Assessing the Potential of Eucalyptus Plantation to Supply Timber for Greener Development in China

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1 Introduction

Recently, the national leadership of China announced two strategic goals. One is to realize peak carbon emissions before 2030, and the other is to realize carbon neutrality by 2060. This raises the expectation that the forest sector will be a main candidate to fulfill the carbon neutrality goal. Among all the developing countries, China has a comparative advantage in forestry development. Its forest volume has expanded over the past four decades, with its forest cover increasing from 12% to 22% in that period. Plantation forests, managed mostly by rural collectives, are the main forces in the expansion of forest resources in China.

To achieve the nation's carbon neutrality ambition, China must look for ways to heighten its forest productivity. Currently, the timber volume per unit area is merely two-thirds of the world average. A back-of-the-envelope calculation indicates that, if China's timber volume per unit area were to reach the world average, the incremental timber production, if used for housing purposes, could replace around one-fifth of the iron and steel, would reduce the concrete associated with the annual housing construction, and would reduce carbon emissions by at least one billion tons.

So far, the forest sector has not lived up to its potential due to historical pathways in the last four decades. These trends have included too much conservation and too little support for increasing forest productivity. Consequently, China has to rely on timber imports and has become the world's leading timber importing country. Figure 1 shows that, after 2000, the year when China's natural forest protection program was launched, timber imports (including logs and sawnwood) kept grow-

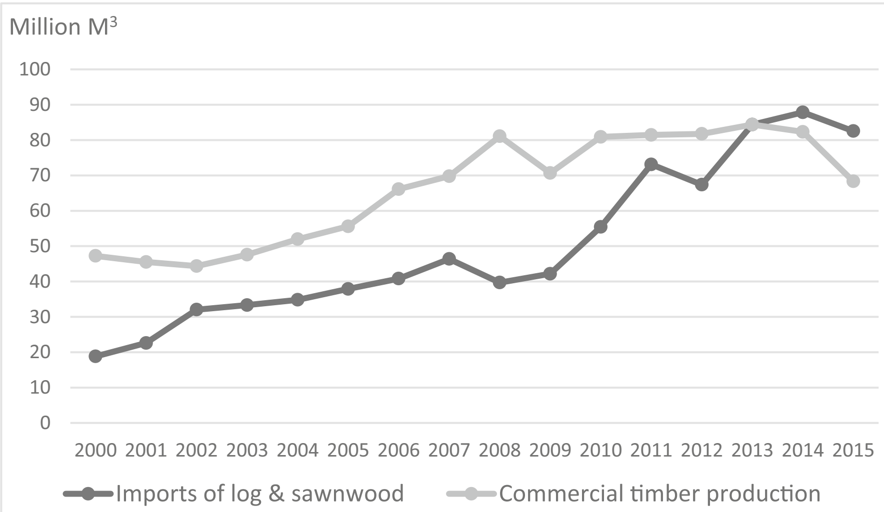

Fig. 1 Logs and sawnwood: production and imports, 2000–2015, China

ing, while domestic production leveled off after 2008. By 2014, timber imports surpassed domestic production.

Growing imports of forest products would have been beneficial to both China and the supplying countries in an ideal world. The actual pattern has helped China preserve its remaining natural forests, giving them an opportunity for restoration. It also has boosted economies in the supplying countries. However, the fast-growing timber trade has been widely criticized as a driving force for rapid deforestation and forest degradation in tropical countries, making it harder to implement REDD+ in the tropics.

It has been problematic in China, too. Inadequate forest productivity has been accompanied by heavy reliance on materials based on exhaustible resources, such as iron, steel, and concrete, making it harder for China to move onto a green and low-carbon growth path. The current growth model has been widely recognized as unsustainable. The need for change, including much higher reliance on renewable materials and energy sources, is increasingly unignorable.

Promoting fast-growing and high-yielding plantation forests seems to be the key approach for China to meet its national ambitions for carbon peaking and carbon neutrality in the next four decades. As Frederick (1983) pointed out near 40 years ago, with higher-yielding forest plantations, “it would be possible to satisfy wood needs on just a small fraction of the land now devoted to forests.” Vincent and Binkley (1993) rigorously argued that specialization might be the best solution if forest managers are seeking to meet societal demand for multiple functions of forests.

This prospect is more important for China now than ever before, as China seeks to achieve carbon neutrality, in part through a forest carbon sink, while increasing forest-based products to make the economy greener and less carbon intensive.

Eucalyptus forest plantation is a promising candidate with great potential. In Brazil, eucalyptus has been planted in agricultural areas away from the Amazon. Based on statistical yearbooks of the Brazilian Forest Plantation Producers (ABRAF), the area growing eucalyptus is about 5,500,000 hectares, which is 73% of the total plantation forests, and eucalyptus plantations supply 72% of the nation’s needs for wood.

In southern China, 4 million hectares (ha) of eucalyptus have emerged, on a roughly equal scale in the provinces of Guangxi and Guangdong, mostly during the past two decades. Quietly, the two provinces became the nation’s largest wood-supplying provinces, because of the tremendous productivity of eucalyptus plantation. Eucalyptus plantation shows remarkable timber yield, high carbon sequestration ability, and much better economic return to the forest owners. In addition, it takes a very small fraction of the forestland in the two provinces, enabling the provinces to set aside large areas of the remaining forests for conservation. It seems that a green revolution has been occurring in the woods.

Due to data availability, we intend to focus our case assessment of eucalyptus development in Guangxi Province.

The paper is organized as follows. In Sect. 2, we provide an overview of China’s industrial policy in relation to timber production and trade and discuss implications for changes in growth patterns in China and the world. In Sect. 3, we review the development of eucalyptus in Guangxi. In Sect. 4, we conclude with a policy discussion.

2 Industrial Policies and Forest Production in China

Persistent environmental issues in China have a lot to do with its industrial and energy policies. Among these, a key reason has been the preference for heavy industrial products, rather than renewable materials such as timber and wood fiber. For a long time, China's industrial policy favored heavy industrial building materials, such as iron, steel, and concrete. However, timber also was heavily relied upon as a building material in the 1950s and 1960s; it also was an important contributor of fiscal revenue (through sales of timber from publicly owned forests). In the 1980s, the national government recognized the extent of deforestation and the failure of reforestation and launched some long-lasting policies to substitute materials made of nonrenewable sources, such as iron, steel, and concrete, for timber, in the name of providing breathing room for forest ecosystems. Domestic timber production, hence, has remained stagnant since then. On the other hand, timber imports have grown rapidly, and China has become the world's largest timber and forest product consumer country in the last two decades.

The consequences of this industrial policy are of both domestic and international importance. Domestically, heavy reliance on imports implies that timber is a scarce and expensive material, and its share in the material mix is small. Although the Ministry of Housing Construction recognizes the promise of building modern wood-based houses, this approach has attracted very limited interest from real estate developers due to lack of timber resources and high cost. China's fast housing growth remains heavily reliant on steel and concrete, with major implications for air pollution and GHG emissions.

Internationally, the growing demand for tropical timber has led to rapid invasion of logging industries into tropical forests in Africa and South America. The rising demand increases competition for tropical timber and makes international climate initiatives such as REDD+ difficult to implement.

In summary, increasing forest productivity and domestic timber supply can contribute to environmental improvements, both domestically and globally.

3 Assessment of Eucalyptus Plantation in Southern China

3.1 Historical Trend of Eucalyptus Plantation Forests (Guangxi)

The history of eucalyptus in Guangxi goes back to the late nineteenth century, when forest gray gum (*Eucalyptus tereticornis Smith*) was introduced from France by missionaries, first to Longzhou County, then spreading to multiple areas. In 1954, the first government-sponsored forest farm was established in Hepu County, to produce protruding eucalyptus (*Eucalyptus exserta F.V. Muell*). In the same period, planting of protruding eucalyptus, forest gray gum, lemon eucalyptus *(Eucalyptus citriodora Hook.f.*), etc., was observed widely across the southern and coastal areas of Guangxi, scattered in villages and along roadsides, and as a source of firewood for farmers.

The first wave of expansion happened in the 1960s. The province established a number of state-owned forest farms (up to 10), led by Qinlian and Dongmen Forest Farms, to promote plantation of protruding eucalyptus, lemon eucalyptus, and western Australian flooded gum *(Eucalyptus rudis Endl).*

By the late 1970s, eucalyptus plantation forests had reached 100,000 hectares. The productivity of the early eucalyptus trees was on par with domestic tree species. However, its advantage was not prominent until the next phase.

It was during 1982–1999, when the "Sino-Australia Technical Cooperation and Demonstration of Eucalyptus in Dongmen State Forest Farm" project was implemented, that systematic seedling introduction and improvement began in Guangxi. This yielded highly recognizable outcomes. During this time span, a nursery with 135 tree species and a genetic bank of more than 600 good-quality clones were established and became the largest source of eucalyptus seedlings and the production base for fine eucalyptus species. In the experimental field, the optimal hybrid species grew at a phenomenal annual rate of 70 cubic meters per hectare, while the best clone yielded 66 cubic meters per hectare.

By the year 2000, based on provincial forest inventory, the area of eucalyptus plantation reached 167,000 hectares, with a volume of 2.2 million cubic meters. Although the actual average annual yield was modest, at 10.5 cubic meter per hectare, eucalyptus plantation became the foundation of a growing business of wood chip production and export, as well as pulp and papermaking.

The development of eucalyptus plantation has experienced a great leap forward since 2000. Fast-growing and high-yielding plantation forests became the key program both in Guangxi and in the whole country. Eucalyptus was chosen as a leading species in the provincial program. In 2002, the provincial government launched a set of supporting policies to facilitate eucalyptus investment, including exempting half of the afforestation fund contribution, prioritizing harvest quota approval, and subsidizing afforestation loan interest. Market expansion also has been remarkable, from unitary chip export to the manufacture of pulp and paper, plywood, mid-to-high density fiberboard, and wood flooring.

The state-owned forest farms have been leading the way in eucalyptus introduction, improvement, and proliferation. A total of 13 farms planted 67,000 hectares of eucalyptus within state forest territory, plus an additional 200,000 hectares on collective forestland under joint contracts. Since 2002, promoted by the joint forces of scientific innovation, policies, and market demand, eucalyptus area has been expanding at an annual rate of 134,000 hectares. By 2013, the total area had reached 2 million hectares, with over 100 million cubic meters of volume. Of the total area, 70% is owned by village collectives and individuals and 30% by the state farms.

The average annual yield at the 6-year eucalyptus stand reached 19.5 cubic meters per hectare, with an average volume of 107 cubic meters per hectare. The highest yield, though, occurred in experimental forests and amounted to 49.5 cubic meters per hectare.

Eucalyptus forests are mainly distributed across eight city jurisdictions in southern Guangxi. This has formed the foundation for rapid growth of papermaking and timber processing industries. By 2013, the total timber industry had an output value of 105 billion yuan, making it the ninth industry to cross the RMB100 billion threshold in the province.

3.1.1 Area, Volume, and Timber Production

In 2013, timber production in Guangxi reached 24.80 million cubic meters, 8.3 times the 2000 level, of which eucalyptus accounted for 70% and 17 million cubic meters. Considering that eucalyptus uses only 14% of the total forestland in the province, this productivity has been extraordinary. While eucalyptus in Guangxi occupies only 0.6% of the forestland in the whole country, it contributes 20% of the national timber production. The fast development of eucalyptus plantations enabled the province to set aside more than 80 million mu (or 5.33 million ha) of timber forests of different species as protected forest (Figs. 2 and 3).

During the Eleventh Five-Year-Plan period (2006–2010), the provincial government made a strong push to enhance the integration of forest, pulp and paper, and wood panel production. The governmental stimulus enabled fast expansion of

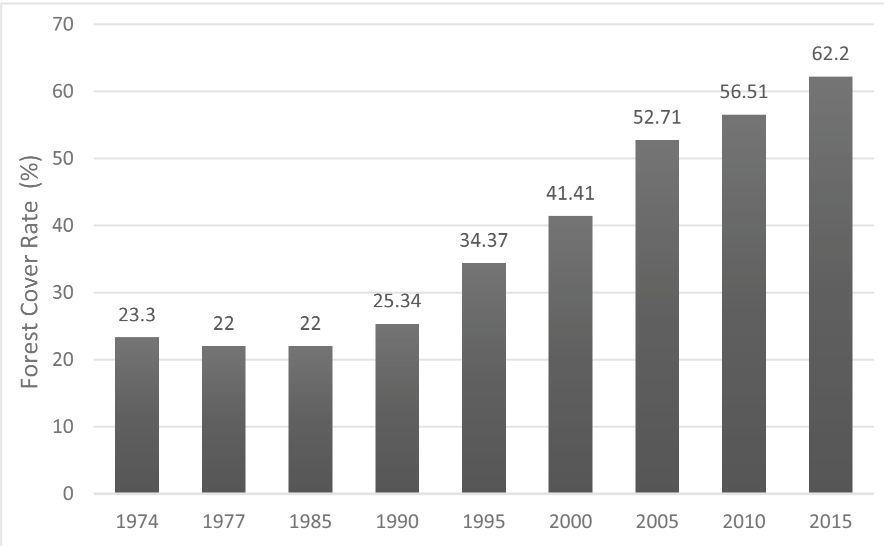

Fig. 2 Forest cover rate change during 1974–2015 in Guangxi, China

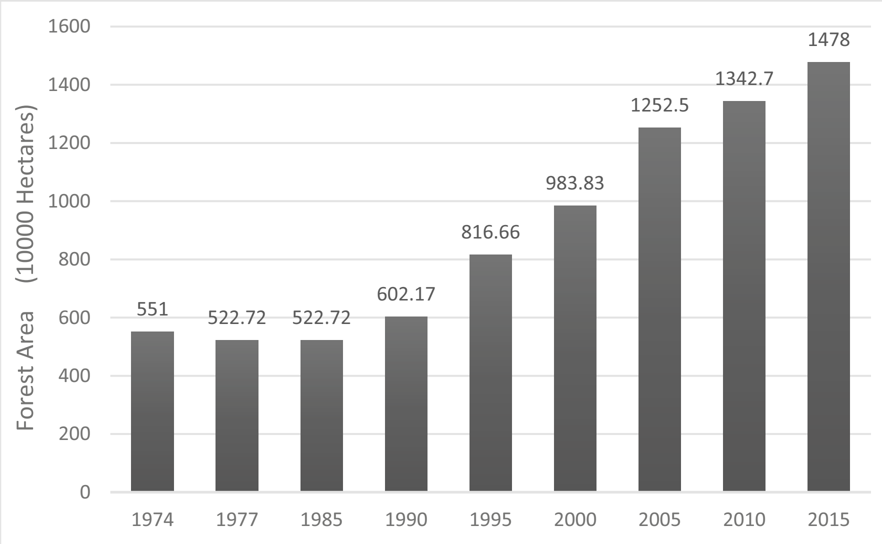

Fig. 3 Forest area change during 1974–2015 in Guangxi, China

high-yielding and fast-growing (HYFG) plantation forests in Guangxi. Based on official statistics, HYFG forests reached 2,333,000 ha in 2010, with 1,653,000 ha of eucalyptus.

Guangxi has demonstrated vast growth potential in eucalyptus. The mean annual growth for a three-year-old eucalyptus stand is 42.26 cubic meters per ha, with the maximum around 49.8 cubic meters. As a comparison, an 8-year-old Chinese fir can grow on average 18.63 cubic meters per ha per year, with 32.71 being the maximum. Masson pine that are 10 years old grow 25.8 cubic meters per ha per year. The eucalyptus plantation demonstrated superior growing ability relative to two major competing species (see Sect. 3.2). Figure 4 shows the annual eucalyptus yield per unit of forest (1 mu = 1/15 ha) in model forest farms.

3.2 *Comparison of Timber Yield Curves: Eucalyptus, Chinese Fir, and Masson Pine*

Using plot-level data and four different curve fitting methods (Hann, 1995; Vanclay, 1995; Weiskittel et al., 2007), we are able to simulate timber yield curves for four different species, including two eucalyptuses (*E.urophylla* × *E.grandis* is shown in solid line; *E.grandis* × *E.urophylla* is shown in dot dash), Masson pine (dotted), and Chinese fir (long dash). It is apparent that the two eucalyptus species have much higher annual yields. See Fig. 5.

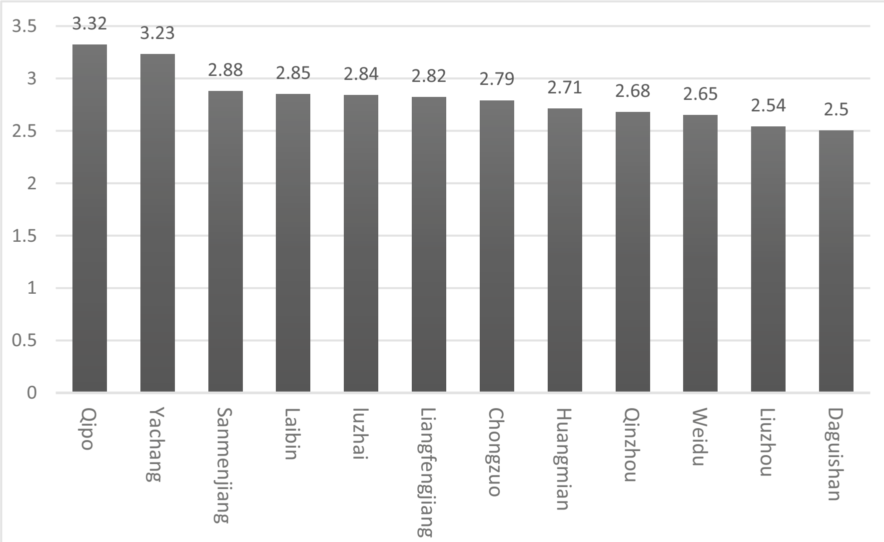

Fig. 4 Annual timber yield per mu in model farms

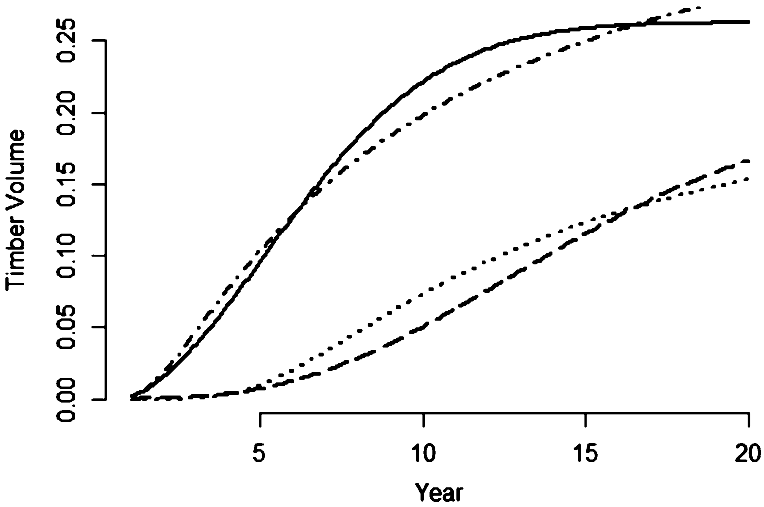

Fig. 5 Growth curves for four plantation species. (solid line, *E.urophylla* × *E.grandis*; dot dash, *E.grandis* × *E.urophylla*; dotted, Masson pine; long dash, Chinese fir)

Averaging over the four different methods, based on the maximum sustainable yield principle, the optimal rotation age is ~7 years for *E.urophylla* × *E.grandis*, ~8 years for *E.grandis* × *E.urophylla*, ~15 years for Masson pine, and 14 years for Chinese fir. Aggregating over 28 years, total timber yield would be 900 cubic meters per ha for *E.urophylla* × *E.grandis*, 940 cubic meters for *E.grandis* × *E.urophylla*, 260 for Masson pine, ~15 years, and 290 for Chinese fir. In summary, eucalyptus stands have far superior growth ability to alternative species such as Masson pine and Chinese fir.

3.3 Comparison of Carbon Sequestration Potential Among Main Species

Based on a study on forest ecosystem function and valuation (a Guangxi government report), carbon sequestration from pine forests is 3.15 ton per ha per year, 4.05 from Chinese fir, 4.20 from broad-leaf forests, 2.70 from bamboo forests, and 4.50 from eucalyptus forests. Eucalyptus again demonstrates superior value in carbon sequestration.

3.4 Expected Land Value

Using the yield curves fitted in Fig. 5, we estimate Faustman rotation age for the four major tree species. Then, we calculate the net present value for one rotation for each species. Next, we calculate the total volume produced from each species in 30 years. Finally, we calculate the expected land value (ELV, estimated based on NPV) for the 30-year span. The two eucalyptus species generate similar ELV to each other, but more than four times the ELV than the other traditional HYFG species (Table 1).

Table 1 Economic rotation age and expected land value for four major species

	Rotation period (Y)	NPV (yuan/Ha)	Volume in 30 years (m^3)	ELV (yuan/Ha)
Chinese fir	16.2	73,146	312	134,465
Masson pine	13.9	74,556	298	149,397
E.u × E.g	5.8	125,876	1011	567,144
E.g × E.u	6	130,765	918	520,256

E.u*E.g stands for *E.urophylla* × *E.grandis and* E.g*E.u stands for *E.grandis* × *E.urophylla*
The tree density of Masson pine is 3 m × 3 m
The tree density of Chinese fir is 2.5 m × 3 m
The tree density of *E.urophylla* × *E.grandis* is 2 m × 3 m
The tree density of *E.grandis* × *E.urophylla* is 2 m × 3 m
The rotation period is economically optimal rotation period, and the interest rate used is 5%

3.5 The Private Sector in Eucalyptus Development

The public sectors, namely, the provincial and county governments and state forest farms, have played a pivotal role in the reintroduction, enhancement, and expansion of eucalyptus plantations. The private sector, however, quickly became the dominant force in this development. Afforestation areas of eucalyptus by the private sector accounted for 82% and 78%, in 2012 and 2013, respectively (see Table 2). In 2015, the total area of eucalyptus plantations owned by the private sector accounted for 87% of eucalyptus forests in the province (Figs. 6 and 7).

Table 2 Area of afforestation and improvement by investment source 2012–2013

	2012		2013	
	Hectares	(%)	Hectares	(%)
1. State and collective-owned forest farm	25,725	17.92	25,257	21.47
2. Domestic enterprises	7230	5.04	3326	2.83
3. Foreign-funded enterprises	3542	2.47	642	0.55
4. Joint venture	51	0.04	0	0
5. Farmer	79,185	55.15	75,100	63.83
6. Others	27,854	19.4	13,335	11.33

Source: Guangxi Department of Forestry

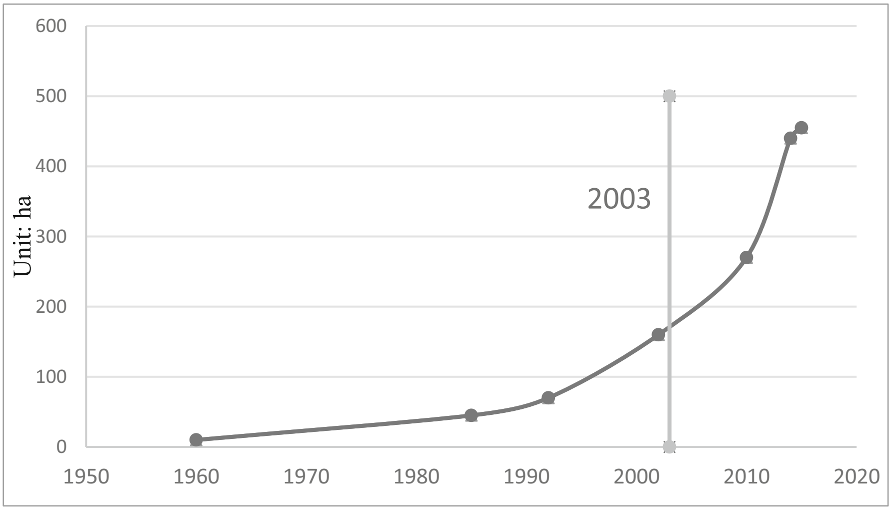

Fig. 6 Eucalyptus area change, 1950–2020

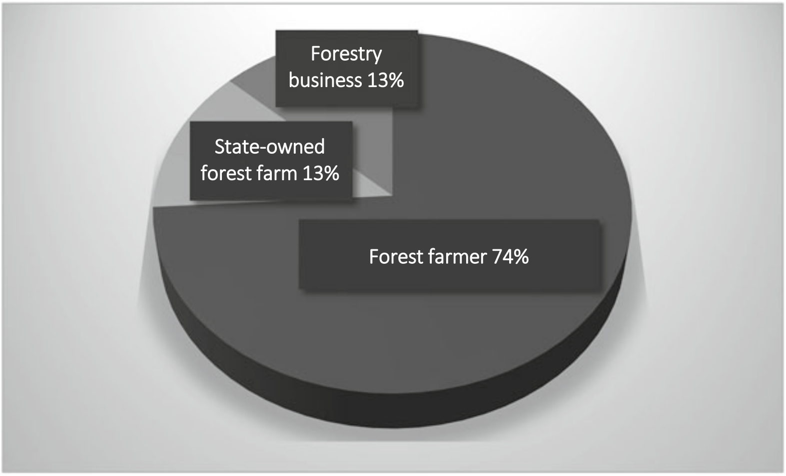

Fig. 7 Eucalyptus share by ownership type, 2015

4 Conclusion

Using Guangxi as a leading case, we examined the productivity potential of eucalyptus plantation forests. In Guangxi, eucalyptus supplies 80% of the timber output, using only 14% of the forestland. Its annual yield per unit area has surpassed those of traditional plantation species, such as Chinese fir and Masson pine. Its carbon sequestration ability also exceeds the other main species. However, eucalyptus forests' potential has not been fully realized. Its average annual yield per ha can still at least double, even triple. If this growth potential is realized, China's annual wood supply will double.

What stands between the promises and reality is weak property rights, constraining forest management policy, and the ensuing lack of incentives for the private sector to make further investments in forest productivity. Government and forest administration need to put forward greater effort to ensure farmer property rights and security of legal contracts, as well as providing an enabling policy environment for forest owners and private investors in the eucalyptus plantation business. If these institutional and policy improvements are achieved, the ambition of timber self-sufficiency will be feasible, given current consumption patterns. This would also make China's ambition of achieving a carbon peak in 2030 and carbon neutrality in 2060 more achievable. The development of eucalyptus plantation would indeed be a green revolution in the woods.

One major caveat is that more research is needed on fire risk due to eucalyptus plantations in China. In California, for example, there are fire risks due to the extensive importation of eucalyptus into a wildfire-prone environment, where eucalyptus compete with native trees that are adapted to a wildfire ecology. Further research is needed on this issue in the context of China.

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