	400-800	Temperate/Warm temperate/Subtropical	Semi-arid/Humid	Temperate continental forest/Subtropical humid	(Shaanxi government 2008)
Shanxi	5	400-650	Warm temperate/Temperate continental		Temperate continental	(China Culture 2003)
Sichuan	16	500-1200	Subtropical	Semi-humid/Humid	Subtropical humid forest	(Sichuan government 2009)
Tibet	-2	400	Highland		Temperate mountain system	(Tibet government)
Xinjiang	11	150	Temperate continental		Temperate continental	(China Culture 2003)
Yunnan	15	1100	Temperate/Subtropical/Tropical		Temperate continental forest/Subtropical humid	(Yunnan government)

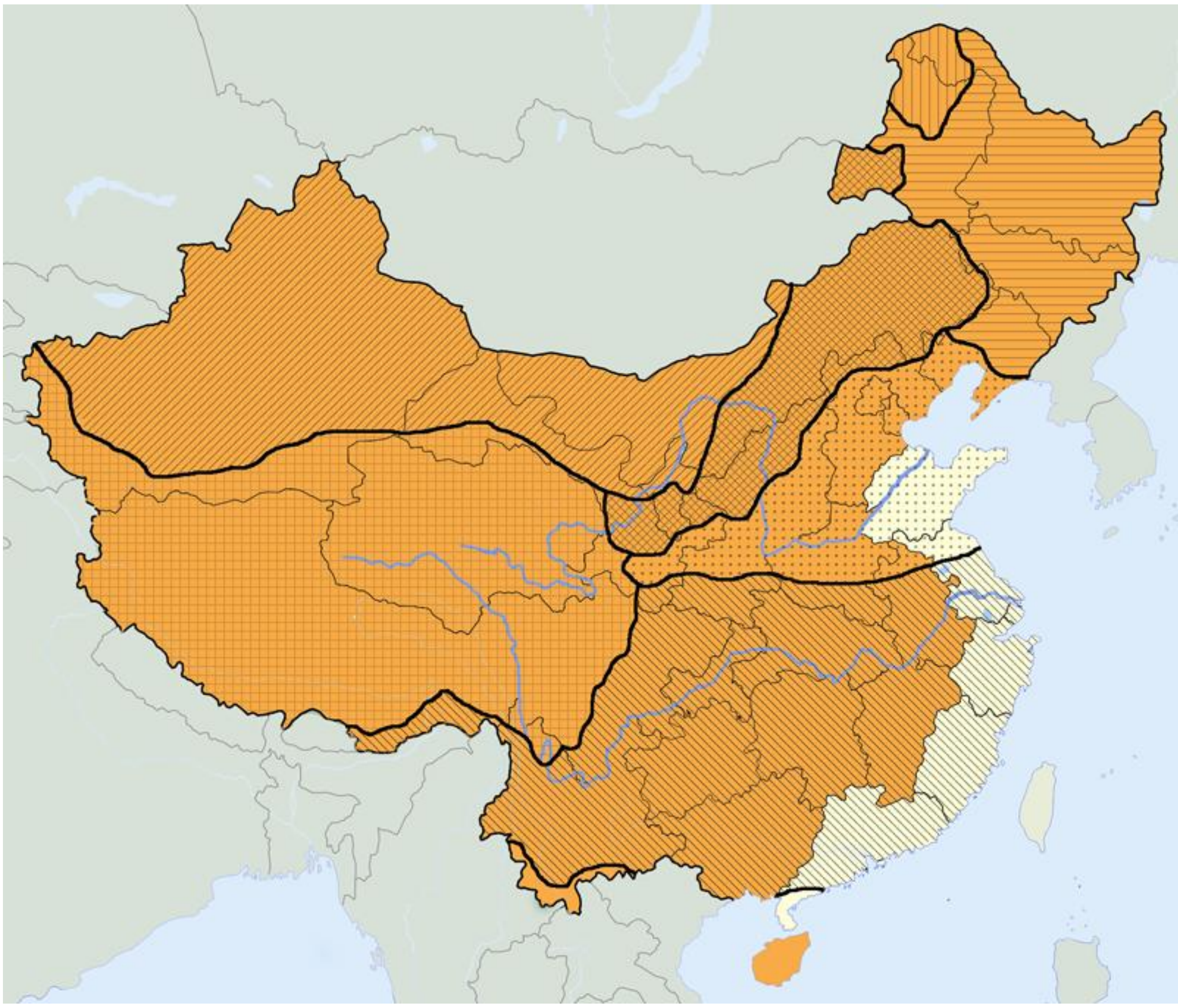

Figure 10. Ecoregions in China (Shaohong et al. 2009).

Table 5. Climate in China (Shaohong et al. 2009)

	Ecoregion	Typical natural ecosystem
	Cold temperate humid region	Deciduous coniferous forest
	Temperate humid/sub-humid region	Broad-leaved and coniferous forest
	North semi-arid region	Steppe
	Warm temperate humid/sub-humid region	Deciduous broad-leaved forest
	Sub-tropical humid region	Evergreen broad-leaved forest
	Tropical humid region	Seasonal rainforest and rainforest
	Northwest arid region	Desert
	Tibetan Plateau region	Alpine shrub meadow, alpine steppe, alpine desert

Approach 1, IPCC Guidelines for National Greenhouse Gas Inventories

The IPCC guidelines provide methods for estimating and reporting sources and sinks of carbon dioxide. IPCC's GNGGI (2006) divide the biomass growth in above-ground biomass and below-ground biomass. IPCC presents three different levels of inventory (Tier 1, 2 and 3). In general, a higher Tier improves accuracy of the inventory and reduces uncertainty but also requires more detailed information. Tier 1 is designed to be the simplest to use and equations and default values are provided by IPCC. For Tier 1 there are often globally available sources of default values to use although these data are usually spatially coarse (IPCC 2006).

Estimate above-ground biomass

This study follows the Tier 1 method and default values for above ground biomass growth (AGBG) were used. The AGBG values are divided into natural forest and for planted forest where planted forests are defined as intensively managed forests. For the GGP both intensively managed forests and extensively managed forest occur. For this reason two simulations with AGBG values corresponding to both intensively managed forests and extensively managed forests have been carried out. According to Marland and Marland (1992) is reasonable to assume that AGBG accumulates linearly until half of the maximum yield. Using this assumption it is possible to apply linear growth, constant AGBG, in the model. The AGBG values presented by IPCC (2006) includes twigs, branches and leaves so no Biomass Expansion Factor[3] is needed.

Estimate below-ground biomass

The root biomass is estimated as a proportion of the above-ground biomass. IPCC presents root to shoot ratio for various climate zones and above ground biomass density. These numbers comes from a study by Mokany et al. (2006) covering 266 sources (books, journals, conference proceedings, published reports, and thesis). According to Cairns et al. (1997) root biomass is normally within a small range of proportion of above-ground biomass with a mean root to shoot ratio (R) of 0.26. The mean root to shoot ratio obtained by Cairns et al. (1997) is slightly lower than the one obtained by Mokany et al. (2006). Because the density of the plantations under the GGP is not available this study uses the more conservative mean root to shoot ratio (R) suggested by Cairns et al. (1997). The below-ground biomass ratio was then multiplied with and added to the AGBG value to obtain a total value for biomass growth.

Carbon content

To convert biomass into carbon content a carbon fraction was used. The carbon fraction values vary between earlier studies. IPCC (2006) presents specific carbon content for selected boreal and temperate tree species between 0.32 for White pine (*Pinus Strobis*) to 0.58 for Oak (*Quercus sp*). Chen (2009) uses specific carbon content for each species, ranging from 0.44 for mixed broadleaf trees and 0.54 for Yunnan Pine (*Pinus Yunnanensis*). Wang (2002) on the other hand uses a carbon conversion coefficient of vegetation biomass of 0.5. This study also uses 0.5 due to no available specific data for all species and because it is suggested by IPCC (2006).

The province specific carbon increment obtained by combining values given by IPCC (2006) with the climate analysis, C_j used in Equation 1, can be seen in Table 6.

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[3] The ratio of the total above-ground tree biomass to the biomass of the merchantable timber

Table 6. Carbon increment using IPCC values for plantations and natural forest for each province (tonnes C $(ha\ yr)^{-1}$) (IPCC 2006).

Province	Plantation	Natural forest
Hebei	2.5 to 6.3	2.5 to 3.2
Shanxi	6.3	3.2
Inner mongolia	2.5	2.5
Liaoning	6.3	3.2
Jilin	6.3	3.2
Heilongjiang	6.3	3.2
Anhui	2.5	2.5
Jiangxi	2.5	2.5
Henan	2.5 to 6.3	2.5 to 3.2
Hubei	6.3	3.2
Hunan	6.3	3.2
Guangxi	2.5	2.5
Hainan	6.3	3.2
Chongqing	2.5	2.5
Sichuan	2.5	2.5
Guizhou	2.5	2.5
Yunnan	1.9	1.9
Tibet	2.5 to 6.3	2.5 to 3.2
Shaanxi	2.5	2.5
Gansu	6.3	3.2
Qinghai	0.6	0.6
Ningxia	2.5	2.5
Xinjiang	2.5 to 6.3	2.5 to 3.2

Approach 2, Net primary productivity

Net primary productivity (NPP) is the rate at which vegetation in an ecosystem fixes carbon from the atmosphere minus the rate at which the plants returns carbon to the atmosphere (McGuire et al. 1993). NPP have a close relationship with actual biomass growth (Zhao and Zhou 2005) and NPP can be divided into biomass growth and the turnover of short-lived plant organs (bark, branches, leaves, roots) also called short-term turnover or litter fall production (Pretzsch 2009). NPP is given in tonnes carbon per hectare and year. The short-term turnover usually follows an annual cycle so to be able to use NPP values for estimation of the carbon stock the short-term turnover must be subtracted. NPP minus the short-term turnover is frequently used in this report and will from now on be defined as: net carbon uptake.

- NPP (tonnes C $(ha\ yr)^{-1}$) – short term turnover = Net carbon uptake (tonnes C $(ha\ yr)^{-1}$)

Pretzsch (2009) mention that the short-term turnover is a substantial part of the NPP and it is closely linked to site conditions. Fine and small root production, which is an important part of the short-term turnover, depends on the soil conditions. Pretzsch (2009) gives an example where the turnover of fine roots is between 50 and 62% of the total NPP on dry soils, yet only between 31 and 40% on soils of medium humidity. The percentage of short-term turnover increases as nutrients and water supply become scarce. The short-term turnover also depends on stand age, species and stand treatment.

Pretzsch (2009) recommend that the net carbon uptake (tonnes C (ha yr)$^{-1}$) stand for 38% of NPP (tonnes C (ha yr)$^{-1}$).

Zhao (2005) studied the same relation between short term turnover and NPP for four planted forest types in China: Chinese pine (*Pinus tabulaeformis),* Masson pine (*Pinus massoniana*), Chinese fir (*Cunninghamia lanceolata*). According to Zhao (2005) NPP increases almost linearly with the increase in short term turnover. Using the correlations in the article the net carbon uptake accounted for 35-39% of NPP for Chinese pine (*Pinus tabulaeformis*)*,* 31-44% of NPP for Masson pine (Pinus massoniana) and 51-57% of NPP for Chinese fir (*Cunninghamia lanceolata*). Fang (2007) have studied short-term turnover for three temperate forest ecosystems, Birch (*Betula platyphylla*) forest, Oak (*Quercus liaotungensis*) forest and Pine (*Pinus tabulaeformis*) plantation in Mt. Dongling, Beijing, from 1992 to 1994. The conclusion was that net carbon uptake for birch forest, oak forest and pine plantation stands are 56%, 42% and 60% of NPP respectively. These two studies verify the arguments made by Pretzsch (2009) that the short-term turnover varies largely. Because it is not possible to get more exact data regarding the relationship between short term turnover and NPP this study uses the approximation made by Pretzsch (2009); net carbon uptake stands for 38% of NPP.

The NPP values used in this study from Jian (2003) and Feng et al. (2007) are China specific values for different forest types and climates from studies. NPP values from a study by Melillo (1993) are world average and was brought into the analysis for comparison with the China specific NPP values. Jian (2003) used forest inventory data when estimating the NPP and (Feng et al. 2007) used remote sensing. Forest inventory data for China, collected by Forest Ministry of China, has been conducted periodically (five-year cycle) for more than 30 years using mainly ground surveys (Zhao and Zhou 2005). The NPP values are given in tonnes carbon per hectare and year, which means that no carbon fraction is needed. The various NPP values for different climates put together in this study can be found in Table 7. From Table 7 it can be seen that the NPP values range from 2.4 (tonnes C (ha yr)$^{-1}$) (Melillo et al. 1993) to 4.5 (tonnes C (ha yr)$^{-1}$) (Jian 2003) for boreal forests, for temperate forests the NPP values range from 4.4 (tonnes C (ha yr)$^{-1}$) (Feng et al. 2007) to 4.5 (tonnes C (ha yr)$^{-1}$) (Jian 2003), for subtropical forest the NPP values range from 6.4 (tonnes C (ha yr)$^{-1}$) (Feng et al. 2007) to 7.4 (tonnes C (ha yr)$^{-1}$) (Melillo et al. 1993) whereas for Tropical forest the values range from 6.5 (tonnes C (ha yr)$^{-1}$) (Feng et al. 2007) to 11 (tonnes C (ha yr)$^{-1}$) (Melillo et al. 1993).

Table 7. Climate, forest type and NPP values. (tonnes C (ha yr)$^{-1}$).

Climate	Forest type	(Jian 2003)	(Feng *et al.* 2007)	(Melillo *et al.*1993)
Boreal	**Boreal forests/Cold temperate**: *Larix*, *Pinus sylvestris* var. *mongolica*	4.5	3.2	2.4
Temperate	**Temperate deciduous broad-leaved forests**: Mixed coniferous-broadleaf, *Larix, Pinus, Abies-Picea, Quercus, Fraxinus, Populus*	4.5	4.4	4.7
Subtropical	**Subtropical evergreen broad-leaved forests and coniferous forests**: *Cunninghamia lanceolata*, *P. massoniana*, *P. yunnanensis, P. khasya, Cupressus*, Bamboo	7	6.4	7.4
Tropical	**Rain and monsoon forests**:	8	6.5	11

These values were recalculated according short-term turnover factor by Pretzsch (2009) in order to obtain the net carbon uptake (tonnes C (ha yr)$^{-1}$). The next step was to combine the net carbon uptake with the climate study in order to obtain province specific carbon increment values, C_j in Equation 1. The province specific C_j values are presented in Table 8.

Table 8. Net carbon uptake (tonnes C (ha yr)$^{-1}$) values for each province.

Province	(Jian 2003)	(Feng et al. 2007)	(Mellio et al.1993)
Hebei	1.7	1.7	1.8
Shanxi	1.7	1.7	1.8
Inner Mongolia	1.7	1.7	1.8
Liaoning	1.7	1.7	1.8
Jilin	1.7	1.7	1.8
Heilongjiang	1.7	1.7	1.8
Anhui	1.7	1.7	1.8
Jiangxi	2.7	2.4	2.8
Henan	1.7	1.7	1.8
Hubei	2.7	2.4	2.8
Hunan	2.7	2.4	2.8
Guangxi	2.7	2.4	2.8
Hainan	3	2.5	1.6
Chongqing	2.7	1.7	2.8
Sichuan	2.7	1.7	2.8
Guizhou	2.7	2.4	2.8
Yunnan	2.7	2.4	2.8
Tibet	1.7	1.7	1.8
Shaanxi	1.7	1.7	1.8
Gansu	1.7	1.7	1.8
Qinghai	1.7	1.7	1.8
Ningxia	1.7	1.7	1.8
Xinjiang	1.7	1.7	1.8

Approach 3, Mean annual increment

A third way of estimating carbon sequestration under the GGP is Mean Annual Increment (MAI). MAI is usually given as the average increase in biomass volume of forest stands per hectare and year (m^3 (ha yr)$^{-1}$). MAI changes with the different growth phases in a tree's life, being the highest in the middle years and then slowly decreasing with age. The point at which MAI peaks is defined as maturity point of the stand (Brack 1996).

Xu et al. (2001) presents MAI values in tonnes carbon per hectare and year and therefore the values does not need to be converted. The values presented by Xu et al. (2001) are for long rotation plantations for three regions that are distributed in the southern and eastern parts of China. Regions and included provinces together with MAI values can be found in Table 9. Xu et al. (2001) does not include the North West part of China, leaving it out because it consist mainly of arid areas, deserts and cold high mountains with relatively little forest cover. When Sathaye et al. (2001) studied the carbon mitigation potential in Brazil, China, India, Indonesia, Mexico, the Philippines and Tanzania they used a total MAI value of 1.6 (tonnes C (ha yr)$^{-1}$) for all of China.

Table 9. Regions and provinces together with MAI values (tonnes C (ha yr)$^{-1}$) (Xu et al. 2001).

Region	Provinces	MAI (tonnes C (ha yr)$^{-1}$)
South West	Yunnan, Guizhou, Chongqing and Sichuan	1.8
South East	Hubei, Anhui, Jiangsu, Zhejiang, Fujian, Jiangxi, Hunan, Guangxi, Guangdong and Hainan	2
North East	Heilongjiang, Jilin and Liaoning	1.6

Food and Agriculture Organization (FAO) (2010) presents an average MAI of all plantations in China being 4 (m^3 (ha yr)$^{-1}$) at an average rotation age 25 years. Using a wood density of 0.5 (tonnes (m^3)$^{-1}$), a biomass expansion factor of 1.5 given by Pretzsch (2009), root to shoot ratio of 1.26 and a carbon fraction of 0.5 the MAI given by FAO (2010) is 1.89 (tonnes C (ha yr)$^{-1}$) which corresponds well with the values presented by Xu et al. (2001). As a comparison FAO (2010) also presents some MAI values for fast growing plantation species; Chinese fir (*Cunninghamia lanceolata*) 10.5 (m^3 (ha yr)$^{-1}$) and Poplar (*Populus sp*). 22.5 (m^3 (ha yr)$^{-1}$). These fast growing species have much higher MAI values than the average. In this study the values presented by Xu et al. (2001) will be used and for the provinces that are not included in Xu et al. (2001) a value of 1.6 (tonnes C (ha yr)$^{-1}$) will be used.

2.6.5. Shaanxi and Sichuan specific analysis

In order to verify the estimation of the carbon sequestration of the cropland converted under the GGP an extra estimation for Shaanxi and Sichuan was done with specie-specific data. The specie-specific data covered planted area and carbon increment for Shaanxi and Sichuan province. The area planted of each species under the GGP was collected from the local forestry departments in Shaanxi and Sichuan. The local data collected, Table 10 and Table 11, covered cropland converted to forestland from year 1999-2006. The area for each species was used as A_{ik} in Equation 2. China specific NPP values for most of the various species were compiled in a literature study and can be found in Table 10 and Table 11. Due to lack of NPP data regarding orchard crops NPP values for deciduous broadleaf trees of 5.45 (tonnes C (ha yr)$^{-1}$) from a study by Jian et al (2001) was used. The same assumption was used by Xinzhang et al. (2007). This assumption has been verified in studies by Yang and Guan (2008) and Wang (2008) where it can be seen that the NPP for orchard crops is similar to the NPP for deciduous broadleaf trees. For bushes such as Chinese prickly ash, Mulberry and Tea bush a general NPP value for bushes of 4.5 (tonnes C (ha yr)$^{-1}$) from a study by Jiang et al. (1999) has been used. The species specific NPP values were recalculated according to the study by Pretzsch (2009) in order to obtain the net carbon uptake (tonnes C (ha yr)$^{-1}$). The net carbon uptake was used in Equation 2 as C_k.

The provincial specific data were not divided between which year each species was planted. Therefore a weighting from the statistics in the China forestry yearbook (1999-2008) was used. The forestry yearbook presents the total area of cropland converted for each province every year. From these values the yearly percentage of converted cropland was calculated. The yearly percentage of cropland converted was multiplied with standing age Y in Equation 2. By doing this a simulated standing age for each species was created.

The data mentioned above was used in Equation 2 to estimate the carbon sequestration by the trees planted on former cropland under the GGP in Shaanxi and Sichuan provinces.

Table 10 Area of the various species used in Sichuan province 1999-2006.

Ecological species	Ha	Category	NPP (tonnes C $(ha\ yr)^{-1}$)	Carbon (tonnes C)	Reference
Alnus *(Alnus cremastogyne)*	32836	Deciduous broadleaf	5.45	440277	(Jian et al 2001)
Bamboo (*Bambusa sp.*)	116893	Specie specific value	8.374	2408236	(Yang et al 2008)
Birch (*Betula*)	3732	Specie specific value	7.165	65782	(Jian et al 2001)
Black locust (*Robinia pseudoacacia*)	12440	Deciduous broadleaf	5.45	166802	(Jian et al 2001)
Chinese cedar *(Cyptomeria fortunei Hooibrenk ex Otto et Dietr)*	9718	Value for *cupressus*	6.18	147752	(Jian et al 2001)
Chinese fir (*Cunninghamia lanceolata*)	64628	Specie specific value	8.33	1324463	(Jian et al 2001)
Cypress (*Cupressus*)	87939	Specie specific value	6.18	1337043	(Jian et al 2001)
Eucalyptus	30330	Evergreen broadleaf	10.96	817817	(Jian et al 2001)
Ginko (*Ginko biloba*)	11226	Deciduous broadleaf	5.45	150516	(Jian et al 2001)
Larch *(Larix gmelini)*	8938	Specie specific value	5.16	113466	(Jian et al 2001)
Other	96840	Mixed coniferous-broadleaf	4.97	1184100	(Jian et al 2001)
Pine (*Pinus sp.*)	52166	Specie specific value	3.33	427373	(Jian et al 2001)
Poplar (*Populus alba*)	31001	Specie specific value	7.165	546466	(Jian et al 2001)
Seabuckthon (*Hippophae rhamnoides*)	15418	Elm sparse woods and shrubs	4.5	170693	Jiang et al (1999)
Yunnan fir (*Abies Forrestii*)	18381	Value for Abies-Picea	4.235	191513	(Jian et al 2001)

Economical species	Ha	Category	NPP (tonnes C $(ha\ yr)^{-1}$)	Carbon (tonnes C)	Reference
Apple (*Malus domestica*)	98	Deciduous broadleaf	5.45	1316	(Jian et al 2001)
Cherry (*Prunus cerasus L*)	466	Deciduous broadleaf	5.45	6249	(Jian et al 2001)
Chestnut (*Castanea*)	16387	Specie specific value	5.45	219724	(Jian et al 2001)
Chinese prickly ash (*Zanthoxylum*)	23819	Elm sparse woods and shrubs	4.5	263697	Jiang et al (1999)
Eucommia ulmoides	6926	Deciduous broadleaf	5.45	92870	(Jian et al 2001)
Grapes (*Vitis vinifera*)	429	Deciduous broadleaf	5.45	5751	(Jian et al 2001)
Loquat (*Eriobotrya japonica*)	4706	Deciduous broadleaf	5.45	63102	(Jian et al 2001)
Mango (*Mangifera indica*)	1775	Deciduous broadleaf	5.45	23803	(Jian et al 2001)
Mulbery (*Morus rubra*)	64829	Elm sparse woods and shrubs	4.5	717724	Jiang et al (1999)
Orange (*Citrus sinensis*)	6952	Deciduous broadleaf	5.45	93214	(Jian et al 2001)
Other	46469	Deciduous broadleaf	5.45	623070	(Jian et al 2001)
Peach (*Prunus persica*)	8228	Deciduous broadleaf	5.45	110326	(Jian et al 2001)

Pear (*Pyrus communis*)	12373	Deciduous broadleaf	5.45	165895	(Jian et al 2001)
Plum (*Prunus*)	1622	Deciduous broadleaf	5.45	21751	(Jian et al 2001)
Pomelo (*Citrus grandis*)	4042	Deciduous broadleaf	5.45	54199	(Jian et al 2001)
Tea bush (*Camellia sinensis var*.)	28739	Elm sparse woods and shrubs	4.5	318169	Jiang et al (1999)
Walnut (*Juglans regia* L)	68003	Specie specific value	5.45	911803	(Jian et al 2001)
TOTAL	888347			13184966	

Table 11 Area of the various species used in Shaanxi province 1999-2006.

Ecological species	Ha	Category	NPP (tonnes C (ha yr)$^{-1}$)	Carbon (tonnes C)	Reference
Black locust (*Robinia Pseudoacacia*)	173893	Deciduous broadleaf	5.45	2496501	(Jian et al 2001)
Caragana (*Caragana sinica*)	10841	Elm sparse woods and shrubs	4.5	128507	(Jiang 1999)
Chinese fir (*Cunninghamia lanceolata*)	29421	Specie specific value	8.33	645577	(Jian et al 2001)
Chinese Pine (*Pinus tabulaeformis*)	16384	Specie specific value	5.955	257009	(Jian et al 2001)
Chinese Toons (*Toona sinensi*)	472	Deciduous broadleaf	5.45	6781	(Jian et al 2001)
Chinese white pine (*Pinus armandi*)	35	Specie specific value	5.955	542	(Jian et al 2001)
Cypress (*Taxodium*)	11411	Specie specific value	6.18	185758	(Jian et al 2001)
Dogwood (*Cornus*)	68616	Deciduous broadleaf	5.45	985087	(Jian et al 2001)
Elm (*Ulmus americana*)	1578	Elm sparse woods and shrubs	4.5	18702	(Jian et al 2001)
False indigo (*Amorpha fructiosa*)	25654	Elm sparse woods and shrubs	4.5	304099	(Jiang 1999)
Honeysuckle (*Lonicera periclymenum*)	200	Elm sparse woods and shrubs	4.5	2365	(Jiang 1999)
Japanese pagoda tree (*Sophora japonica*)	175	Deciduous broadleaf	5.45	2517	(Jian et al 2001)
Japanese raisin tree (*Hovenia dulcis thunb*)	442	Deciduous broadleaf	5.45	6350	(Jian et al 2001)
Jujube (*Ziziphus zizyphus*)	39387	Elm sparse woods and shrubs	4.5	466893	(Jian et al 2001)
Maple (*Acer Truncatum*)	47	Specie specific value	5.65	706	(Jiang 1999)
Masson pine (*Pinus massonia*)	4740	Specie specific value	8.74	109128	(Jian et al 2001)
Oak (*Quercus*)	5674	Specie specific value	5.665	84671	(Jiang 1999)
Oriental arborvitae (*Platycladus orientalis*)	28895	Specie specific value	3.45	262603	(Jiang 1999)
Poplar (*Populus sp.*)	12620	Specie specific value	7.165	238194	(Jian et al 2001)
Sea Buckthorn (*Hippophae rhamnoides*)	64125	Elm sparse woods and shrubs	4.5	760138	(Jian et al 2001)
Torch tree (*Ixora pavetta*)	31	Deciduous broadleaf	5.45	442	(Jian et al 2001)
Tree of heaven *(Ailanthus altissima)*	12375	Deciduous broadleaf	5.45	177657	(Jian et al 2001)

Economical species	Ha	Category	NPP (tonnes C (ha yr)$^{-1}$)	Carbon (tonnes C)	Reference
Apple (*Malus domestica*)	8076	Deciduous broadleaf	5.45	115936	(Jian et al 2001)
Apricot (Prunus armeniaca)	129251	Deciduous broadleaf	5.45	1855586	(Jian et al 2001)
Prunus armeniaca/Caragana sinica	13518	Deciduous broadleaf	5.45	194064	(Jian et al 2001)
Bamboo (*Bambusa sp.*)	3673	Specie specific value	11.26	108940	(Jian et al 2001)
Chestnut (*Castanea*)	33404	Deciduous broadleaf	5.45	479562	(Jian et al 2001)
Chinese prickly ash (*Zanthoxylum*)	66462	Elm sparse woods and shrubs	4.5	787846	(Jian et al 2001)
Dry fruit	8147	Deciduous broadleaf	5.45	116959	(Jian et al 2001)
Eucommia ulmoides	6437	Deciduous broadleaf	5.45	92420	(Jian et al 2001)
Fruit trees	2871	Deciduous broadleaf	5.45	41221	(Jian et al 2001)
Ginkgo Biloba	453	Deciduous broadleaf	5.45	6502	(Jian et al 2001)
Grapes (*Vitis vinifera*)	110	Elm sparse woods and shrubs	4.5	1302	(Jiang 1999)
Ziziphus zizyphus/Prunus armeniaca	167	Deciduous broadleaf	5.45	2394	(Jian et al 2001)
Kaido crab apple (*Malus micromalus Makino*)	33	Deciduous broadleaf	5.45	479	(Jian et al 2001)
Lacquer tree (*Rhus verniciflua*)	6359	Deciduous broadleaf	5.45	91295	(Jian et al 2001)
Lemon tree (*Citrus*)	1498	Deciduous broadleaf	5.45	21510	(Jian et al 2001)
Loquat (*Eriobotrya japonica*)	307	Deciduous broadleaf	5.45	4400	(Jian et al 2001)
Medecinal shrubs	1154	Elm sparse woods and shrubs	4.5	13674	(Jiang 1999)
Medecinal trees	13631	Deciduous broadleaf	5.45	195697	(Jian et al 2001)
Mulberry (*Morus rubra*)	28841	Elm sparse woods and shrubs	4.5	341884	(Jiang 1999)
Nut fruit	28264	Deciduous broadleaf	5.45	405766	(Jian et al 2001)
Papaya (*Carica papaya*)	2558	Deciduous broadleaf	5.45	36719	(Jian et al 2001)
Peach (*Prunus persica*)	15214	Deciduous broadleaf	5.45	218422	(Jian et al 2001)
Pear (*Pyrus communis*)	4450	Deciduous broadleaf	5.45	63884	(Jian et al 2001)
Persimmon (*Diospyros virginiana*)	3969	Deciduous broadleaf	5.45	56982	(Jian et al 2001)
Plum (*Prunus*)	84	Deciduous broadleaf	5.45	1200	(Jian et al 2001)
Pomegranate (*Punica granatum*)	398	Deciduous broadleaf	5.45	5710	(Jian et al 2001)
Pomelo (*Citrus grandis*)	88	Deciduous broadleaf	5.45	1267	(Jian et al 2001)
Tea bush (*Camellia sinensis var.*)	6550	Elm sparse woods and shrubs	4.5	77639	(Jian et al 2001)
Walnut (*Juglans regia L*)	39709	Deciduous broadleaf	5.45	1484603	(Jian et al 2001)
TOTAL	932688			13964090	

2.6.6. Survival rate analysis

As mentioned earlier, the greatest challenge that the GGP have faced, according to many researchers, is low survival rates. Low survival rates could have an impact on the carbon sequestration potential of the GGP, and therefore it is of interest to analyze the impact. Although survival rate is already included in the values given by IPCC, the NPP and MAI values it have been argued that survival rate can be even lower. Survival rate have been included in the mathematical model as shown below:

$$C_{Total} = \sum_j \left[\sum_i (A_{i,j} \times SR \times C_j \times (Y - i)) \right] \quad \text{Equation 3}$$

where $A_{i,j}$ (ha) is the converted cropland for region j in year i. Y is the year the study was initiated, i.e. 2009. C_j (tonnes C (ha yr)$^{-1}$) is the carbon increment per hectare and year fitted for the conditions of each for region j and SR is the survival rate. Based on the discussion about survival rate, section 2.3.2, together with the fact that the initial survival rate criteria in the pilot phase was 70%, a conservative survival rate of 70% has been assumed in this analysis.

In order to receive subsidies, farmers have usually replanted the areas where trees have failed to survive. In many places, converted cropland has had to be replanted repeatedly in order to raise the survival rates. Therefore it is of interest to include replanting in the analysis. In this analysis it have been assumed that the area where trees have failed to survive have been replanted next year.

Replanting has been included in the mathematical model as shown below:

$$C_{Total} = \sum_j \left[\sum_i (A_{i,j} + (1 - SR) \times (A_{i-1,j})) \times SR \times C_j \times (Y - i)) \right] \quad \text{Equation 4}$$

where $A_{i,j}$ (ha) is the converted cropland for region j in year i and $A_{i-1,j}$ is the area planted the year before. Y is the year the study was initiated, i.e. 2009. C_j (tonnes C (ha yr)$^{-1}$) is the carbon increment per hectare and year fitted for the conditions of each for region j and SR is the survival rate. A survival rate of 70% has been assumed also in this analysis.

It is assumed that all trees that don't survive the first year are replanted the year after, but replanting only occurs once. The reason for replanting only once is that it is sufficient for reaching an acceptable survival rate.

3. Result

In this section the result of the calculations is presented. First the estimated carbon sequestration by converting cropland is presented. Second, estimated carbon sequestered by converting barren land is presented. Third, the result from the specific analysis of cropland converted in Shaanxi and Sichuan are shown. In the fourth part the effect of survival rate is presented and last the result have been compared to earlier work.

3.1. Conversion of cropland

In Figure 11 the carbon sequestrated by converting cropland is presented, three of these are based on NPP values whereas two are based on values from IPCC and one is based on MAI. The highest result is given by IPCC plantations while the lowest result is given when using NPP from the study by Feng et al. (2007). All the NPP results and the MAI result are lower than the IPCC results. The result ranges from 103 million to 209 million tonnes carbon sequestered for the total area of cropland converted. The China specific NPP from studies by Jian (2003) and Feng (2007) results and the result by the global values used by Melillo et al. (1993) are very similar with Melillo et al. (1993) being slightly larger.

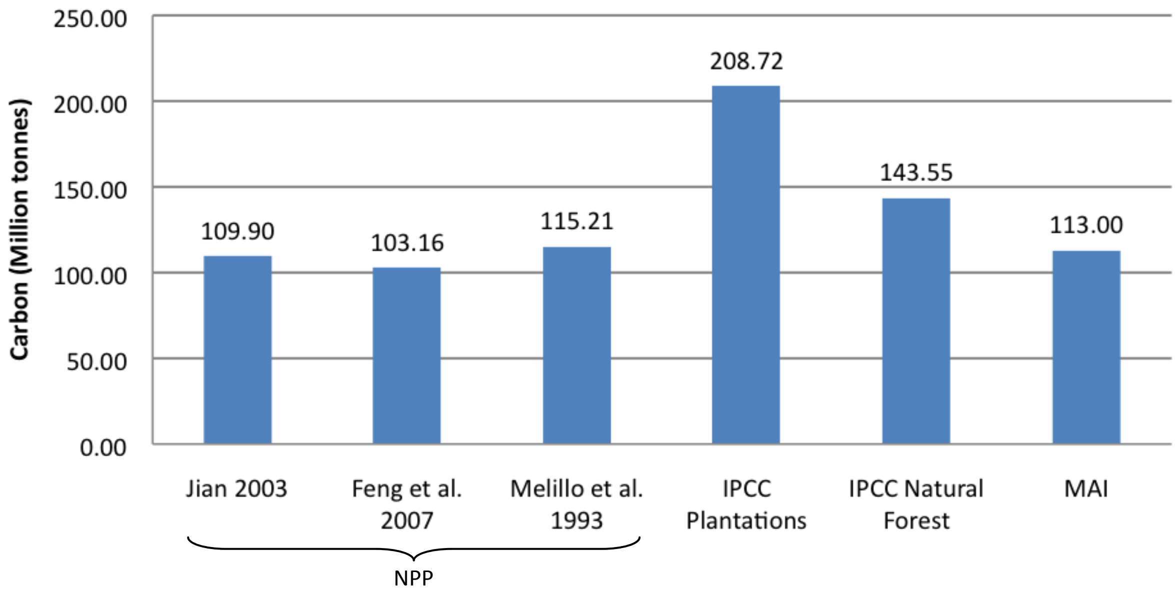

Figure 11. Total amount of carbon sequestrated by conversion of cropland under the GGP 1999-2008 (tonnes).

3.1.1. Conversion of cropland per province

Figure 12 shows the average carbon sequestration for each province. Sichuan has the highest value, 17.5 million, followed by Shaanxi, 14 million tonnes carbon. Sichuan and Shaanxi are the only two provinces with values higher than 10 million tonnes carbon. Other provinces with large values are Guizhou, Hunan, Hubei, Gansu, Inner Mongolia, Chongqing and Yunnan. All these provinces except Shaanxi, Inner Mongolia and Gansu have sub tropical climate meaning higher annual carbon sequestration per hectare. Gansu and Inner Mongolia are the provinces with the largest converted area after Shaanxi and Sichuan. Tibet has the lowest carbon sequestration value being only 26 500 tonnes carbon.

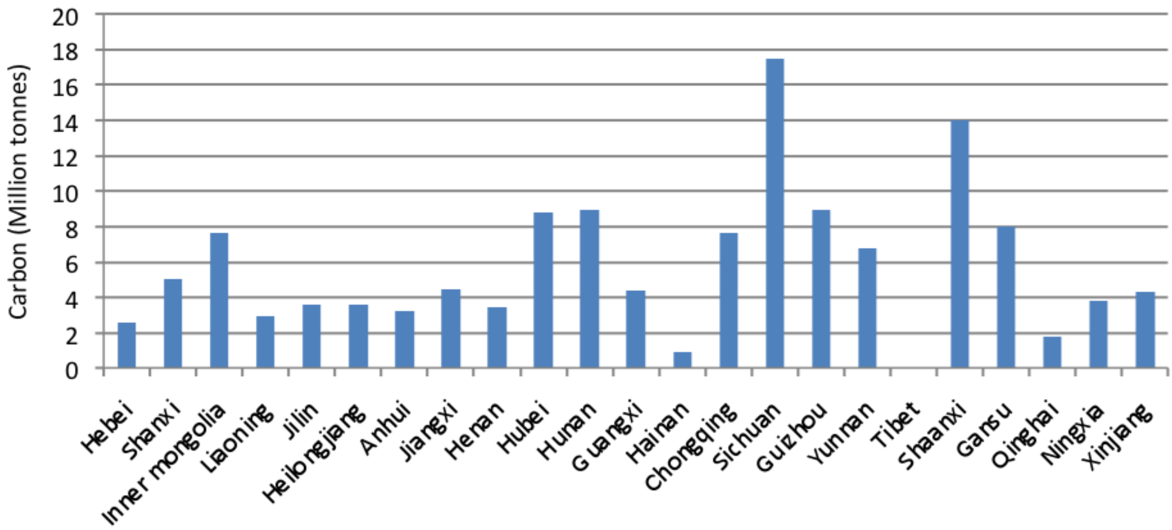

Figure 12. Average amount of carbon sequestrated by conversion of cropland under the GGP 1999-2008 per province (tonnes).

3.2. Conversion of cropland and barren land

Even though the data used for barren land converted only is from 2001 to 2008, the total area of barren land converted is larger than the area of cropland converted. Because of this the result of carbon sequestrated by barren land conversion is also larger as can be seen in Figure 13. The highest value for cropland and barren land conversion is 468 million tonnes carbon and the lowest value is 222 million tonnes carbon. There is a large difference, 246 million tonnes, between the highest value by IPCC Plantations and the lowest using NPP by Feng et al. (2007).

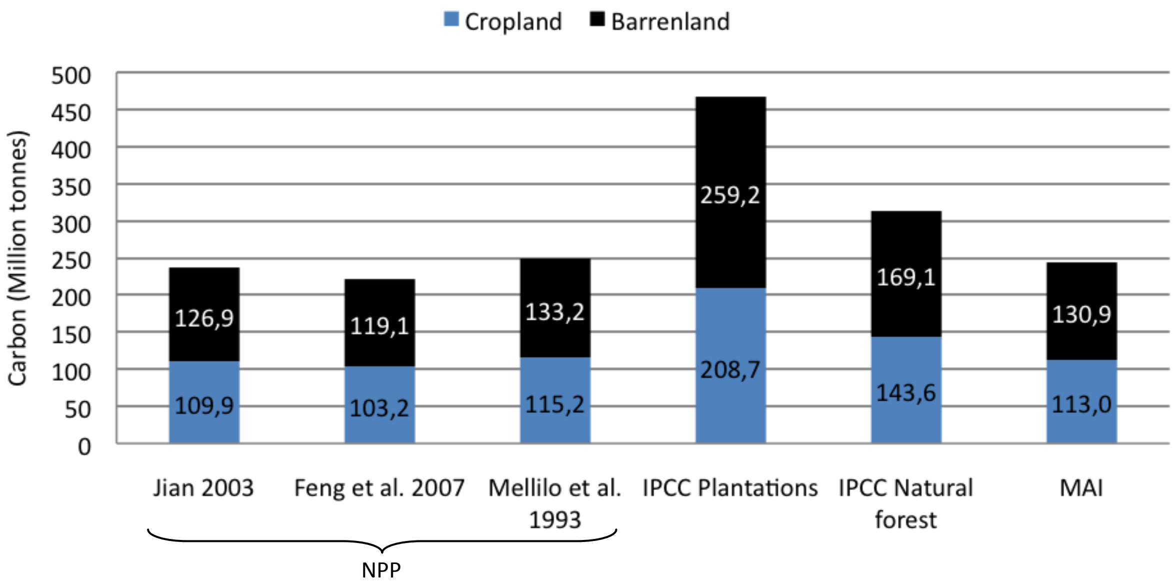

Figure 13. Total amount of carbon sequestrated by conversion of cropland (46.4%) and barren land (53.6%) under the GGP 1999-2008, data missing for barren land 1999-2000 (tonnes).

3.2.1. Conversion of cropland and barren land per province

Shown in Figure 14, for most provinces the carbon sequestration under barren land and cropland is almost equally large, barren land being a little larger. Only Xinjiang, Qinghai, Shaanxi, Sichuan and Jilin have larger carbon sequestration through cropland conversion than through barren land.

Sichuan has the largest value, 31.7 million tonnes carbon while Tibet has the lowest, 209 thousand tonnes.

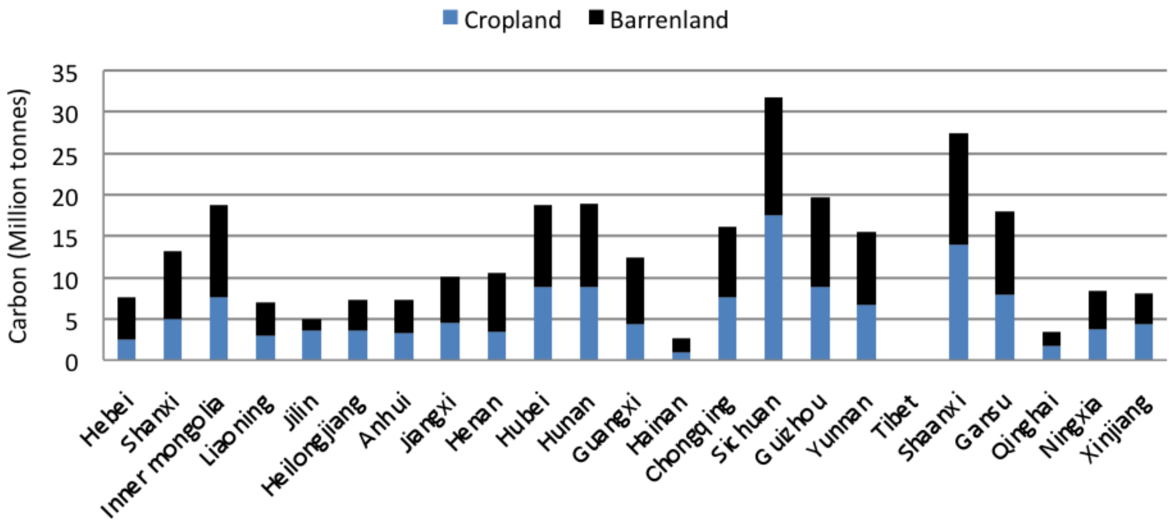

Figure 14. Average amount of carbon sequestrated by conversion of cropland and barren land under the GGP 1999-2008 per province (tonnes).

3.3. Shaanxi and Sichuan specific analysis

The result from the Shaanxi specific analysis, seen in Figure 15, corresponds well with the results given by NPP and MAI while the result given by the IPCC values is higher. The carbon sequestration according to Shaanxi specific analysis is 14 million tonnes carbon.

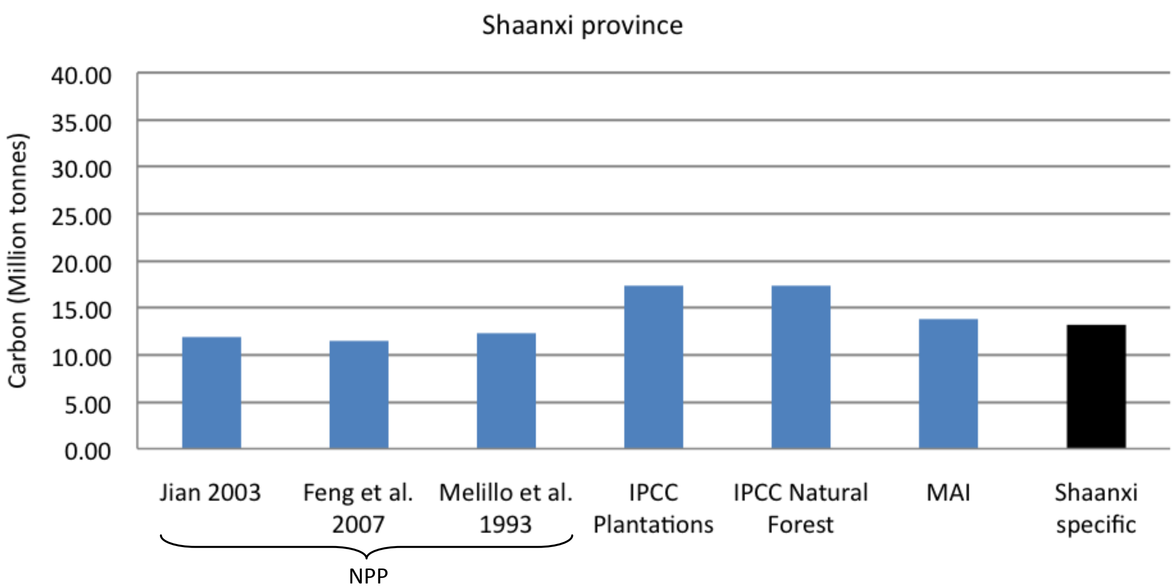

Figure 15. Amount of carbon sequestrated by conversion of cropland under the GGP 1999-2008 in Shaanxi Province.

Figure 16 shows that the Sichuan specific result corresponds well with all the other results except the IPCC Plantation result. The Sichuan specific value is 13,2 million tonnes carbon. The IPCC Plantation result is more than twice as much as the rest of the results.

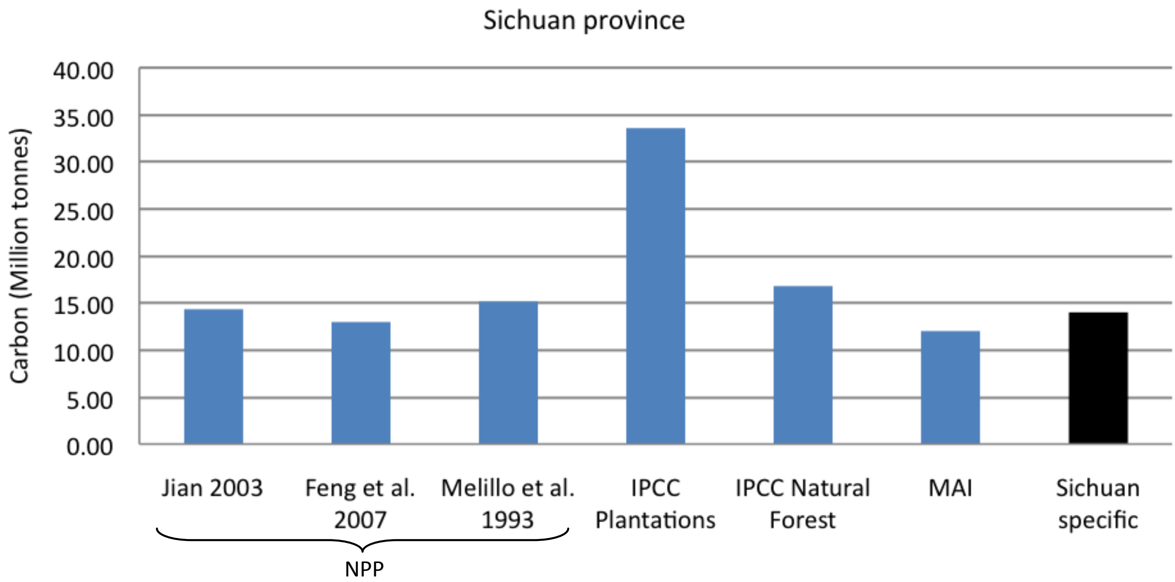

Figure 16. Amount of carbon sequestrated by conversion of cropland under the GGP 1999-2008 in Sichuan Province.

3.4. Survival rate

The result of the calculations including a survival rate of 70% is shown in Figure 17. Because there is a linear relation between the survival rate and the result the result is 30% less than without survival rate. Survival rate of 70% together with replanting of the dead plants does not affect the result significantly; the result is only 5% less than without survival rate.

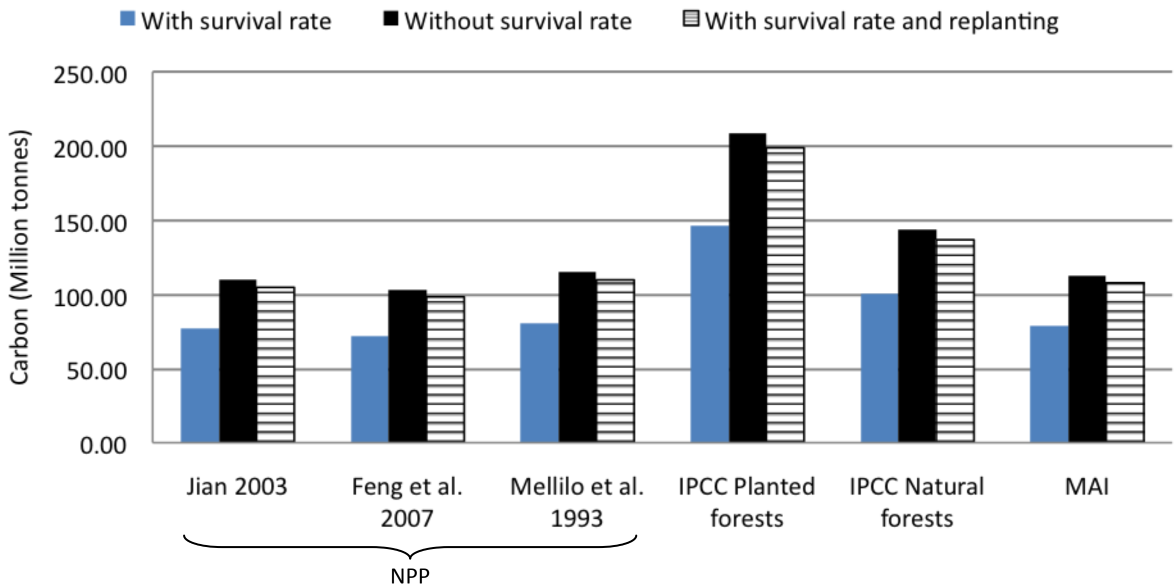

Figure 17. Sequestration by conversion of cropland including survival rate.

3.5. Comparison to earlier work

The result for Yunnan province is 10.7 million tonnes carbon for MAI, 11.6 for Feng et al. (2007), 12.7 for Jian (2003), 13.5 for Melillo et al. (1993), 14.9 for IPCC Natural Forest and 29.8 for IPCC Plantations. According to the article mentioned in section 2.5 by Chen et al. (2009) the GGP-stands in Yunnan Province will increase by 12.6 million tonnes carbon by the year 2010. All results accept IPCC Plantations corresponds well with the result given by Chen et al. (2009). The results are very similar but it is important to point out that the time frames of the two studies differ with one year. The results are compared in Figure 18.

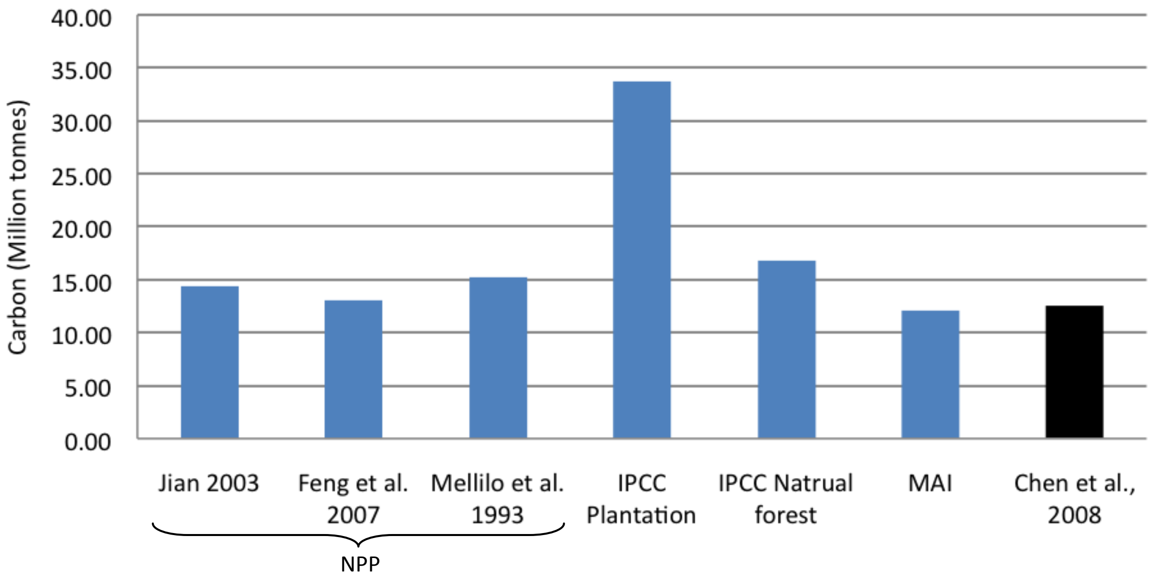

Figure 18 Carbon sequestration under the GGP-stands in Yunnan Province

Chen et al. (2009) have also analysed the carbon stocks in the GGP-stands in Chongqing Municipality and finds it to be 14.5 million tonnes carbon by the year 2010. The result of this study, 9.6 million tonnes carbon for MAI, 12.0 for Feng et al. (2007), 13.2 for Jian (2003), 14.0 for Melillo et al. (1993), 16.7 for IPCC Natural Forest and 33.5 for IPCC Plantations, also corresponds well with the result by Chen et al. (2009) with the exception of IPCC plantation. The results are compared in Figure 19.

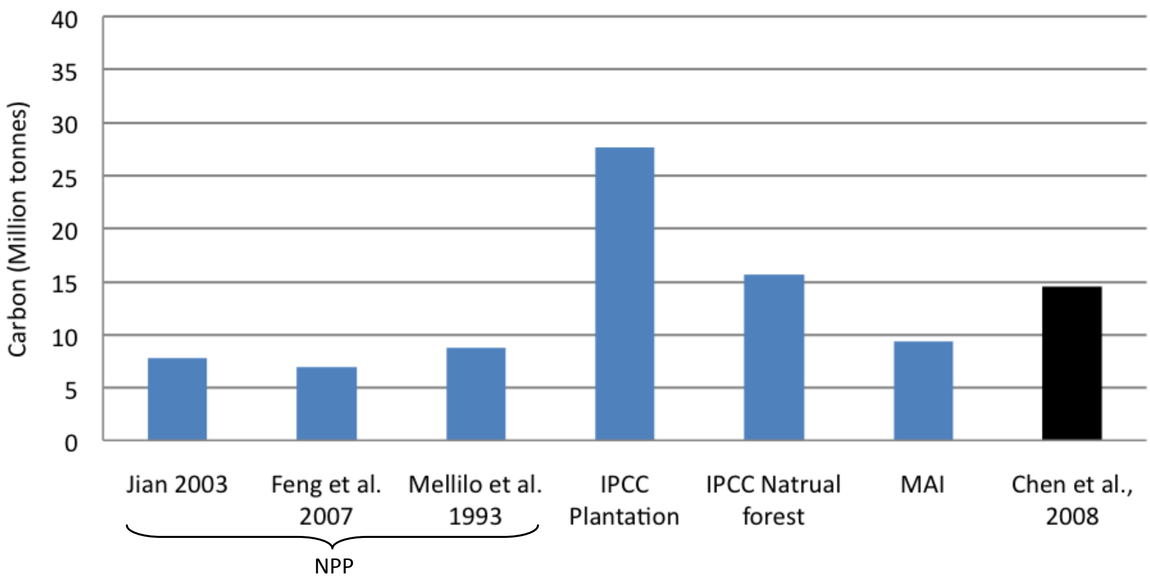

Figure 19 Carbon sequestration under the GGP-stands in Chongqing Municipality

4. Discussion

4.1. Uncertainty in the calculations of carbon sequestrated

Depending on the biomass growth used in the model the amount of carbon-sequestered ranges from 103 million tonnes of carbon when using approach 2, i.e. NPP values by Feng et al (2009), 113 million tonnes carbon when using approach 3, i.e. MAI, 143.55 million tonnes when using IPCC's values for natural forest up to 209 million tonnes carbon when using IPCC's values for planted forests. This means that the result differ by 103% between using the most conservative growth rate and the most optimistic growth rate. Because the span is so large the median gives a better description of the result than a mean. The median is 114.1 million tonnes carbon while the average is 132.3 million tonnes carbon. IPCC's method is a mature method that is well known and developed to be able to compare carbon sequestration between different countries in different regions and therefore seems like the most valid model. When adding cropland and barren land together the span between the largest value, IPCC Plantations, and the smallest value, Feng et al. (2007), becomes even larger. Also in this case the median gives a better description than the mean. The median is 246 million tonnes carbon while the mean is 289 million tonnes carbon. The croplands and barren lands used under the GGP usually have a very low productivity (Chen et al. 2009), which supports the usage of a lower value, IPCCs value for natural forests, of biomass growth when estimating the carbon sequestration.

Another uncertainty in the estimation is the actual area of cropland and barren land converted under the GGP. According to Bennett (2008) the total area converted until 2010 will be 32 million hectares whereas the area converted according to China forestry yearbooks between 1999-2008 sums up to only about 20 million hectares (State Forestry Administration 1999-2008). Even though the time span differ between the two studies it seems unlikely that 12 million hectares will be converted during the last two years of the GGP. Especially since area of converted land has been decreasing during the last years of the program. The conservative area used in this analysis from China forestry yearbooks seems more valid.

The amount of carbon dioxide sequestered by the planted trees can be compared to the amount of carbon dioxide emissions due to fossil-fuel use and cement production. China is the world's largest emitter of carbon dioxide with 1.78 billion tonnes of carbon in 2007 (Boden et al. 2010). Comparing the median of the result given by converting cropland and barren land to forestland to China's carbon dioxide emissions gives that the sequestrated carbon equals 14%. The total amount of carbon sequestrated under the GGP does not by far cover the carbon emissions by China's carbon dioxide emissions due to fossil-fuel use and cement production.

4.2. Uncertainty in biomass growth values

IPCC recommend slightly larger biomass growth values than the biomass growth values obtained when the NPP values from the literature study was recalculated. The reason for this is probably the relationship between net carbon uptake and the NPP values from the study by Pretzsch (2009). Within the recalculation from NPP to net carbon uptake are several potential sources of error.

The IPCC Guidelines provide methods for estimating and reporting sources and sinks of greenhouse gases only for managed forests. IPCC (2006) define managed forests as land where human interventions and practices have been applied to perform production, ecological or social functions.

According to IPCC's GNGGI it is important to distinguish between intensively managed forests (forest plantations) and extensively managed forests (naturally re-growing stands with reduced or minimum human interventions). The forest planted under the GGP fits within the criteria of the GNGGI and the GNGGI therefore seems like a valid model to use when estimating the carbon sequestration. It can be argued whether the barren land converted to forestland falls under extensively managed forest or not since little is known about the management and survival rate of this type of converted land, although with the definition used by IPCC it fits under managed forest. According to IPCC their method is valid both for natural regeneration and for plantations. This implies that the result obtained by using IPCC's method should be valid in this case. Because of the uncertainties in the recalculation of the NPP values by Pretzsch (2009) and because IPCC's values are widely used for estimating carbon inventories we consider the results from using IPCC's values most reliable.

Laumonier (2010) have studied the forest of Sumatra and concluded that the above-ground biomass estimated in the study was 23% higher than the default value for tropical wet forest given in the IPCC. This implies that, even though the result obtained by using IPCC's values gives the largest values in this study, they can still be conservative.

The difference between the China specific NPP values from studies by Feng et al. (2007) and Jian (2003) and the world average NPP values from a study by Melillo et al. (1993) is relatively small and is most likely explained by the widespread degradation of soils in China. This makes the China specific NPP values lower than world average NPP values.

4.3. Sub research question

What is the potential for bio-energy from the forest planted under the GGP? Since the legislation behind the GGP states that the forest planted may not be harvested until over mature there are low potential to grow fast rotational energy forests on the land converted under the GGP. Even if the legislations would allow harvesting of the forest the potential for usage as bio-energy is low since large amount of the species planted are bushes and economical trees that are not suitable for usage as bio-energy. Only 0.61% of the forest planted falls under the category firewood whereas as much as 77.93% of the forest planted is for protection and most of these species are not suitable for usage as bio-energy.

During the field trip it was witnessed that bamboo has been widely planted. This bamboo is today used mostly for construction but could also be used as firewood.

4.4. Soil organic carbon

In degraded lands considered for afforestation and reforestation, the stock of soil organic carbon (SOC) is likely to be low (Ravindranath and Ostwald 2008). Ravindranath and Ostwald (2008) mention that the annual incremental addition of SOC due to afforestation will also be low. According to Niu and Duiker (2006), annual incremental addition vary greatly in young forest stands with SOC either increasing or decreasing. Although in the long-term soil is likely to be a potential sink of carbon following afforestation. Paul (2002) indicate that there is generally an initial decrease in SOC after afforestation before gradually increasing so that, after about 30 years, C within the surface 30 cm of soil is often greater than that in the previous agricultural soil. Previous land use, and to a lesser extent climate and forest type influence the extent of change in SOC. Paul (2002) concludes in his study that in the first 10 years, C within soil from <10 cm (or <30 cm) depth decreased by 0.53% per year (or 0.28% per year) on ex-pasture sites, yet increased by 0.87% per year (or 1.88% per year) on ex-cropping sites. Zhang (2009) have studied the change in SOC following the GGP and found that SOC stocks accumulated at an average rate of 0.37 tonnes C $(ha\ yr)^{-1}$ in the top 20 cm but with large variation. After land use change, SOC stocks decreased in the initial 4–5 years, followed by an increase due to vegetation restoration. The main reasons for initial decrease of SOC after afforestation are the soil disturbance by site preparation and low organic carbon input from a young forest stand (Paul et al. 2002). Intensive site and soil preparation is not permitted under the GGP and original vegetation is requested to be maintained as much as possible (Chen et al. 2009). Chen (2009) and Nui and Duiker (2006) uses an SOC stock increase of 0.70 tonnes C $(ha\ yr)^{-1}$ for the first decade after afforestation with the assumption that some best management practices were adopted, such as planting groundcover crops/grass between trees and minimizing soil disturbance. There is evidence that best management practices have not always been implemented because some areas included in the GGP were not traditional forest areas. The farmers lacked experience in afforestation and the necessary technologies (Zuo 2002). It can be discussed if SOC should be included in this study but due to very young forest stands and the above-mentioned uncertainties SOC has been left out in this study.

4.5. Carbon leakage

Carbon leakage is defined as the problem when emission reductions in one location result in an increase in emissions in another location. If the area conversion under the GGP resulted in increased carbon emission somewhere else this would be defined as carbon leakage. According to Bennett (2008) the program is not design to prevent or reduce leakage. A possible carbon leakage induced by the GGP would be if farmers don't have sufficient amount food after converting their farmland. This lack of food supply could mean that forestland have to be converted to cropland somewhere else. Chen (2009) argues that the croplands and barren lands used for GGP usually have a very low productivity and the Chinese government provides food and/or cash subsidies for farmers who have converted their land. Where land has competing scope of use the project's impact may extend beyond the area of direct project activities. For example, a project that stops the conversion of forest to agricultural land will face leakage problems because if an economic activity in the forest is stopped with no alternative taking its place, people will shift the activity to a surrounding area (IPCC 2000). If carbon leakage is an issue or not regarding the GGP can be discussed. Since the land converted is mostly degraded land where the yield has been relatively low and since farmers mostly plant economical trees, which replace the loss in crops from former cropland carbon leakage is most likely not an issue here.

4.6. Bamboo

According to the forestry department in Hongya county, Sichuan province, harvesting of bamboo occurs within a few years interval. This was taken into account in approach 2 where a NPP value assuming harvesting every fifth year was used. Whether 5 years is a suitable interval for different species of bamboo and different provinces in China is not clear and this is a source of uncertainty. Although it should not affect the total result too much since the total amount of bamboo planted is relatively small.

4.7. Future work

In order to make the estimation more accurate it would be interesting to collect province specific data regarding the species used and province specific biomass growth rate for all provinces. This would make the estimation more accurate since biomass growth is strongly dependent on local factors such as soil quality, thinning, irrigation and fertilization.

Another way to obtain more accurate results would be to divide the converted land into smaller areas that has a homogenous climate. By doing so better approximations of the biomass growth rates could be obtained.

5. Conclusion

- The carbon sequestrated by the conversion of only cropland under the GGP between 1999-2009 range from 103 to 209 million tonnes. The median is 114.1 million tonnes carbon while the average is 132.3 million tonnes carbon. With IPCC's approach for natural forests the amount of carbon sequestrated by the conversion of cropland between 1999-2009 is 143.55 million tonnes.
- The carbon sequestrated by the conversion of both cropland and barren land under the GGP ranges from 222.3 to 467.9. The median is 246 million tonnes carbon while the mean is 289 million tonnes carbon. With IPCC's approach for natural forests the amount of carbon sequestrated by the conversion of cropland and barren land between 1999-2009 is 312.5 million tonnes carbon.
- The carbon sequestered in the biomass (above and below ground) from this program is equivalent to 14% (based on median of all three approaches) of China's carbon dioxide emissions due to fossil-fuel use and cement production.
- The potential for bio-energy from the forest planted under the GGP is low since the part of trees planted that are suitable for bio-energy is low and since the legislations prevents harvesting of the forest until over mature.

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