

Review

Adapting Chinese Forest Operations to Socio-Economic Developments: What is the Potential of Plantations for Strengthening Domestic Wood Supply?

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Received: 9 February 2018; Accepted: 30 March 2018; Published: 1 April 2018



Abstract: Over recent decades, China's forestry sector went through a transition phase characterized by a management and institutional reform process, with a constant rethinking of the ecological and societal role of forests within a unique political system. Nevertheless, despite impressive achievements in forest restoration and conservation efforts, the enhancement of ecosystem services and forest area expansion through plantation development, China was not able to improve its domestic timber supply capacities according to its demands. Consequently, the continually growing wood processing industry is facing a severe demand-and-supply gap, causing high dependencies on timber imports. Outdated forest operations practices, dominated by manual labour, are not able to meet supply demands or to implement new silvicultural strategies for enhancing forest quality and productivity and are a widely unnoted disruption of a sustainable development. Therefore, this review presents the status quo of China's forest operations sector, how it is shaped by forest policy reforms and recent socio-economic developments. In addition, suggestions are developed how the sector can progress through policy adaptations in order to develop sustainable timber supply capacities based on a domestic plantation sector.

Keywords: China; forest operations; socio-economic development; wood supply; policy reforms

1. Introduction

China's forests cover an area of 208 million ha, representing 21.6% of the country's land area and ranking it globally on 5th position in terms of forest area, including the largest area of timber plantations in the world [1]. However, despite of the high rank in areal surface, the country's forest area per capita of just 0.13 ha is far below the world's average of 0.65 ha. Same applies to the low standing stock of only 10 m³ per capita, compared to a global average of 66 m³ [2]. Respectively, per unit stocking volume with a national average of 88.9 m³/ha [1] can be considered as very low, too. The low forest unit stocks, arising from natural forest depletion and the high number of juvenile plantations with partly overdue tending [3–5]. This situation results in major limitations for a sustainable development of the forest product industries due to raw material deficiencies, causing high dependents on timber imports [6]. This causes also specific challenges to forest operations, which ought to counteract the supply deficits through efficient operational systems.

The country's opening process strongly affected both, forestry sector and depending industries, including tremendous changes in the forestland's coverage and composition, causing country specific

operation conditions. Li and Wang [7] thoroughly described the forest operations sector in China at the end of the previous millennia. At this time, the sector was characterized by the utilization of “appropriate technology” fitting the operation conditions and sector’s demand, shaped by the ample availability of cheap labour, expensive machinery costs, lack of funds for forestry activities and road building, shortage of energy and a lack of maintenance and repair facilities for advanced machinery. Yet, nearly two decades later, China has implemented an intensive conservation orientated forest policy reform [8], has further moved towards a market economy with associated socio-economic changes and has emerged to one of the main timber processing countries in the world, despite facing a severe raw material demand-and-supply gap [6,9]. In particular, the latter is a tremendous challenge the Chinese forestry sector has to cope with and ongoing progress needs to account for that in order to become less dependent on timber imports [9]. Nevertheless, utilization of natural forests has not been the focus of the latest forest policy reforms, favouring timber production from plantations, a development of manifold influence on Chinese forest operations. Yet, the presence of efficient and suitable operational systems is essential to make use of the timber supply potential from plantations and therefore play a key role in sustainable progress to enhance the productivity of the Chinese forestry sector. Indeed, despite the diverse academic work on the Chinese forest sector development, the field of operation has recently been not one of the priorities given focus areas in the context that China shifted the primary focus of forest management from wood production to ecological restoration and protection.

Therefore, the questions rise (1) what is the status of the Chinese forestry sector in terms of forest resource development and utilization; (2) How did forest operational practices evolve since the review of Li and Wang [7]; (3) how is it affected by recent socio-economic developments and (4) can plantation forests actively contribute to the mitigation of the domestic timber demand-and-supply gap? This paper aims to specify the current situation of the Chinese forestry sector and its operations through a synthesis analysis by reviewing relevant literature and other sources of information. In a wider context, barriers of progress and further research demand is identified, as well as opportunities for development to further stimulate forest policy reforms for enhanced sustainable timber supply capacities in China.

2. Improved Forest Situation and Timber Shortage

2.1. Forest Sector Reforms

China’s timber supply limitation dates back to a long history of overexploitation. It was intensified through the establishment of the People’s Republic of China in 1949 with a further deterioration of the forest resources during the collectivization period from 1958–1982, in particular notable within the periods of the *Great Leap Forward* and the *Cultural Revolution* [2]. The opening of China towards a market economy at the beginning of the late 1970s and early 1980s further fuelled the demand for raw materials for an export orientated manufacturing sector but also domestic needs with rising living standards increased the pressure on forest resources [6,10]. As counter measures, in 1985, logging quotas were introduced and afforestation following clear-cuts became mandatory. Still, a further depletion of the forest resource took place, also as a direct consequence of a poor enforcement of the logging quotas and the unsolved problem of corruption in the state forestry sector [2,6,11]. Therefore, in order to preserve the remaining forest resource and to enhance its productivity with respect to ecosystem services and raw material supply capacities, a consequent rethinking of forest management practices was necessary [11].

China’s forestry sector underwent a radical change in the year 1998, after experiencing extraordinarily flood events along the Yangtze River, associated as a direct consequence of deforestation, which has caused the loss of 3000 human lives and 10 billion USD (9.3 billion EUR) in damage [6]. In a wake of this event, a growing awareness among the public for the environmental consequences of deforestation and overexploitation was noticeable. As a direct response, the central government

launched the *Six Key Forestry Programs* (SKFP) (Table 1), with an initial budget of 22 billion USD (20.4 billion EUR) and an allocation of additional 68 billion USD (58.4 billion EUR) in the following years [11]. The structural reform of the *Ministry of Forestry* (MoF), with its transformation into the *State Forestry Administration of the People's Republic of China* (SFA-PRC), was implemented to increase the institution's efficiency, making it able to administer the increasing challenges of sustainable forest management in line with the economic development of the country and in accordance with the SKFPs [12]. The implementation of the SKFPs achieved a significant improvement of the forest resource but as a side effect of the strict conservation efforts, for example, implemented through the Natural Forest Protection Program (NFPP), an overall decrease of timber production occurred due to lacking supply from natural forests [9]. Related to the NFPP, Yuexian [13] quantifies the production output from natural forests with 33.2 million m³ in 1997 but a reduction down to only 12.2 million m³ already by the year 2003. Generally, over the last 25 years, the overall contribution of natural forests on domestic timber production has decreased from an average of 81% in the period 1994–1998, down to only 2% in the year 2016 [14], shifting the supply task to the plantation sector.

Table 1. The Six Key Forest Programs (SKFP) as introduced in 1998 [12].

1.	The Natural Forest Protection Program (NFPP)
2.	The Program for Conversion of Cropland into Forests (CCFP)
3.	The Sandification Control Program for the Vicinity of Beijing and Tianjin (SCP)
4.	The Three-North Shelterbelt Development Program and the Shelterbelt Development Program along the Yangtze River Basin (SDP)
5.	The Wildlife Conservation and Nature Reserves Development Program (WCNRDP)
6.	The Forest Industrial Base Development Program in Key Regions with a Focus on Fast-Growing and High-Yielding Timber Plantations (FIDP)

Since the 1998 reforms and its implementations through the SKFP, wood supply from an uprising plantation sector in the *Southern Collective Forest Region* steadily increased through several tenure reforms and has replaced the north-eastern region with its natural forest as the country's *Wood Basket* [9,15]. The 1978 begun tenure reforms, separating land management from ownership, brought up the China specific land tenure forms of "state-owned and collectively managed" and "collectively owned and privately managed" forests, resulting in a contract forestry system [16]. However, actual ownership of collective land was and often is unclear and legally treated differently in the various regions, often leading to tenure insecurity also affecting plantation management practices [17]. Particularly smallholders face tenure conflicts also to a non-existing legal definition of the term "collective" on national level [18]. Ongoing and frequent changes in policy for forest tenure and management have caused often a complete lack of confidence on the part of villagers in regard to tenure security [19]. This, in return, has a significant effect on forest management practices since the landholder is under a constant threat of losing his livelihood. The situation promotes the practice of short-term profit generation with low capital requirements instead of sustainable long-term management [20,21]. Chinese scholars have identified the shortfalls and failures of the land tenure system and previous reform attempts, including the weak position of the individual and partly ambiguous titling, also due to an inexistent cadaster [22,23]. The central government has, once again altered the course in the tenure reforms, this time focusing more on a private property regime. In this second phase of privatization, launched by the State Council of China in 2008 after a four-year pilot phase, land leases for forest use rights have been extended from 30 to 70 years, with the possibility of inheriting and lease renewal at the end of the period [20]. This newly generated planning horizon for forest farmers allows them to adapt to the national forest management objectives of continuous cover

forestry [24] and multiple use plantations [25] that can generate higher returns with native species through dimensional saw log production by means of thinning [26].

The constant reform process of tenure rights for collectively owned land since the beginning of the opening policy has strengthened the position of private forest farmers and supported the development of the plantation sector in the south [2,21]. Yet, the government also imposed a management responsibility to the landholder [27], being still a highly regulating body. Inflexible provisions like the logging quota system, not orientated on optimal rotation cycles or local ecological metrics [17] hampers for instance the implementation of new silvicultural approaches for improved forest management. Bai et al. [28] criticize the intensive governmental control over the Chinese forestry sector in general, limiting capacity development and therefore request the introduction of a *Market-Orientated Forestry* in China in order to promote forestland productivity. A new phase of forestry reforms already intends to further open the forest sector with much greater individual and corporate participation, largely through private sector financing and institutional support by the *Forest Industrial Base Development Program* (FIDP) with a focus on fast-growing and high-yielding timber plantations [11].

But, although the Chinese government intensively promotes private foreign direct investments in the forest products sector through loans and tax benefits (e.g., covered by the FIDP), the land tenure situation, for example, does not permit an efficient development of integrated pulp projects and has brought up examples where foreign companies withdrew their interest to invest in China [4].

Private sector corporations can access land either through leasing it from individual landholders, who themselves gained their tenure rights from the collectives, or by directly leasing it from the collective village councils [29]. This situation has promoted transfer towards scale economy but on the other hand caused problems for investors in terms of efficient land acquisition. In return, the development of industrial orientated forest management is very limited and legal and socio-economic constraints arose. Identifying the legal title holder and concluding on agreements is not always straightforward, as, for example, a Finish pulp manufacturer experienced in a bitter way and was subject to criticism by international publicity [30].

2.2. The Demand-and-Supply Problem

Despite of China's achievements in improving the state of the forest through governmental programs and reforms, it was yet not possible to balance the growth in wood demand with environmental needs and social justice [11]. The country's booming forest products industry, already taking over global leadership in the production of wood-based panels as well as paper and paperboard for export, with 49% and 27% of the global production in 2014 [31], respectively. Additionally, the continuously progressing GDP, coupled with higher incomes and increased purchase power, also increase the domestic demand for forest products mainly fuelled by the housing market. These economic developments are coupled with increasing demand for timber, projected with an annual growth rate of 5% [9].

Unlike the increasing demand, total domestic timber production was nearly constant between 1988 and 2006, forcing imports to rise, which nearly tripled since the late 1990s, being worth 10 billion USD (9.3 billion EUR) annually [9]. The resulting demand-and-supply gap cannot be resolved in the short- or medium-term despite the increasing forest productivity and area expansion. Official projections by the SFA-PRC for the year 2020, optimistically accredits a domestic timber supply capacity of 300 million m³ per year, compared to the current 180 million m³, with an increased industrial demand of 467 million m³, leaving a deficit of 167 million m³ to be covered by imports [32]. He and Xu [9] project a lower demand for the year 2020, of only 335 million m³, obtainable by the assumed raising domestic production in combination with further increasing import capacities (Figure 1). However, these projections include timber output from natural forests, too. Although Zhang et al. [5] give evidences for increasing supply capacities of the natural forest regions in the northeast after the recovery period until 2020, enforced by the *Natural Forest Protection Program* (NFPP), it is questionable how productive the stands actually will be and if the operations are economic. Additionally, the Chinese

government recently announced to extend the logging bans under the NFPP, to phase out all commercial logging operations in natural forests by 2017, reducing the current domestic annual timber output already by another 50 million m³ [3,33]. Apart of socio-economic impacts such as regional loss of livelihoods for forest operation-dependent communities, the extension of logging bans will further increase the volume of timber imports to China [34], currently already being the third largest foreign exchange commodity behind oil and steel [9]. Trade liberation for forest products were induced already in the 1990s and several reductions on import tariffs were direct measures by the government to counteract the existing timber shortage through promotion of imports [35]. Consequently, China took over a leadership with its timber imports accounting for 31% of the global totals, received mainly from Russia, Malaysia, Papua New Guinea, New Zealand and Gabon, with Russia accounting for 61% of the total imports as the most important country of origin [35]. Among the share of forest product imports, there is also a clear shift from value-added products (e.g., plywood, veneer, fibreboard and paper) to semi-finished wood products (logs, sawn wood, wood pulp) noticeable over the last years, reflecting China's strategy to develop its wood processing industry with imported raw material in order to export higher value-added products [2]. Nevertheless, the Russian government follows a similar strategy of strengthening its value-added forest products sector through subsidies for mill development, reduction of import tax on high-technology wood processing systems and, on the other hand, introducing export taxes on logs in order to favour domestic processing [36]. On the long run, this could significantly affect the Chinese forest product industries, which have settled along the Russian border near the traditional import routes, since on the Chinese side the industry is surrounded by the remaining natural forests going under strict protection [8,37,38].

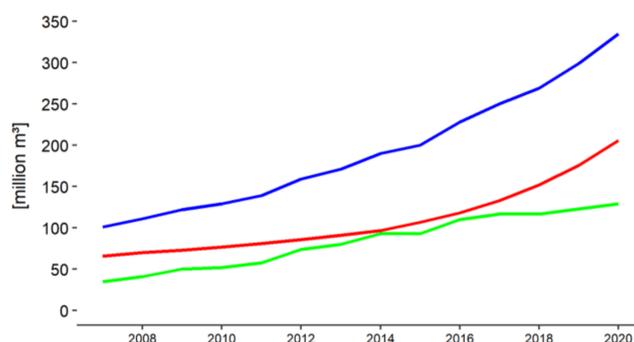


Figure 1. Projection of Chinese timber demand (blue line), domestic production (red line) and imports (green line), as modelled by He and Xu [9], until the year 2020.

Although China's high demand for timber has not yet resulted in a global shortage of wood and associated price increase [39], it though has caused displacement effects on the global forest product markets [6]. Particularly the reduced import quantities from Russia, at consistently rising round-wood demand in China, promotes an intensive purchase policy towards other exporting countries. This includes also unsustainable and illegal sources, rising concerns about the depletion of natural forests especially in the Southeast Asia region [40]. Lang and Chan [41] describe how increasing log demands from China facilitate deforestation through illegal logging in Southeast Asia, with associated problems for the producer countries and that the timber is "laundered" in transit countries such as Malaysia, Singapore, Vietnam and Thailand. In addition, the remaining timber exports to China from Russia's Far East and Southeast Siberia are to account up to two-thirds from illegal harvests [42]. The international community raised concerns about China's timber import strategies and requested to take up responsibilities to assure diverse, legal and sustainable origin of its imports [35]. Indeed, China showed efforts to diversify its import trade partners in recent years, also as a direct benefit of its membership in the World Trade Organization (WTO) since 2001, enabling sourcing of softwood also from other markets than Russia [40]. Additionally, China started to

introduce a national *Timber Legality Verification System* (TLVS), along with bilateral trade agreements of exporters, to verify sound origin of timber and to tackle illegal timber trafficking [43]. The adaptation of forest certification and particularly *Chain-of-Custody* (CoC) certificates, is supposed to decrease illegal practices in the Chinese logging and timber business [44].

Yet, on a long-term sustainable development agenda, China needs to become more self-sufficient in timber supply from domestic sources, which is also a clearly stated aim by the central government [8]. Since natural forest management for timber production will be only second-tier in domestic forest policy development, supply capacities from plantations has to strengthen the sector. The availability and implementation of efficient operational systems for stand establishment, tending, thinning and harvesting with subsequent intermodal extraction and transport, are vital requirements in order to achieve such goals, as for example demonstrated during the development of a plantation based forest industry in Brazil [45].

2.3. Plantations as the Lifebelt of the Forest Products Industry?

The major reforestation and afforestation programs have significantly increased the forest area in China. Particular the *Conversion of Cropland to Forest Program* (CCFP) and the *Forest Industry Development Program* (FIDP) contributed to the vast establishment of plantations [46,47]. Wang and Chokkalingam [48] give a comprehensive overview of the FIDP: The program followed earlier plantation development programs with the aim of meeting 40% of the industrial wood demand by the year 2015. This ambitious target, supported through an investment volume of 63.8 billion RMB (8.88 billion EUR), the new establishment of 10.8 million ha of plantations for paper and panel-making industries and 2.5 million ha of plantations for large diameter timber for furniture and construction purposes. The FIDP is one of the stimulators for the development of integrated large-scale plantation based pulp projects in the south, contributing a significant portion to the increased plantation area and stock volume in China (Figure 2). These projects, also backed by foreign investments, providing cellulose biomass through fast growing and high yielding plantations of mainly exotic *Eucalyptus* spp. managed in conventional clear-cut systems [4,49], shifting the focus of timber production from the northeast temperate forest area to the subtropical south [50]. Yet, despite of the impressive total plantation area in China of 69.3 million ha [1], volume stocks and yields, as well as timber quality are generally low due to silvicultural improvement needs [25]. Comparing *Eucalyptus* spp. performance in short rotation industrial plantations globally (Table 2), China exposes very low mean annual increments (MAI). Particular in comparison with major pulp log producing regions in South America, having up to tenfold higher MAIs, China is losing a competitive base for its pulp and paper industry. Consequently, also from an economic perspective, Chinese plantations are often no successful venture compared to imports as long as international log prices are competitive and therefore failed to contribute to sustainable domestic timber supply chains [4,26].

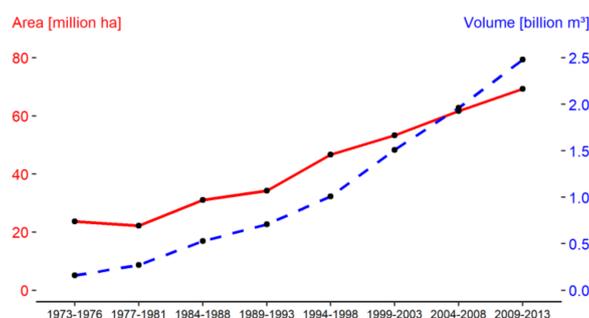


Figure 2. Forest plantation area (red solid line) and growing stock volume (blue dashed line) increase in the course of the eight periods for national forest inventories conducted in China between 1973 and 2013 [51].

Table 2. Growth parameters of *Eucalyptus* spp. by global regions “[52], modified”.

Region	MAI (m ³ /ha/Year)		Rotation (Years)		Estimated Rotation Yield (m ³ /ha)	
	Min	Max	Min	Max	Min	Max
China	1.6	8.7	5.0	15.0	8	131
North Africa	12.0	14.0	8.0	15.0	96	210
South/Southeast Asia	7.0–8.0	10.0–12.0	6.0–10.0	8.0–20.0	42	80
West/Central Asia	4.0	10.0	10.0	25.0	40	250
South America	15.0–20.0	36.0–70.0	6.0–8.0	12.0–16.0	120–130	400

Despite a pure volume supply, plantations are supposed to fulfil manifold functions within the Chinese forestry strategy. The wider recognition of multiple-use forestry through sustainable forest management (SFM) practices is gaining popularity among Chinese forestry scholars and management institutions [15]. This approach is an additional driver but also a new challenge for the plantation sector of the south, which needs to adapt to these silvicultural practices, not only focusing on short rotation pulp plantations [25]. A clear objective of such SFM practices is the improvement of forest quality by transferring low productive and disturbance prone monocultures into mixed stands with valuable species managed in a selective cutting system of periodic thinning [53]. In a wider context, it also follows the objectives of continuous cover forestry, evolving to close-to-nature forest management practiced innovatively in China, widely applying the crop tree management, which creates opportunities to produce valuable saw logs through plantation forestry instead of natural forest exploitation [24,25]. However, such practices require higher management attention, far beyond plantation establishment, which has been the primary focus of forest area expansion in the past. Lacking management activities following tree planting, such as tending and thinning, have merged in vast areas of low productive juvenile stands of low quality [3,54], which indicates the huge needs of tending and thinning activities in short term, such as 5–10 years and subsequent harvest operations in long run within the next 30–50 years. The capacity of forest operations has to be prepared already also for these future needs.

From a market perspective, there is a demand for larger diameter logs of valuable species from domestic plantations, particularly fuelled by the rising Chinese furniture industry [55,56]. This also offers a variety of livelihood diversification options for smallholder forest farms. On the other hand, for a continuous supply with raw material to the pulp and paper industry, as well as the wood based panel manufacturers, mass assortments from for example, *Eucalyptus* spp. plantations in short rotations are required, too [26,47]. These competing interests are also a fundamental driver of efforts to increase productivity of plantations, since land availability for new plantation areas is the key limiting factor and seen as one of the major challenges in the future development of the sector [25,49].

Altogether, the Chinese plantation sector is indeed a very important contributor to the raw material supply chains of the forest products industry, however, currently it cannot sustain it, nor can it significantly reduce its dependency on international log imports.

3. Forest Operations in China

Despite of silvicultural obstacles, land-use competition and inefficient land acquisition, forest operations in Chinese plantations have yet not been adapted to new forestry strategies, nor to the changing socio-economic situation accompanied by the country’s economic progress, which in return further limits the supply capacities [57].

3.1. Work Systems

Conventional plantation operations in southern China are conducted in clear-cut systems and are characterized by labour intensive manual operations due to the currently still inexpensive work force (Figure 3), giving few incentives to managers to improve operational systems or to invest in

modern equipment [58]. Engler [59] comprehensively described and analysed the manual operations in southern China throughout the various stages of a plantation cycle, from site preparation up to the harvest, ending with manual truck loading for further conveyance of the timber to the next log terminal. Depending on log diameter, he quantified an overall productivity range of only 0.19–0.34 m³/man hour for *Eucalyptus* spp. operations with the common manual practices. Although manual process handling is dominant, chainsaws have become the equipment of choice for tree felling and processing [7]. However, a professional training in felling techniques for chainsaw operators in China generally rarely happens and safety awareness as well as the use of personal protective equipment is very limited [60]. Indeed, daily rated villagers and migrant workers, lacking any vocational training in forest operations, conduct most of the forest work. They are not only exposed to higher risks in terms of occupational health and safety but are also not capable of performing efficient operations and can even cause unnecessary impact on the site and devaluation of future crop trees in thinning operations [61].



Figure 3. Conventional clear-cut operation in Guangxi with daily rated villagers extracting short wood by means of gravity and manual labour (Engler, 2011).

In the natural forest areas of the northeast, with its gentle slopes compared to the often-steep terrain in the south, more mechanized techniques—like extraction with skidders—gained popularity mainly in exploited forests due to very long skidding distances [7,62]. However, particularly in stands with short extraction distances, manual and animal skidding methods were rated as more suitable mainly due to the low costs, in contrast to high fixed costs of machines, outcompeting the introduced skidders in many operations again already in the 1990s [63]. Log extraction purely by manual and gravity force is therefore still the dominant form in many regions of China [64], particularly in the southern plantation regions, where skidders are moreover almost unknown. But the dominating form of manual extraction also limits plantation management systems to small diameter log production of short lengths and characterizes operations with low hourly outputs, despite high labour inputs [57]. The manual extraction is further also the main cost factor of southern plantation operations due to the inaccessibility of many stands with accompanied low forest road standard, which creates long distances to be covered until the next trafficable road [47]. This situation is further exacerbated by the fact that China's countryside is made up to two thirds by mountainous terrain and many plantations are located on steep slopes [10]. The common dilemma after many successful plantation establishment phases is just purely “how to get the logs to the forest road?” This is further intensified when large volumes need to be frequently mobilized for large-scale pulp mills, or dimensional longwood needs to be delivered to saw mills. Both is currently not feasible with the current work system and forest road infrastructure and therefore a major limitation for the forest products industry [4,65]. Yet, also intended

thinning and low impact harvesting operations to rise the quality and yield of plantations [28] are more difficult with the conventional work systems.

Low-impact extraction systems, such as cable yarding (Figure 4), offer various technical solutions to overcome these problems. Yet, such systems are applied only to a very limited scale. A major drawback of these systems are comparably high equipment costs, exacerbated due to the fragmented location of harvesting sites and limited timber logistic options, which reduce the utilization rates during the rainy periods in the subtropical plantation regions [58,65,66].



Figure 4. Recently introduced mobile standing skyline cable yarding extraction of long wood within a thinning demonstration for valuable saw log production at the Experimental Centre for Tropical Forestry in Pingxiang/Guangxi (Hoffmann, 2016).

The fragmentation of operations as a result of mainly smallholder tenure [67] but also due to the highly bureaucratic harvest permitting system [68], make it difficult to plan annual operations for efficient system utilization in order to reduce operation costs. This applies also to industrial orientated pulp log producers, regardless of applying low capacity technology or state of the art imported fully mechanized equipment [69,70]. Although Engler et al. [57] model that within a medium planning horizon even mechanized forwarding based on equipment with high fixed costs (e.g., forwarder) will outcompete manual systems, a survey among forest farm managers show currently only little potential to shift towards more mechanized systems due to the high initial investments and difficulties in operational planning [61]. Also, the existence of a professional machine contracting sector for forest operations—as, for example, those successfully shaping Chinese agriculture efficiency [71]—does not currently exist, to the authors' knowledge. However, the mechanization of forest operations is gaining the interest of Chinese equipment producers, developing especially harvesting machinery competitive to the purchase price of foreign equipment, which in return could create a base for local contractors.

China's biggest producer of wood processing machinery, FOMA (Zhenjiang Zhongfoma Machinery Co. Ltd., Zhenjiang, China), and experts from the Beijing Forestry University developed the FB150-9P tracked harvester—a forestry adapted excavator—factory fitted with the Finish harvester head LAKO 43 (Lako Forest Oy Ltd., Naantali, Finland). Yet, although purposely developed for plantation operations and even promoted for export [72], no reference is available of the machine's utilization or performance in China. Furthermore, Guo and Lu [73] report a domestically developed rubber wheeled harvester based on the chassis of the ZL50 (Shandong Yineng Heavy Industry Co. Ltd., Shandong, China) articulated wheel loader, with a cutting limit of 30 cm DBH, which is therefore

particularly suited to large-scale southern plantations with small diameter trees. This machine, rated to be 25–30 times more productive than manual felling and processing [73], meet the needs of the industrial plantation sector in the south [74]. However, empirical studies investigating the performance and costs of this equipment or verifying their potential to improve Chinese forest operations are inexistent.

Despite of the availability of domestically and imported forestry equipment for more mechanized harvesting and extraction systems, Chinese forest operations are still mainly characterized by manual labour, to the same extend as described by Li and Wang [7] at the end of the previous millennia. In fact, in some regions the utilization of machines for forest operations has even further declined due to the context of the continuing policy of reducing operations in natural forests. On the other hand, the wood supply policy focus on plantations, would expect a higher level of mechanization of forest operations to increase supply efficiency by the concentrated mobilization of logs from smaller areas—despite of compared to other global regions relative low plantation yields (Table 2).

3.2. Workforce Changes and Degree of Mechanization

Migrant workers have been the backbone of the development of various economic sectors in China [75]. Recently, there has been much attention drawn to the availability and costs of an unskilled workforce and the effect of change in both rural areas and industrial urban centres. Some economists argue that China has already reached the Lewis [76] turning point, leading to an era of labour shortage and rising costs, gradually causing China's labour-intensive and export driven growth model to lose its competitive advantage with significant socio-economic effects at the national level [77]. On the other hand, Felipe et al. [78], for example, argue that the high employment rate of 31% in agriculture in 2013 is in strong contrast to the rate of 5% in industrial countries. Knight et al. [79] even argue that a country as large and highly regulated as China does not necessarily reveal a distinct Lewis turning point and further exposes the phenomena of potential migrant workers remaining in rural areas, while labour shortages are experienced in urban areas. Whichever economic scenario becomes true, there is no doubt that the Chinese labour market is changing significantly, which in turn highly affects conventional forest operations in terms of workforce availability and costs, clearly recognizable in the state forestry sector. According to official SFA-PRC statistics, in the past 20 years, the number of employees in the state forestry sector of China reduced by 52%, whereas annual salaries have increased by 754%. Yet, despite of the high timber demand, average domestic sale prices have increased only from 450 RMB (58 EUR) to 777 RMB (100 EUR) [14]. This in return means that despite of the remaining low productivity of the manual operations, revenues of timber sales cover less person-hours, which dropped from still 145 person hours in 2001 to 33 person-hours in the year 2016, underlying the demand for more efficient operations (Figure 5).

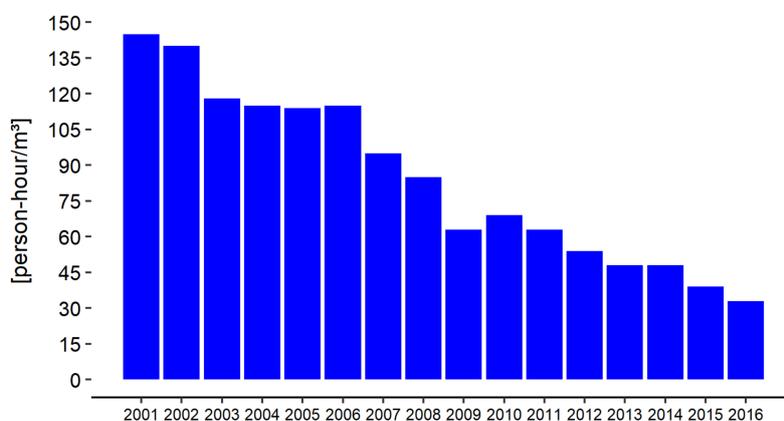


Figure 5. Person hours covered by timber sales revenues per m^3 in the state forestry sector, calculated on employment and economic figures published by SFA-PRC [14].

For Chinese forestry, the workforce situation and migration is both a driver and restrictor of mechanization at the same time. Rural out-migration is driving the intensification of agriculture and forestry, changing the land-use practices in these sectors from subsistence to commercial. The aim is to supply the demand of the increasing urban populations but also to further improve rural off-farm employment opportunities due to a competing labour market [80]. The adaptation of commercial forest operations will certainly affect the application of work systems and the labour skill requirements, causing a necessity for offering corresponding training opportunities to un-skilled labourers, which will become a challenge for forest managers. In addition, with respect to low impact operations from the planning to the implementation phase, training and consequent professionalization of the workforce is inevitable [81].

The introduction of equipment, of whichever scale, will become necessary with commercial operations, as they need to achieve higher efficiency. Low mechanization involves less efficient logging operations but at the same time higher labour demand and costs [82]. The example of high turnover rates experienced during the mechanization of Canadian forest operations in the 1970s [83], shows that this can become a major challenge for Chinese operation managers, too, if it cannot be avoided by competitive wages and job security. This is particularly critical in work systems where skills are highly dependent on experience, such as cable yarding for example [84]. This is the dilemma at the current stage of the sector's development in China. On the one hand, it experiences a shift towards commercial operations that involve a higher degree of mechanization, requiring skilled labour in form of professional machine operators and operation managers but also servicing personnel and facilities, which are only available to a limited extent [57]. On the other hand, forest landholders are not willing or able to offer higher wages that would make the occupations attractive and improve retention. Therefore, the majority of the labour pool currently remains those who are unqualified and without other chances in the job market, whether in rural off-farm employment or in the urban areas. However, this pool of workers is aging, which, in consequence, reduces their productivity and future availability even further [80]. A revitalization of this labour class is generally limited due to the rising educational level of young people also in rural China. This is further promoted through spillover effects by the rural out-migration and the changing financial situation of the benefiting relatives staying in the villages, for example [85]. Therefore, the pure availability of these labourers in quantities necessary for the conventional manual work systems is not guaranteed anymore, a problem other transitioning economies also experienced, forcing them to further mechanize their operations, for example [86,87]. In Guangxi's border region to Vietnam—a major forest plantation area, this shortage of low qualified and cheap workforce might be compensated through Vietnamese migrant workers to a certain extent (see [48]). However, this supply source will most likely become limited in the near future too, due to the ongoing economic progress in Vietnam, as well as stricter enforced work regulations in China.

Nevertheless, supply shortfalls related to conventional work systems will not only affect the forest products industry in terms of volume and just in time delivery limitations due to a lower availability of manual labour. In a comprehensive evaluation, it is obvious that the pure technical handling of new assortments such as dimensional long wood is not manually feasible, too. Despite the silvicultural achievements increasing the ability to produce more valuable and dimensional sawlogs within plantations [53], Engler et al. [57] demonstrate that efficient manual extraction is limited to log diameters of <15 cm. This underlies that forest managers in particular, need to review the extraction systems currently applied and adapt them accordingly.

Li and Wang [7] anticipated that utilization orientated forest operations will transfer to a planting-silviculture in China, with logging becoming less important in the future. Although this development applies to many of the traditional timber regions with its natural forests, it is not the case for the plantation areas in the subtropical regions, both on smallholder and industrial level. There, the transfer to a more industrialized timber production is visible, rising from the steadily increasing raw material demand through China's economic progress. However, despite of changed operation frameworks, forest operation systems have remained mainly the same as at the end of

the previous millennia, not able to keep pace with the development and are therefore a significant limitation for the establishment of plantation based sustainable timber supply chains in China.

4. The Way forward

The sustainability of forest operations is directly linked to the overall management of the resource under the concept of sustainable forest management (SFM): *“a notion which has shifted from sustained wood yield and steady forest cover to increasing diversity of goods, benefits and ecosystem values demanded by society [88]”*. In order to verify the sustainability of an operation from a holistic perspective, it has to be considered as an interactive unit within the complete forest-wood supply chain and evaluated among the three pillars of sustainability: economic, environmental and social factors, as well as complemented by technical feasibility [89]. The sustainability of operations therefore is, already highly determined by the objective of SFM. Low impact and productive work systems can serve as decisive tools in the implementation of SFM objectives and can facilitate successive supply chains for a sustainable resource utilization and economic development through the generation of value added products.

4.1. Entrepreneurship

Forestry as a land-use system is more periodic in work nature than agriculture, requiring high labour input only during specific stages of operation: stand establishment, tending, thinning and harvesting [90]. With a shift from subsistence to commercial land-use, plot size of a management unit is increasing and, thus, a higher level of input is required during the work periods, usually conducted by the landowner through hired labour. If hired labour becomes expensive or unavailable at the required periods and scale, as it is currently the case in China, then *“the road for mechanization is paved.”* Yet, in transitioning economies like China, the majority of farmers still own small plots and are not in the position to purchase and/or adequately use and maintain capital-intensive equipment. This is further prevalent in China due to limited access to bank loans for many rural dwellers [91]. This in return offers opportunities to the medium to large-scale farmers who have more capital to run equipment and rent them out when they do not require the machines themselves [92]. Agricultural tractors offer many opportunities to be fitted for Chinese forestry operations to improve log extraction by accessory equipment such as winches or forestry trailers [61], enabling an extension and further business opportunities for the already existing agricultural entrepreneurs [29]. In Chinese forestry, such a form of entrepreneurship bears a wide potential for application since smallholder forest farmers criticize their lack of access to forest operation equipment due to insufficient funds [21]. On the other hand, the availability of professional contractors would also support the state forest enterprises to increase their efficiency by substituting their outdated equipment (see [2]) with contracted services and adverse the economic pressure resulting from the workforce situation (Figure 5).

Generally, various opportunities for professional entrepreneurship in the forest operations sector of China arise. Yet, a rising demand for professional equipment and associated operation personnel, opposes limited financial, managerial and operative capacities of many landholders. Although the central government has provided large funds for plantation establishment, as outlined in this paper, it is lacking any program to support the purchase of modern forestry equipment, or the development of operation infrastructure such as forest road construction [7,49,58,61]. There are a few large-scale private firms, also backed by foreign investors, which could afford large investments in operational systems. But experiences from other countries have shown that such companies too, generally prefer to contract operation services instead of managing their own equipment—as long as such services are available, for example [93]. Despite increasing efficiency and entrepreneurial job creation, the adaptation of mechanization in a contract service environment can launch other ventures as well, such as service facilities and operation supplies retailers, triggering further knowledge transfer, creating off-farm employment opportunities with fiscal returns for local governments and, thus, stimulate rural development.

The development and promotion of a professional forest service entrepreneurship supported by governmental funding programs, also offers opportunities to further implement forest certification. This would enhance sustainable forest operation practices, a strategy that is currently fairly rare in China, despite the government's objectives [94]. The definition of work standards for sustainable operations, accompanied with the qualification of contractors through training courses and the proceeding verification of its implementation and observation of conduct through independent bodies, could facilitate CoC (chain-of-custody) certification, too [44,95]. Hiring certified contractors can reduce the efforts that an individual landholder must undertake to acquire forest certification.

The availability of, and particularly the access to, equipment that fulfils the needs of local operational conditions, infrastructure and capacities are prerequisites for successful mechanization through rural entrepreneurs. In this case, governmental instruments, focusing on individuals acquiring equipment, subsidies or access to favourable loans, as well as vocational training in operations and equipment management, are mandatory for transitioning economies striving towards rural mechanization in order to ensure a sustainable change-over [96]. State-run training centres with certificate courses, a standardized examination, skills acknowledgement and up to date insights on best practice offer the best platforms to generate a professional workforce. The regional experimental centres of the *Chinese Academy of Forestry* could play a leading role and develop to important training hubs. Currently, however, the development of technical training for rural, land-use related stakeholders is generally low in China and capacities need to be build up in that sector to contribute to a more positive trend [97].

4.2. Forest Tenure

Land tenure, or rural land-use rights, play a fundamental role in sustainable plantation forestry, as well as the land manager's perspective on security and subsequent intentions regarding investment [90]. Despite of the recent achievements in tenure reforms, particularly the collective managed plantation sector of the south requires further improvements in tenure rights in order to rise interest and capacities for an appropriate management [17,26]. Although the recent collective forest tenure reform could strengthen the position of small-holders, it failed to create more favourable investment and planning conditions for larger private sector companies, thus hampering industrial development and scale economies [23]. Yet, once again, particular foreign investor-backed, large-scale plantation developers are in the best position to introduce new operation systems and equipment and to support the related infrastructure development. This in return also revitalizes rural economies and fosters investments, for example, in forest roads [49], operational improvements smallholder plantation owners will benefit from, too and improve contractor conditions. In combination with modern and sustainable operation systems, such a system would provide more fiscal revenue for the government when compared to the highly deficient governmental managed enterprises with their outdated equipment (see [2]). Furthermore, a direct interaction between governmental institutions and private sector corporations would ensure a better documented and more transparent tenure transfer with officially issued titles, in contrast to the often-criticized dubious transfer by the collectives' local village authorities [23].

Whether from a smallholder or industrial perspective, tenure rights are a prerequisite for long-term planning and investment decisions. Although the tenure reform is now leaning towards a market-orientated direction, the government is still a highly regulating body. In legal cases, local institutions often give priority to the government rather than to the landholder [23]. Moreover, China's bureaucratic and inefficient scheme for logging permits is in need of reform in conjunction with the tenure rights and the annual allowable cut, to create more favourable market conditions for the development of the forest industry [28,68]. Time wise operational planning can be realized in a strategic way on macro level only with ensured tenure rights. Yet, such planning is fundamental for the realization of sufficient annual utilization hours to enable efficient management of capital-intensive operational systems, which is currently a major concern for potential equipment owners in China [61].

4.3. Research and Education

The knowledge base of suitable operational systems and equipment for the Chinese forestry sector is despite of regional expertise not sufficient to meet the current demand. National research programs as for example conducted on forest operations across Italy during the mechanization process of the country's forestry sector [98] are lacking in China. Such programs are essential in order to identify suitable alternatives to the conventional manual systems are necessary to improve China's timber supply chains and to establish a managerial base for operation on enterprise level. Although international equipment manufacturers see great potential in the Chinese market [72], it is the task of Chinese forest research institutes to pay more attention to forest operations and work science in order to identify suitable work systems and associated equipment, fulfilling the needs according to local requirements. This can also help to further increase the efficiency of state forest enterprises, by identifying operations, which can be contracted out to private enterprises and thus will reduce costs [3].

Currently, research but also academic education in China focuses more on forest ecology and silviculture [99]. Despite designated research facilities, forest utilization works are primary focusing on the forest products sector. The efficient linkage of ecological production and secondary timber product conversion need the support of intensified work in forest operations research and education. Also, further cooperation between research institutes, state-owned forest farms and liaisons with collective managed forest farms and the private industrial sector through organizational platforms could enhance operational developments and shape vocational training for a professional local workforce. Only with professionals, the fundamental problem of low plantation productivity can be addressed in an efficient way to solve the demand-and-supply gap. Besides increased efficiency of Chinese forest operations, capacity development throughout the various hierarchical levels of the sector, can address other challenges as well. With established standards, timber supply chains become more transparent and makes it easier to implement certification and legal origin verification of timber. On the other hand, social responsibility and international labour standards in terms of occupational health and safety, work legality and labourer rights, as demanded with China's general development [100], will be possible to realize only with a fundamental scientific and educational base in Chinese forest operations.

5. Conclusions

The forest operation sector of China is in transitions and facing various challenges of which a contribution to efficient timber supply is of national importance. However, the sector has not gained the required attention in research and practice. Nor was its contribution to achieve sustainable domestic timber supply capacities considered in forest policy reforms. It has not been subject of interest in management of natural forest, neither in plantation operations. Although particular for the latter, it plays a fundamental role in order to achieve the goals set by the forestry reform process and to guaranty a sustainable progress. The justification of conventional operations based on manual labour is expiring due to a changing socio-economic situation with rising labour costs and a lower workforce availability. Also increasing work standards in conjunction with supply efficiency requirements and new forest management regimes demand more efficient and low impact operations. This is mandatory for short rotation plantations but also within thinnings and dimensional timber production of semi-natural forests, regardless if it is applied to smallholder ventures or on an industrial scale. Sustainable forest management intentions are strong drivers for a higher degree of mechanization and are therefore vital in order to establish efficient long-term timber supply chains in China, an objective which currently is not met by domestic plantations.

Forest policy reforms in China over the last decades changed significantly the forest landscape, contributed to area extension, biodiversity conservation and enhanced forest ecosystem services. Additionally, through the tenure reforms it was possible to improve the forest depending livelihoods for rural dwellers. Yet, the reforms failed to mitigate the timber demand-and-supply gap by

increasing forest productivity. Further, up to now, it was not possible to establish a market orientated forest industry build on a sustainable resource utilization concept. Ongoing forest policy reforms should further focus on the promotion of efficient, low impact operation systems, which suite the socio-economic developments and endorse the private sector development of entrepreneurs and plantation estate ventures. This needs to include access to capital through governmental grants, secure production ground through ongoing tenure reforms, a suitable forest road network and intensified research and education efforts. Nevertheless, it is essential to further monitor, adapt and develop the progress.

Acknowledgments: The study presented in this paper was conducted within the framework of the Sino-German research project “Lin2Value: Innovative Technologies and Services for Sustainable and Multifunctional Land Use Systems in China,” a cooperation between the University of Freiburg, University of Goettingen, Technical University of Dresden and the Chinese Academy of Forestry, Beijing. The Federal Ministry of Education and Research (BMBF, support code 033L049A) and the Eva Mayr-Stihl Stiftung provided project funding on the German side and on the Chinese side the Ministry of Science and Technology (MOST, support code 2015DFA31440). The authors would like to express their thanks for the financial support of the abovementioned organizations. The article processing charge was funded by the German Research Foundation (DFG) and the Georg-August University Goettingen as part of the funding program Open Access Publishing.

Author Contributions: S.H. conceived and conducted the review and drafted the manuscript which includes results and aspects of his PhD-thesis [61]. D.J. initiated the research and guided the manuscript writing. W.S. contributed to the literature and data access and the draft of the manuscript. All authors read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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