The Comparison of Carbon Trade-offs between Eucalyptus in Southern China and Loblolly Pine in North Carolina, USA

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Abstract

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Forests have a critical role in slowing climate change because it acts as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass. Variation in forest management prescriptions could achieve higher levels of carbon storage compared to a baseline condition. Improvements in forest management becomes more important in the growing global carbon markets since carbon credits have been developed as a serious financial instrument. Eucalyptus is the most common species planted in southern China and loblolly pine is the most common species planted in North Carolina, USA. Both of species are widely used for a variety of timber products but their optimal rotation ages are typically calculated without including of carbon value. This study uses two growth and yield models, one for China's eucalyptus and one for North Carolina's loblolly pine and compares them in terms of net present value of both timber and carbon, timber SEV, and carbon SEV. This study combines timber value with tree carbon value and re-calculates their optimal rotation age considering carbon credits. The result shows the average optimal rotation age of China's eucalyptus increases from 7 years to 21 years and loblolly pine increases from 20 years to 22 years. From the IRR analysis, loblolly pine in NC is more worth to be invested. Though there are more conditions that need to be considered in managing the forest, this study discusses the possibility to postpone the rotation age of plantations to encourage more carbon credits.

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1. Introduction

As we all know, carbon dioxide is a major greenhouse gas (GHG). Increased atmospheric CO_2 is attributable mostly to fossil fuel combustion and deforestation worldwide. Every year, atmospheric carbon is estimated to be increasing by approximately 2600 million metric tons (Schneider, 1989). Forests cover nearly one-third of earth's land area, containing up to 80% of the total above-ground terrestrial carbon and 40% of the below-ground carbon, thus, having a critical role in the global carbon cycle (Winjum and schroeder, 1993). Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass, which can reduce atmospheric carbon dioxide significantly. Further, when harvested, wood products can store carbon for a number of years depending on product.

1.1 Forest Carbon Management and Trading:

From 1990 to 2015, total forest area on earth decreased from 4.28 billion hectares to 3.99 billion hectares, while global planted area increased from 1990 to 2015 from 167.5 million hectares to 277.9 million hectares (Payn et al., 2015). Plantations account for 7% of global forest cover and provide more than 60% global industrial round wood (Liu et al., 2013).

Winjum and Schroeder (1993) mentioned that forest and agroforest management practices throughout the world can enhance the capability of forests to sequester C and reduce accumulation of greenhouse gases in the atmosphere, stressing the importance to actively manage global forests. In the meantime, greenhouse-gas emission trading has risen in popularity to become the most broadly favored government strategy. Carbon permits have then quickly been developed as a serious financial instrument in markets turning over billions of dollars a year (Ruddell et al., 2007). What's more, developing carbon markets will also increase the potential effort to manage forest properly because carbon markets indicate the important role of forests in the terrestrial C cycle. It's a win-win strategy for the effort to slow down the climate change and increase forest economic value worldwide.

The research from Birdsey (1992) shows forest in the United States were a carbon sink, sequestering approximately 10% of U.S carbon emissions in 1992. Recently research shows trees and forests in the US urban areas store 643 million tonnes of carbon (Nowak et al., 2013). As for China, its forests has made up 5% of the global total in 2010 (FAO 2010). During the period from 1973 to 2008, total biomass carbon storage of all types of forests in China increased from 4.93 PgC to 8.12 PgC. Average forest stands in China acted as a biomass carbon sink of 0.17 PgC per year from 1999 to 2008 (Zhang et al., 2013).

Carbon trading is a market-based tool to limit GHG. The carbon market trades emissions with credits that pay for or offset GHG reductions (Nowak and Crane, 2002). In terms of carbon trading in forests, there are two kinds of markets. According to Cubbage and Roise (2013), carbon storage markets for forests have existed through the verified carbon standards markets and mandatory markets, such as the California

Air Resources Board. Forest Trends website (www.forest-trends.org) reported that businesses around the world financed the management, conservation or expansion of 26.5 million forested hectares by purchasing nearly 28 million tonnes of carbon offsets from forestry projects in 2012, valued at $216 million. There is a carbon market in forestry.

Different carbon market in the world has its own carbon market policies according to certain society environment in certain country. In the US, the Acid Rain Program, the Regional Greenhouse Gas Initiative (RGGI), and California's cap-and-trade program are all examples of this trend. Australia, New Zealand, and the Canadian province of Quebec have all recently created their own cap-and-trade programs to regulate greenhouse gas emissions, and China, Japan, South Korea, and Brazil are individually making moves toward launching their own (Calel & Dechezlepretre, 2012).

1.2 Eucalyptus in Southern China:

Eucalyptus (*Eucalyptus robusta Smith*) is a fast-growing tree species, with various species planted in tropical and sub-tropical environments around the world. It is known for its adaptability, fast growth, versatility, good material for industry and easy-breeding. Eucalyptus was indigenous to Australia, Indonesia and Philippines, and is grown to provide paper pulp, solid wood, gum, and oil used in medicines. The genus has 945 eucalyptus species, subspecies or varieties, with 100 of them are economically important (Wang, 2012). With a plantation area of 3.1 million hectares, Brazil has the world's largest area of Eucalyptus plantation forests,followed by China (Wang, 2012).

The website of Eucalyptus of China (eucalypt.forestry.gov.cn) shows the Chinese ambassador to Italy introduced eucalyptus back to Guangzhou and Fuzhou Province in 1890. Also according to the data (eucalypt.forestry.gov.cn), China has more than 300 eucalyptus species and more than 20 of them are widely planted for production, such as *E. urophylla*, *E. grandis* and *E. globulus*, etc. They are mainly distributed in Guangxi, Guangdong, Hainan, Yunnan, Fujian, and Sichuan Province in southern China. The total plantation area exceeded 2.5 million hectares by 2010. Guangxi Province has the largest area of eucalyptus plantations in China.

1.3 Loblolly pine in North Carolina:

Loblolly pine (*Pinus taeda*) is the most important commercial timber species in the southern United States, where it is dominant on about 29 million acres and makes up over one-half of the standing pine volume (Baker and Langdon, 1990). It is a fast-growing member of the yellow pine group, which grows in an area extending from the Coastal Plain throughout the eastern Piedmont. And it is the most hardy and versatile of all southern pines, in terms of its ability to reproduce and grow rapidly on diverse sites. It seeds profusely, regenerates easily, provides large yields per hectare, provides many different marketable products at a relatively early age, and makes good wildlife habitat when stands of many ages are growing in close proximity (Schultz, 1997). Loblolly pine reaches maturity by age 80 and rarely lives beyond age 300 even under the best conditions.

2. Methods

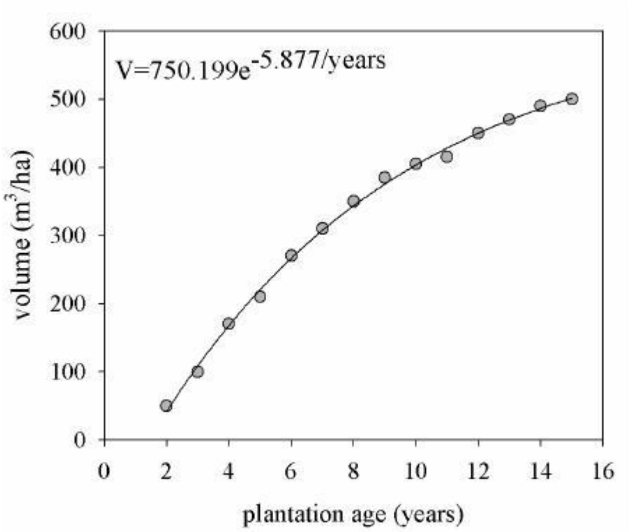
This section presents the complete dataset used in this study and methods. To study the economics of the two species, we need to know the growth and yield associate with them. Then I use stand volume data to do economic analysis.

2.1 Study of eucalyptus in southern China

Growth and yield model:

This study will use eucalyptus *grandis* as a representative eucalyptus species in southern China. It is one of the most commonly planted eucalyptus species in Guangxi province. Usually after several years, the volume of eucalyptus will remained almost unchanged, which is not an advantage in terms of long-cutting rotations. It is proved by a stand volume curve (Imaña-Encinas, 2011) shown as Figure 1.

Figure 1. Mean annual increment of eucalyptus stand volume (Imaña-Encinas, 2011).



However, a proper growth and yield model of eucalyptus has not been developed in China yet. There is one in Brazil called SisEucalipto. Brazil is currently the world's top producer and exporter of eucalyptus wood and pulp and the model was developed by Embrapa, which is a Brazilian public agricultural research corporation (www.embrapa.br/en/international). This model interfaces with a whole stand growth and yield model of eucalyptus *grandis* and provides options for evaluating eucalyptus plantations under different manage conditions, including site index, tree density, thinning age. The stand volume projection equation in this model is:

$$V_n = S \times e^{-2.72\times(A^{-0.51}\times 15^{-0.51})}$$

Where V_n= Stand volume at age n, S= Site index of the stand in meters, A=Ages.

Site index is an important measurement that determines the relative productivity of a particular site, we assume that we can use this model to estimate growth and yield of eucalyptus *grandis* in China by inputting proper site index values.

Site index:

Chen et al. (1995) collected and analyzed the data on the sample trees and the average height of dominant trees from the hilly areas of eucalyptus *urophylla* planting areas in Guangxi province. They developed a site-index table with high precision under the base age at 7 years, shown as marked black box in Table 1. The table shows the proper range of site index of eucalyptus *urophylla* in Guangxi should be from 10 to 26 m (33 to 87 ft). I assume *urophylla* has the same growth pattern as *grandis*.

Table 1. Dominant height (m) of *E.urophylla* in Guangxi

Age / SI	10	12	14	16	18	20	22	24	26	
1	2.4	2.9	3.5	4.0	4.5	5.1	5.6	6.1	6.7	7.2
2	4.1	5.1	6.0	6.9	7.8	8.7	9.6	10.6	11.5	12.4
3	5.5	6.7	7.9	9.1	10.3	11.5	12.7	13.9	15.2	16.4
4	6.5	8.0	9.5	10.9	12.4	13.8	15.3	16.7	18.2	19.6
5	7.5	9.1	10.8	12.4	14.1	15.8	17.4	19.1	20.7	22.4
6	8.3	10.1	12.0	13.8	15.6	17.5	19.3	21.2	23.0	24.8
7	9.0	11.0	13.0	15.0	17.0	19.0	21.0	23.0	25.0	27.0
8	9.7	11.8	13.9	16.1	18.2	20.4	22.5	24.7	26.8	29.0
9	10.2	12.5	14.8	17.1	19.4	21.6	23.9	26.2	28.5	30.7

Cash flow:

A input costs table for eucalyptus from Smith Eucalyptus (smithii.zhujiazao.com) is shown as Table 2.

Table 2. 2015 Input costs table for eucalyptus

Activities	Price ($)
Site Preparation and Planting	429.0 /ac
Fertilization	208.0/ac /year
Management	135.0 /ac /year

According to China Wood Industry (wood365.cn), the prices in unit $\$/m^3$ are listed as Table 3.

Table 3. 2015 stumpage prices of eucalyptus in Guangxi

Product	Price ($ / m^3)
Pulpwood	71.0
Sawtimber	98.0

2.2 Study of loblolly pine in North Carolina

Growth and yield model:

In this study, loblolly pine will be projected using the Forest Nutrition Cooperative Decision Support System (LobDSS). LobDSS interfaces with a whole stand growth and yield model developed by the Loblolly Pine Growth and Yiled Research Cooperative at Virginia Tech. This model provides options for evaluating thinning and mid-rotation fertilization treatments (Amateis et al., 2001). The result can give the distribution of volume for different timber products under each age. Total and merchantable yield prediction equations in this model are used for determining the wood content of stands to any merchantable limit (Amateis et al., 2001). Here are the approach presented by Amateis et al. (1986):

For total yield equation:

$$\ln(Y) = c_0 + c_1(1/A) + c_2(Hd/A) + c_3(A\ln(N)) + c_4\ln(B)$$

where Y = total ob or ib yield (cu ft/ac), A = years since planting, Hd = average height of dominant and codominant trees (ft), N = number of planted pine surviving (per acre), B = basal area of planted pine (sq ft/ac), In = natural logarithm, c_0 - c_4 = coefficients.

For merchantable yield equation:

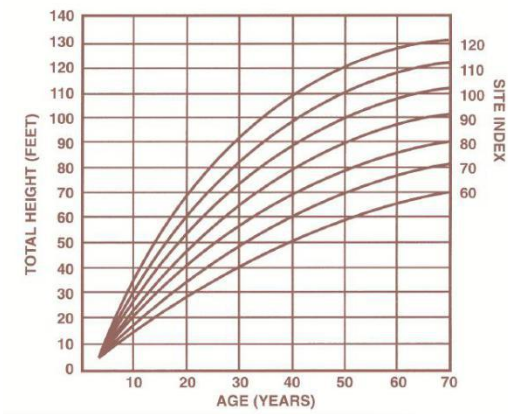
$$Y_m = Ye^{b_1(t/D)^{b_2} + b_3N^{b_4}(d/D)^{b_5}}$$

where Y_m = merchantable ob or ib yield (cu ft/ac) for trees d inches and above to a t inch top diameter limit, Y = total ob or ib yield (cu ft/ac), D = quadratic mean dbh (in.), N = number of loblolly pine surviving (per acre), t = top diameter (ob) merchantability limit (in.), d = threshold dbh limit (in.), e = base of the natural logarithm, b_1, b_2, b_3, b_4, b_5 = parameters to be estimated.

Site index:

The same as in eucalyptus stand, the amount of wood produced by a loblolly pine stand will greatly differ depending upon the site quality, the number of seedlings planted, the intensity of the management regime employed and rotation length. The average height of the dominant tree in a stand at age 25 is used as site quality in LobDSS growth and yield models. Figure 2 (Hamilton, 2000) shows height over age curves for loblolly pine. At age 25, the proper range of site index of loblolly pine in LobDSS model should be from 35 to 80 ft.

Figure 2. Site index curves for loblolly pine at index age 50 years in the Coastal Plain of Virginia, North Carolina, and South Carolina (Hamilton, 2000).



Though the base age of the site index of loblolly pine is different from eucalyptus, I assume I can compare two species under different base age. Because each species has its own specific situations in each country. So it is impossible to get the same base age of site index.

Cash flow:

As for loblolly pine, I assume its site preparation is aerial method, it costs $132.30 per acre in southern coastal plain (Barlow & Dubois 2011). I assume its planting method is machine planting, which costs $66.72 per acre in southern coastal plain. And the burning costs $21.55 per care (Barlow & Dubois 2011). The fertilization costs $82.54

per acre at the beginning (Barlow & Dubois 2011). And annual administration is $5 per acre (Zinkhan and Cubbage, 2003). So an input costs table for loblolly pine in NC ia shown as Table 5.

Table 5. Input costs table for loblolly pine in NC

Activities	Price ($)
Site Preparation, burning, planting	220.57 /ac
Fertilization	82.54 /ac at the beginning
Administration	5/ac /year

According to Timber Mart-South (2015), the stumpage prices of loblolly pine in south is shown as Table 6.

Table 6. 2015 south-wide stumpage prices of loblolly pine

Product	Price
Pulpwood	10.0 ($ / ton)
Sawtimber	25.0 ($ / ton)

2.3 Study Steps:

This study includes 3 steps:

1) Running growth and yield models (Table 7).

In SisEucalipto, set eucalyptus plantations initial age as 0, with density 300 trees/acre (750 trees/ha). Running for three site index 55, 65, 75 ft (16.5, 19.5, and

22.5 m) by age 40. Equally in LobDSS, set loblolly plantations initial age as 0, with reasonable density 300 trees/acres. Running for three site index 55, 65 and 75 ft by age 40.

Table 7. Input table of 2 models

Input	Data
Site index	55, 65, 75 ft
Initial density	300 trees/acre
Initial age	0
Final harvest	40 years

2) Calculating revenue and analyzing the data from two models.

I assumed the carbon market in this study will measure the carbon including those carbon that contained in the forest products. With the timber product prices (Table 3 and 6), the carbon price of CO_2 emissions 15 $/ton (Luckow et al,, 2015), the input costs (Table 2 and 5), and a discount rate 6%, calculating the timber revenue, timber NPV, timber SEV, carbon revenue, carbon NPV, carbon SEV, and combined SEV.

3) Making graphs and analyzing final results.

Comparing the timber and carbon net present value (NPV), soil expectation value (SEV) between loblolly pine and eucalyptus.

3. Results

Eucalyptus and loblolly pine output from model is attached (Appendix table 1 and table 2) Here are volume tables from age 0 to 40 years of timber and carbon for eucalyptus and loblolly pine. Live tree carbon volume is 0.25 tons per m^3 of live tree volume (Smith et al., 2004), which is 0.007 tons/ft^3.

Figure 3. Stand volume of eucalyptus when SI=55, 65, and 75 ft.

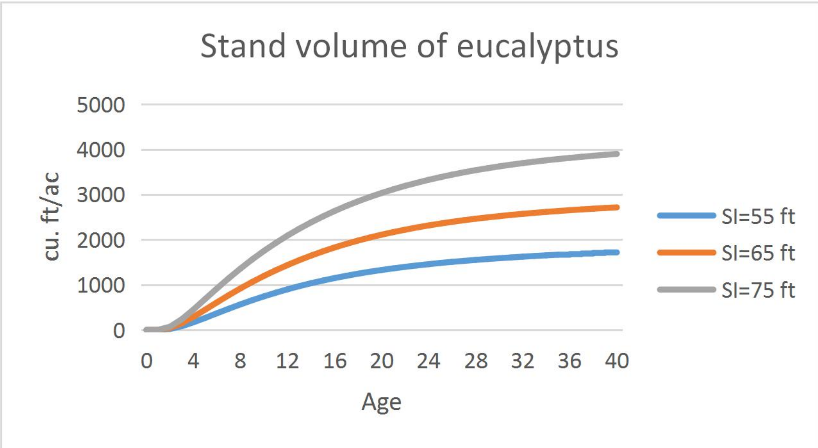


Figure 4. Stand volume of loblolly pine when SI=55, 65, and 75 ft.

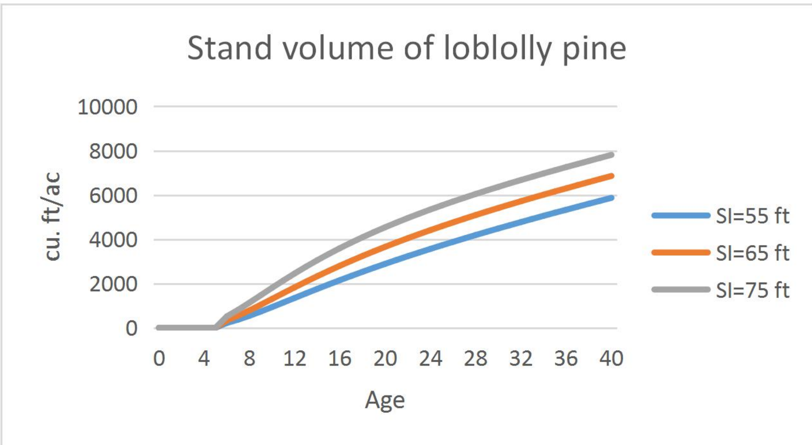


Figure 5. Carbon volume of eucalyptus when SI=55, 65, and 75 ft.

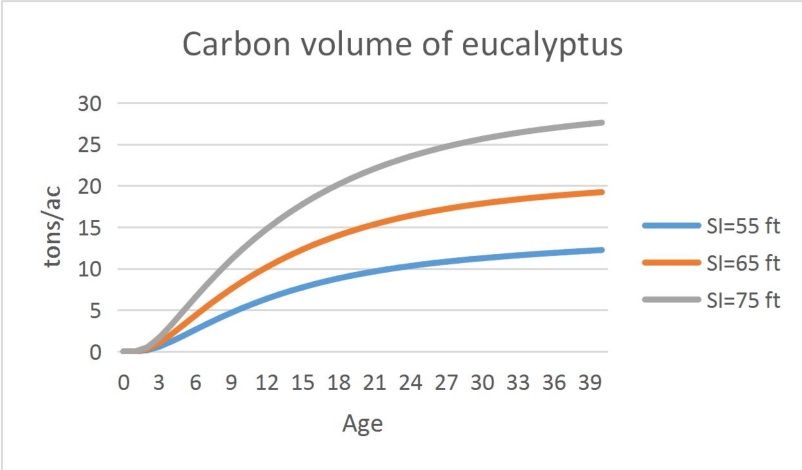
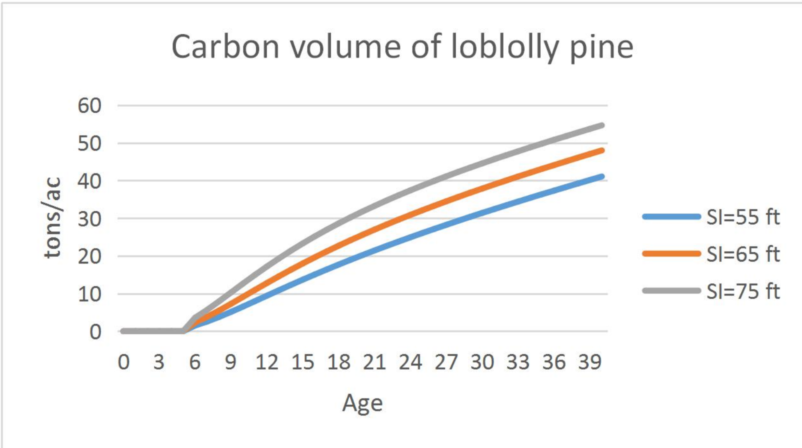


Figure 6. Carbon volume of loblolly pine when SI=55, 65, and 75 ft.



3.1 Net present value (NPV) analysis

The net present value (NPV) of an investment project is the sum of present values of all cash inflows and outflows related to the investment (Talavera et al., 2007). It is a easy way to determine whether an investment will result in a net profit or a loss. We would accept an investment that has a positive NPV. It implies that the rate of return on the project (per unit of land) is higher than the cost of the capital (Zinkhan and

Cubbage, 2003). But we might reject that positive NPV when another project has a greater NPV. NPV equation:

$$NPV = \sum_{j=1}^{n} \frac{R_j - C_j}{(1+i)^j} \quad \text{(Bettinger et al., 2010)}$$

Where: R_j = Revenue at year j, C_j = cost at year j, i = Interest rate, n = Number of years, j = 0, 1, 2..., n.

This study also assumes that forest landowners received payments for both carbon sequestered in standing trees and harvested wood products. Forest accumulate carbon year by year, the increment of carbon volume at year n: $\Delta V = V_n - V_{n-1}$ (n>0), so carbon increased revenue at year n: $R_n = P \times \Delta V$ (P = Price). Then we can calculate accumulate present value (PV) of carbon:

$$PV = \sum_{n-1}^{N} \frac{R_i}{(1+i)^n}$$

Eucalyptus NPV:

From age 0 to 40 years, timber NPV and carbon PV of eucalyptus at each age under 3 site index (SI=55, 65, 75 ft) are shown as Figure 7 and 8.

Figure 7. Timber NPV of eucalyptus when SI=55, 65, and 75 ft.

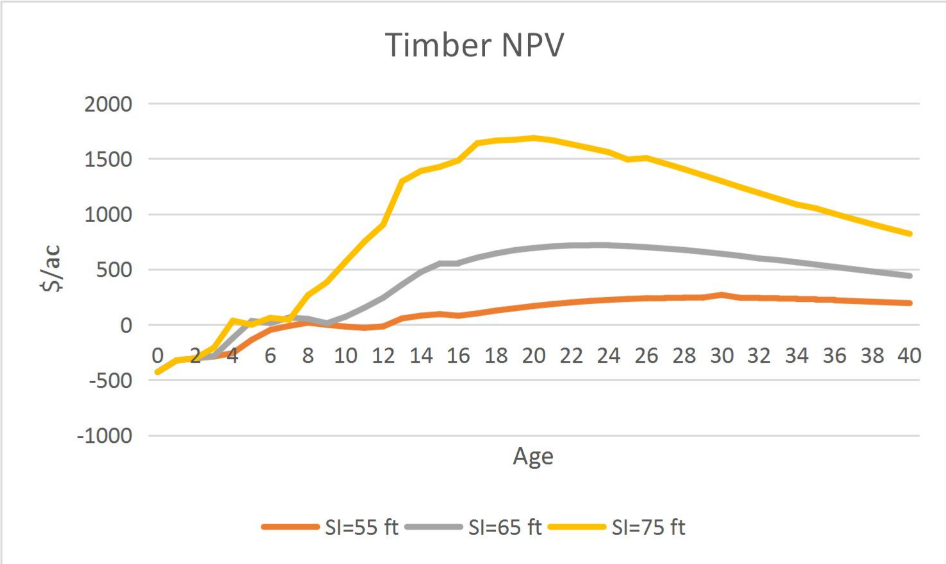
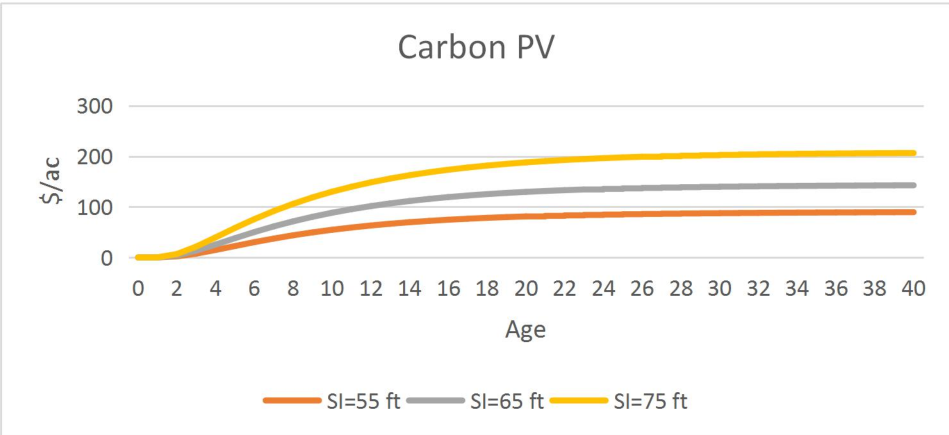


Figure 8. Carbon PV of eucalyptus when SI=55, 65, and 75 ft.



Loblolly pine NPV:

From age 0 to 40 years, timber NPV and carbon PV of loblolly pine at each age under 3 site index (SI=55, 65, 75 ft) are shown as Figure 9 and 10.

Figure 9. Timber NPV of loblolly pine when SI=55, 65, and 75 ft.

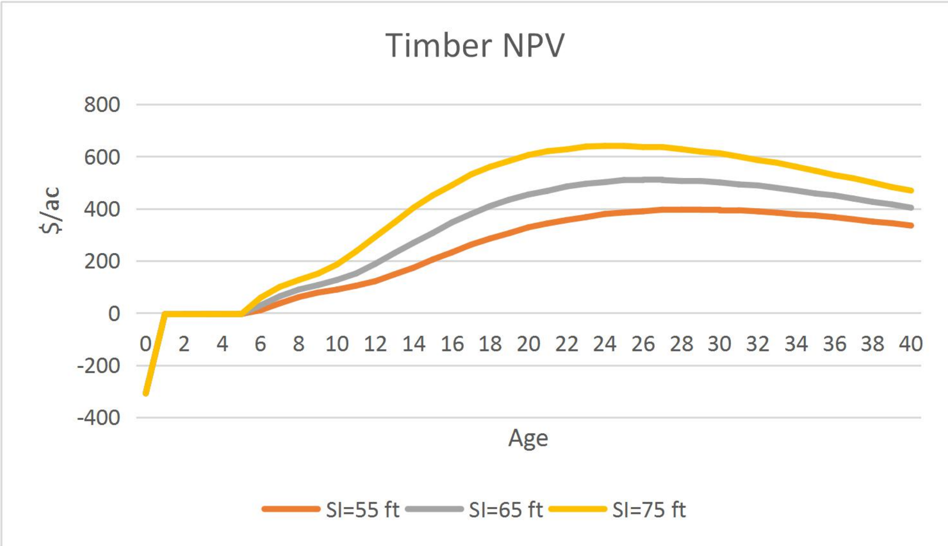
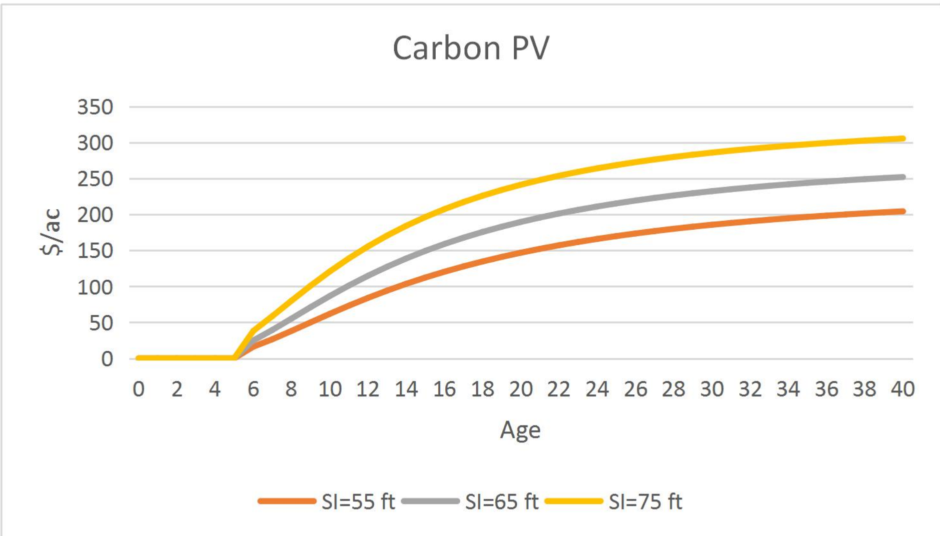


Figure 10. Carbon PV of loblolly pine when SI=55, 65, and 75 ft.



Eucalyptus vs. Loblolly pine in NPV:

Comparing timber NPV (Figure 11-13) and carbon NPV (Figure 14-16) when eucalyptus and loblolly pine are at the site index.

Figure 11. Eucalyptus vs. loblolly pine in timber NPV when SI=55 ft.

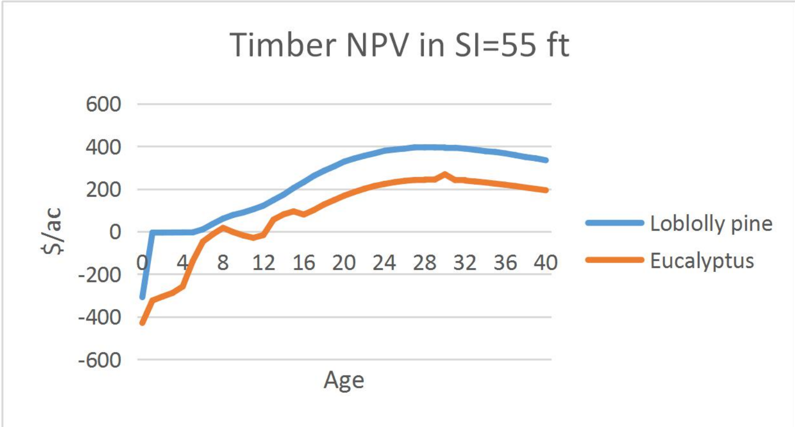


Figure 12. Eucalyptus vs. loblolly pine in timber NPV when SI=65 ft.

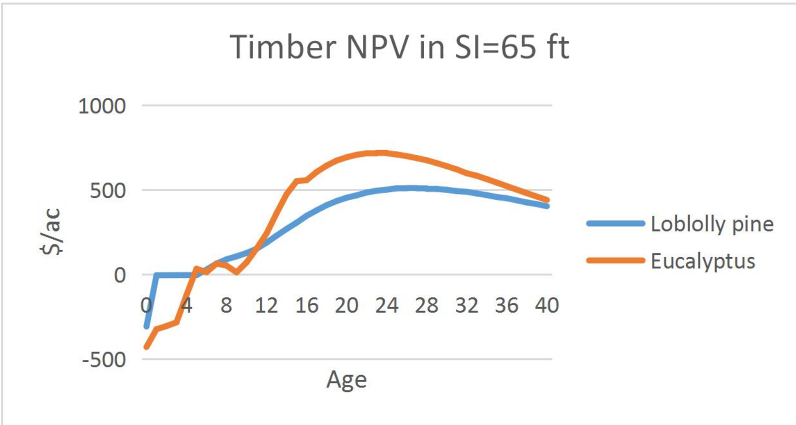


Figure 13. Eucalyptus vs. loblolly pine in timber NPV when SI=75 ft.

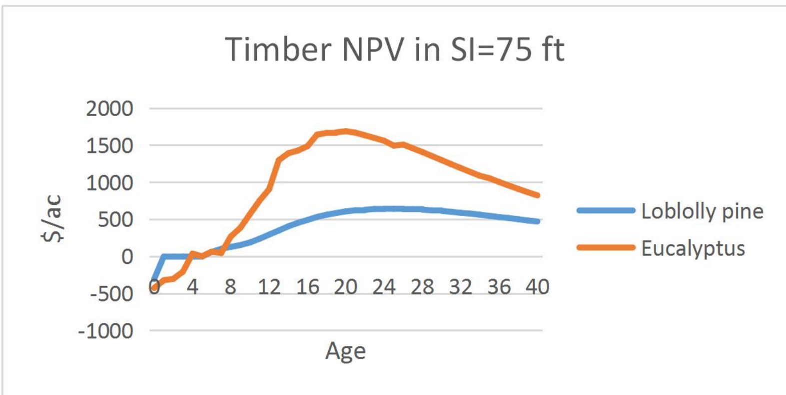


Figure 14. Eucalyptus vs. loblolly pine in carbon PV when SI=55 ft.

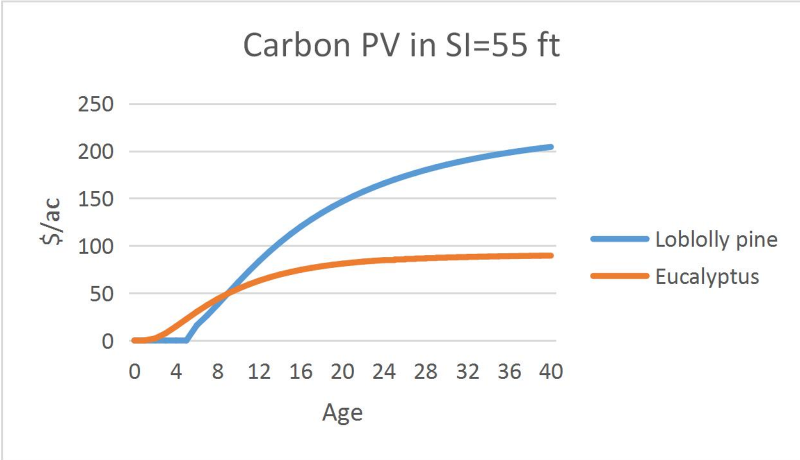


Figure 15. Eucalyptus vs. loblolly pine in carbon NPV when SI=65 ft.

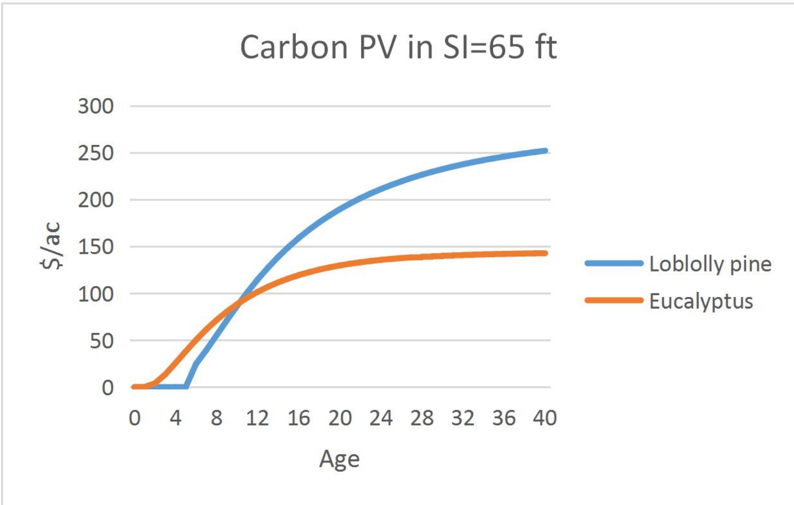
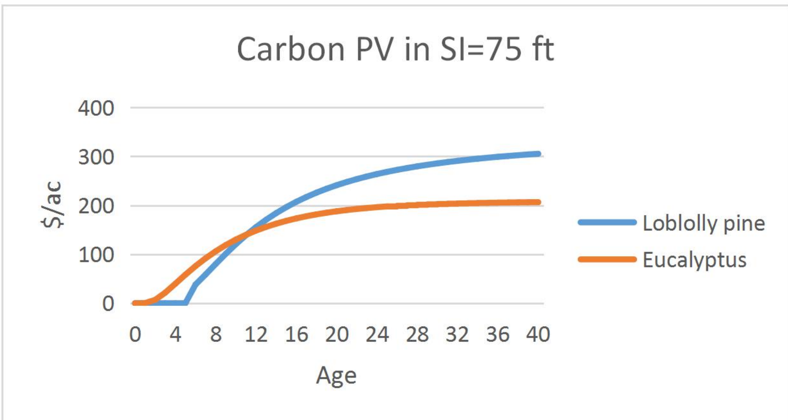


Figure 16. Eucalyptus vs. loblolly pine in carbon NPV when SI=75 ft.



According to Figure 7-10, timber NPV of both species increases quickly over 0 at the beginning years and then eucalyptus decline. It means the value of timber products increases quickly at the beginning but will decrease after few years, that's why we need rotation age to keep high financial benefit. As for carbon PV, the value of both species slowly increases to a certain number and stay invariable.

Figure 11 shows from 0 to 40 years, when SI=55 ft, timber NPV of eucalyptus is always lower than loblolly pine's timber NPV. While it changes when SI=65 and 75 ft: from Figure 12 to 13, we can see that timber NPV of eucalyptus is more and more higher than loblolly pine, which means timber value are more valuable in eucalyptus plantations when site index is high.

Figure 14 to 16 all indicate that loblolly pine has more carbon credits than eucalyptus when SI=55 to 75 ft. But the difference of maximum between two species is getting smaller when SI increases from 55 to 75 ft. It also shows the carbon value of eucalyptus and loblolly pine plantations could be close in high site index, though their growth and yield pattern is different.

3.2 Soil expectation value (SEV) analysis

The soil expectation value (SEV) represents the net present value of an investment in an even-aged stand from the time of planting, through infinite rotations of the same management regime. If the even-aged rotation lengths are the same, SEV and NPV assessments will produce the same ranking of potential investments (Bettinger et al., 2010). SEV equation at year n:

$$SEV = NPV + \frac{NPV}{(1+i)^n - 1} \quad \text{(Bettinger et al., 2010)}$$

Where: NPV = Net value at year n, i = Interest rate, n = Number of years

Eucalyptus SEV:

From age 1 to 40 years, timber SEV and carbon SEV of eucalyptus at each age under 3 site index (SI=55, 65, 75 ft) are shown as Figure 17 and 18.

Figure 17. Timber SEV of eucalyptus when SI=55, 65, and 75 ft.

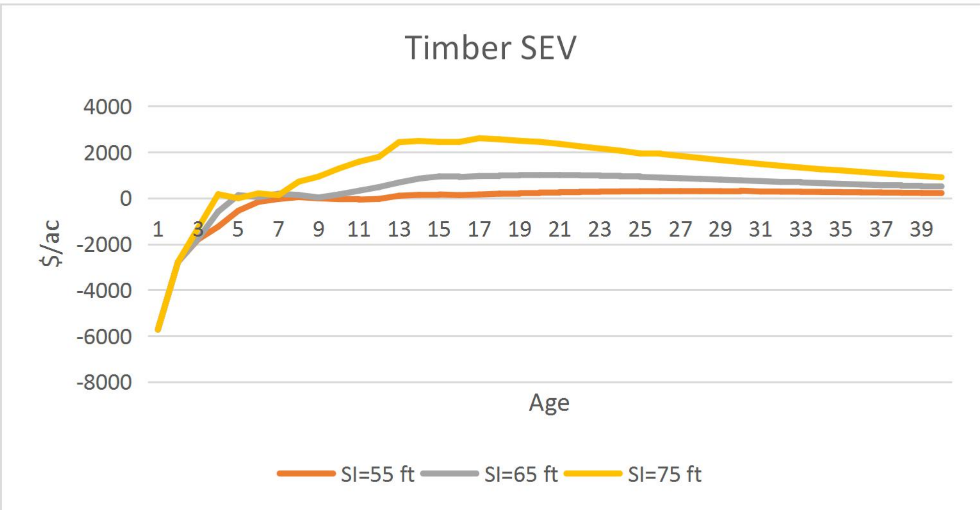
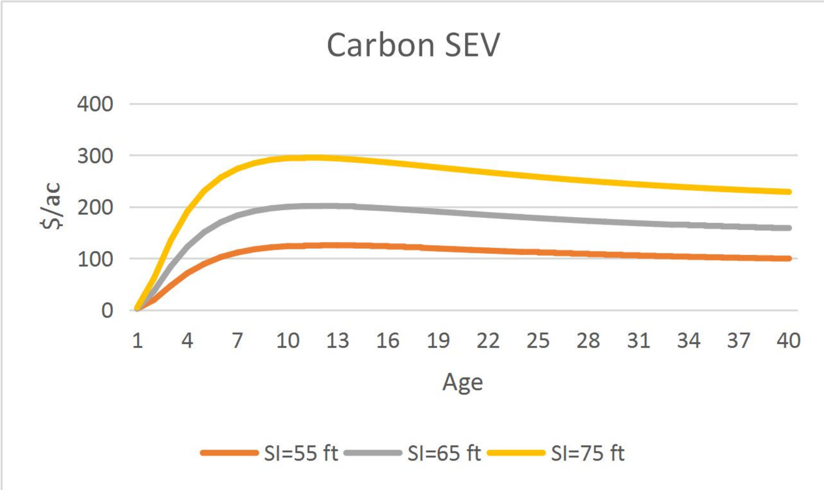
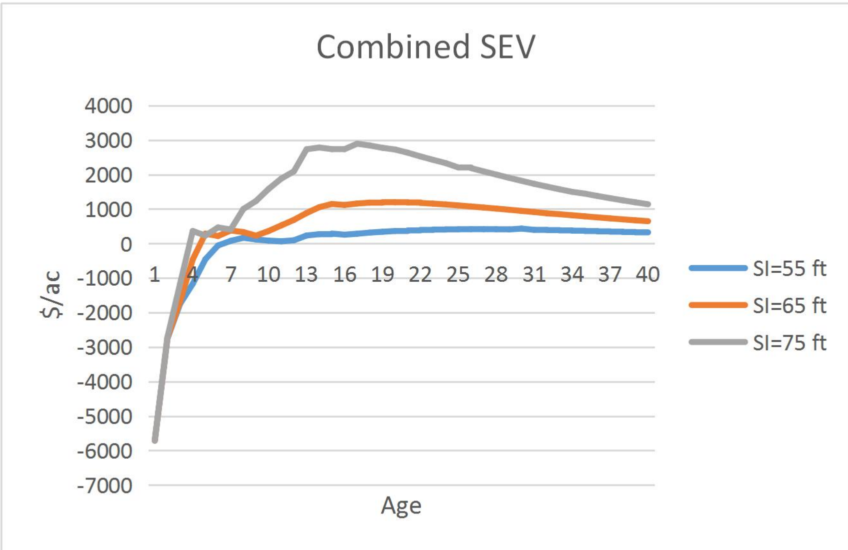


Figure 18. Carbon SEV of eucalyptus when SI=55, 65, and 75 ft.



Timber and carbon combined SEV of eucalyptus as each age from 1 to 40 years under 3 site index (SI=55, 65, 75 ft) is shown as Figure 19.

Figure 19. Timber and carbon combined SEV of eucalyptus when SI=55, 65, and 75 ft.



Loblolly pine SEV:

From age 1 to 40 years, timber SEV and carbon SEV of loblolly pine at each age under 3 site index (SI=55, 65, 75) are shown as Figure 20 and 21.

Figure 20. Timber SEV of loblolly pine when SI=55, 65, and 75 ft.

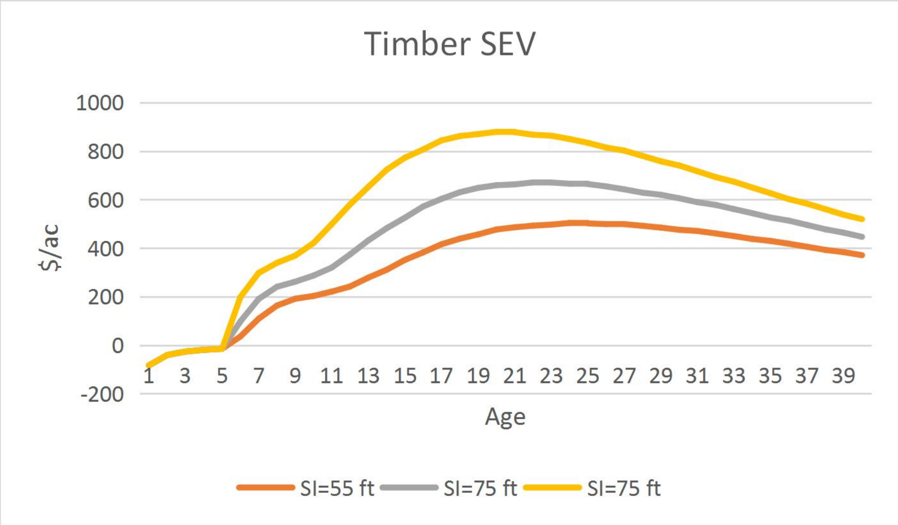
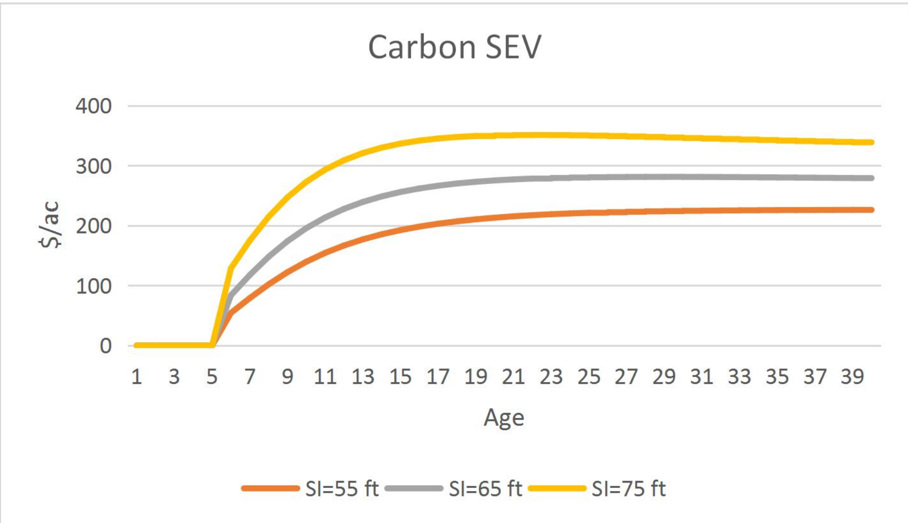
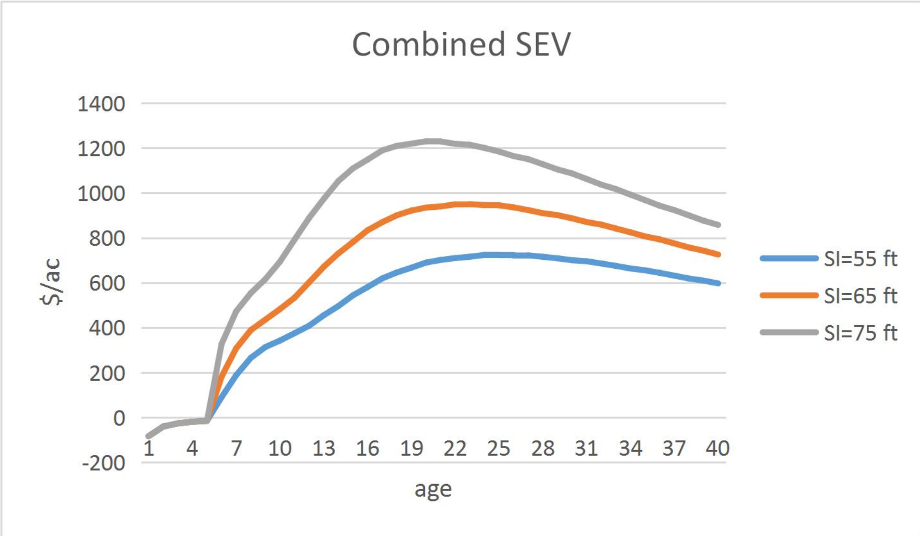


Figure 21. Carbon SEV of loblolly pine when SI=55, 65, and 75 ft.



Timber and carbon combined SEV of loblolly pine at each age from 1 to 40 years under 3 site index (SI=55, 65, 75) is shown as Figure 22.

Figure 22. Timber and carbon combined SEV of loblolly pine when SI=55, 65, and 75 ft.



Eucalyptus vs. Loblolly pine in SEV:

The maximum timber and carbon combined SEV occurs at the optimal rotation age. So the optimal rotation age of eucalyptus under SI=55, 65, 75 ft is shown as Figure 23. And the optimal first thinning age of loblolly pine under SI=55, 65, 75 ft is shown as Figure 24.

Figure 23. Optimal rotation age of eucalyptus when SI=55, 65, 75 ft.

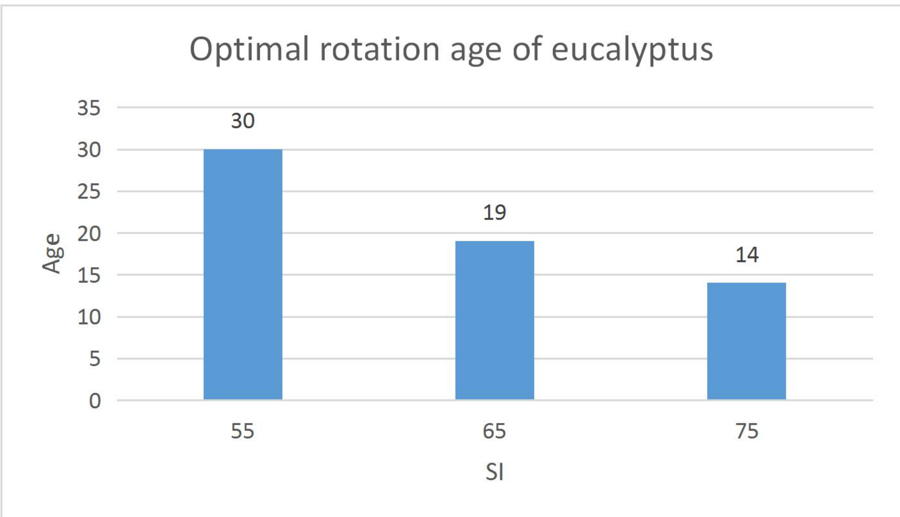


Figure 24. Optimal rotation age of loblolly pine when SI=55, 65, 75 ft.

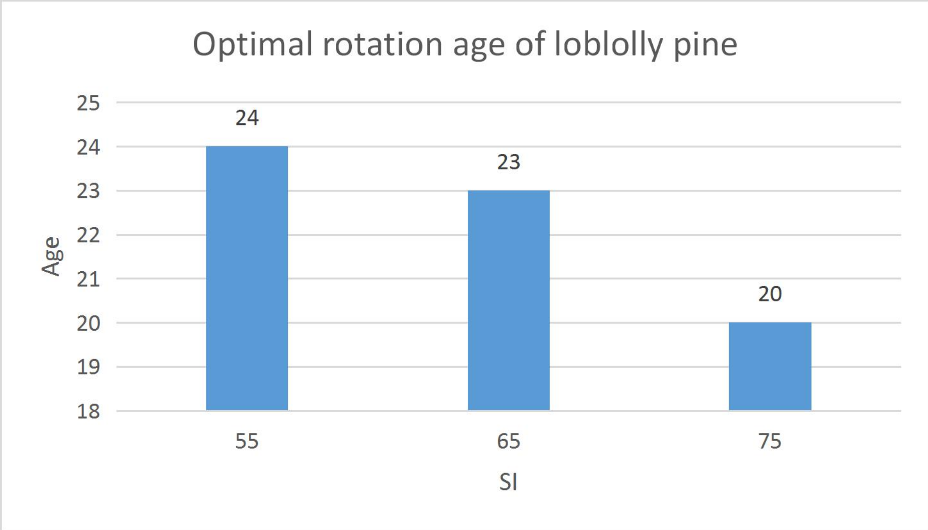


Figure 17 to 22 all show that SEV increases with the site index. In both of the species, the lower site index is, the later maximum SEV occurs, in other words, the older optimal rotation age is. However, their timber and carbon SEV curves are significantly different. Comparing Figure 17 and 20, when SI=55 ft, timber SEV of eucalyptus is nearly stay 0 after 7 years while timber SEV of loblolly pine is close to 500 $/ac. But when SI=75 ft, timber SEV of eucalyptus is almost all the way higher than loblolly pine's timber SEV. From Figure 18 and 21, we can see that carbon SEV of eucalyptus increases immediately after being planted, but loblloly pine's carbon SEV increases after 5 years in all site index. That is because the stand volume of loblolly pine (Figure 4) stay 0 before year of 5.

According to Figure 23 and 24, the average optimal rotation age of southern China's eucalyptus is (30+19+14)/3 = 21 years and North Carolina's loblolly pine is (24+23+20)/3 = 22 years. After considering the carbon value, optimal rotation age of eucalyptus increases from 7 years to 21 years and loblolly pine increases from 20 years to 22 years. So the carbon credits influences eucalyptus more than loblolly pine.

3.3 Internal rate of return (IRR) analysis

Internal rate of return is generally considered a theoretically inferior criterion and it is easy to understand, explain, and compare with other investment metrics (Cubbage et al., 2014). IRR provides a means of comparing investments intuitively with the implied cost of capital. Internal rate of return avoids problems of project scale or length in making comparisons.

IRR: i such that

$$\sum_{n=0}^{N} B_n/(1+i)^n = \sum_{n=0}^{N} C_n/(1+i)^n \quad \text{(Bettinger et al., 2010)}$$

Table 8. IRR of eucalyptus and loblolly pine in each site index

	Eucalyptus	Loblolly pine
SI = 55 ft	5%	19%
SI = 65 ft	14%	22%
SI = 75 ft	23%	26%

So in each site index, loblolly pine in North Carolina is more worth to do investment, because its IRR is always higher than eucalyptus in southern China.

4. Recommendations

There are three key driving forces for the expansion of planted forests: government programs, market, and technology (Liu et al., 2013). In order to make a continuous expansion of planted eucalyptus in southern China and loblolly pine in North Carolina, which has significantly contributed to an increase in timber supply and carbon sequestration, bonding with the results of carbon trade-off, this study has 3 recommendations for both China's and North Carolina's stakeholders.

4.1 Seek strategic transition to multi-purpose management for forest

A strategic transition in the management of planted forests with incenxues from government is needed, from traditional timber production to multi-purpose management, especially thinking of tree carbon value as part of timber products.

The result shows the average optimal rotation age of China's eucalyptus increases from 7 years to 21 years and loblolly pine increases from 20 years to 24 years. Though there are more conditions need to be considered in managing the forest, it is possible to postpone the rotation age of eucalyptus and loblolly pine to encourage more carbon credits.

4.2 Need professional assistant to help check the market

Market-based approaches can provide powerful incentives and efficient means of conserving forests and the public goods they provide, while at the same time offering new sources of income. Because carbon price and timber products prices fluctuate widely, forest owners need to check the current timber and carbon market demand and recent trends. In North Carolina, landowners may obtain this information from state agencies, universities, and businesses that provide price report information. However, forest market is not as well done as the US in China, it is necessary to develop a more open and easy-accessed forest information system in southern China where growth a great area of eucalyptus.

4.3 Encourage to develop the carbon credits sale plan

Decision makers should actively explore the possibility of using forests as a carbon sink with the rise in concern about potential global climate change, meanwhile not slow down the normal development of economics. Because new rotation ages of two species postpone the traditional rotation age, which means landowners will get the revenue several years late, stakeholders probably could conduct some favorable financial policy (such as lower tax required) to support them during these postponed years to promote carbon credits as a new kind of timber product at the beginning.

Appendix table 1: output from eucalyptus model

SI=55ft	Dominant height	Density	Basal Area	Volume	Pulpwood	Sawtimber
Age	meter	Trees/ha	sq.m/ha	cu.m/ha	cu.m/ha	cu.m/ha
1	2.2	742	0.1	0.1	0	0
2	4.8	742	1	1.6	0	0
3	6.9	742	2.5	5.8	0	0
4	8.5	742	4.2	11.9	0.6	0
5	9.9	742	5.8	18.7	5.5	0
6	11	742	7.2	25.9	9.6	0
7	11.9	742	8.5	32.9	11.3	0
8	12.7	742	9.6	39.7	12.9	0
9	13.5	742	10.6	46.1	11.8	0
10	14.1	742	11.6	52.1	10.8	0
11	14.7	742	12.4	57.7	10	0
12	15.2	742	13.2	63	9.4	1
13	15.7	742	13.9	67.9	13.2	2.1
14	16.1	742	14.5	72.4	13.6	3.4
15	16.5	742	15.1	76.5	12.8	5.1
16	16.9	742	15.7	80.4	9.2	7.1
17	17.2	742	16.2	83.9	8.7	9.2
18	17.5	741	16.7	87.2	8.4	11.7
19	17.8	741	17.1	90.2	8	14.1
20	18.1	741	17.5	92.9	7.8	16.6

21	18.4	740	17.9	95.4	7.5	19.1
22	18.6	740	18.3	97.8	7.3	21.6
23	18.9	739	18.7	99.9	7.1	24.1
24	19.1	739	19	101.9	7	26.4
25	19.3	738	19.3	103.8	6.8	28.8
26	19.5	738	19.6	105.5	6.7	31.1
27	19.7	737	19.9	107	6.6	33.3
28	19.9	737	20.1	108.5	6.5	35.4
29	20.1	736	20.4	109.9	6.4	37.4
30	20.2	735	20.6	111.1	6.3	43
31	20.4	734	20.8	112.3	6.3	41.2
32	20.5	734	21	113.5	6.3	43
33	20.7	733	21.2	114.6	6.2	44.7
34	20.8	732	21.4	115.6	6.2	46.3
35	21	731	21.6	116.6	6.1	47.8
36	21.1	730	21.8	117.5	6.1	49.3
37	21.2	729	22	118.4	6.1	50.7
38	21.4	729	22.1	119.3	6	52
39	21.5	728	22.3	120.1	6	53.3
40	21.6	727	22.4	120.9	6	54.6

SI=65ft	Dominant height	Density	Basal Area	Volume	Pulpwood	Sawtimber
Age	meter	Trees/ha	sq.m/ha	cu.m/ha	cu.m/ha	cu.m/ha

1	2.5	742	0.1	0.1	0	0
2	5.7	742	1.6	3	0	0
3	8.2	742	3.8	10.4	0.2	0
4	10.1	742	6.1	20.4	6.6	0
5	11.7	742	8.1	31.5	13.5	0
6	13	742	9.9	42.8	12.6	0
7	14.1	742	11.6	53.9	15.3	0
8	15.1	742	13	64.4	13.7	0.8
9	15.9	742	14.2	74.4	8.8	2.8
10	16.7	742	15.4	83.8	8.1	6
11	17.3	742	16.4	92.5	7.8	10.3
12	18	741	17.3	100.6	7.8	15.3
13	18.5	741	18.2	108.2	10.1	20.8
14	19	740	18.9	115.2	12.7	26.5
15	19.5	739	19.6	121.7	13.2	32.4
16	19.9	739	20.3	127.8	8.6	38.1
17	20.3	738	20.9	133.3	8.4	43.7
18	20.7	737	21.4	138.5	8.2	49
19	21.1	736	21.9	143.2	8	54.2
20	21.4	735	22.4	147.6	7.8	59
21	21.7	734	22.8	151.6	7.7	63.7
22	22	733	23.2	155.3	7.6	68.2
23	22.3	732	23.6	158.8	7.5	72.4

24	22.6	730	24	161.9	7.4	76.4
25	22.8	729	24.3	164.8	7.3	80.1
26	23	728	24.6	167.5	7.3	83.6
27	23.3	727	24.9	170	7.2	87
28	23.5	725	25.2	172.3	7.5	90.2
29	23.7	724	25.4	174.4	7.5	93.1
30	23.9	722	25.7	176.3	7.5	95.9
31	24.1	721	25.9	178.2	7.5	98.5
32	24.3	720	26.1	179.8	6.8	101
33	24.5	718	26.3	181.4	8.2	103.3
34	24.6	717	26.5	182.9	8.2	105.7
35	24.8	715	26.7	184.2	8.2	107.9
36	24.9	714	26.9	185.5	8.2	109.9
37	25.1	712	27	186.7	8.2	111.8
38	25.2	711	27.2	187.8	8.2	113.6
39	25.4	710	27.3	188.9	8.2	115.3
40	25.5	708	27.5	189.9	8.2	116.9
SI=75ft	**Dominant height**	**Density**	**Basal Area**	**Volume**	**Pulpwood**	**Sawtimber**
Age	meter	Trees/ha	sq.m/ha	cu.m/ha	cu.m/ha	cu.m/ha
1	2.9	742	0.2	0.2	0	0
2	6.6	742	2.3	5	0	0
3	9.4	742	5.2	16.6	3.3	0

4	11.7	742	8.1	31.7	13.5	0
5	13.5	742	10.6	48.1	11.9	0
6	15	742	12.8	64.4	14	0.7
7	16.3	742	14.8	80.2	8.7	4
8	17.4	741	16.4	95.2	12.2	10.5
9	18.4	741	17.9	109.4	8.1	19.1
10	19.2	740	19.2	122.6	7.6	28.8
11	20	739	20.4	134.8	7.5	39.1
12	20.7	738	21.4	146.3	7.3	49.2
13	21.4	737	22.4	156.9	12.5	69.2
14	22	736	23.2	166.7	10.9	79.9
15	22.5	735	24	175.8	7	89.7
16	23	733	24.7	184.3	7	98.6
17	23.5	732	25.4	192.1	7.1	114.8
18	23.9	730	26	199.3	7.1	123.2
19	24.3	728	26.5	206	7.2	130.9
20	24.7	727	27	212.2	9.5	138.1
21	25.1	725	27.5	217.9	9.6	144.5
22	25.4	724	27.9	223.2	8.8	150.4
23	25.7	722	28.3	228	9	155.7
24	26	720	28.7	232.6	9.9	160.5
25	26.3	718	29	236.7	7	165
26	26.6	717	29.3	240.6	6.9	176.3

27	26.9	715	29.6	244.2	6.9	180.6
28	27.1	713	29.9	247.5	7.2	184.5
29	27.3	711	30.2	250.5	7.1	188
30	27.6	710	30.4	253.4	7.1	191.3
31	27.8	708	30.6	256	6.2	194.7
32	28	706	30.9	258.4	6.2	197.6
33	28.2	704	31.1	260.7	6.2	200.2
34	28.4	703	31.2	262.8	6.1	202.6
35	28.6	701	31.4	264.7	10.3	204.9
36	28.8	699	31.6	266.5	10.2	207
37	29	698	31.8	268.2	10.2	209
38	29.1	696	31.9	269.8	10.2	210.8
39	29.3	694	32	271.3	10.2	212.5
40	29.4	693	32.2	272.7	10.1	214.1

Appendix table 2: output from loblolly pine model

SI=55 ft	Density	Dominant height	Basal Area	Volume	Pulpwood	Sawtimber
Age	Trees/ac	ft	sq.ft/ac	cu.ft./ac	tons	tons
1	284	2	0	0	0	0
2	284	4.4	0	0	0	0
3	284	6.9	0	0	0	0
4	284	9.5	0	0	0	0

5	284	12.2	0	0	0	0
6	284	14.8	31.1	217.3	2	0
7	283	17.4	43.7	366.4	6	0
8	283	19.9	56	541.3	10.2	0
9	282	22.4	67.7	732.9	13.7	0
10	281	24.9	78.5	934.2	16.3	0.1
11	281	27.3	88.5	1140.2	18.6	0.7
12	280	29.6	97.6	1347.1	20.5	1.8
13	278	31.9	105.8	1552.7	22.3	3.9
14	277	34.1	113.4	1755.8	23.7	6.4
15	275	36.3	120.3	1955	25.1	9.8
16	273	38.4	126.6	2150.1	26.2	13.3
17	271	40.5	132.4	2340.9	27.2	17.5
18	269	42.5	137.6	2527.5	27.9	21.6
19	267	44.4	142.5	2710	28.5	25.8
20	264	46.3	147	2887.7	29	30.7
21	262	48.1	151.1	3062.5	29.4	35.1
22	259	49.9	155	3232.8	29.5	39.7
23	255	51.7	158.5	3398.7	29.4	44.5
24	252	53.4	161.8	3562.5	29.6	49.8
25	249	55	164.9	3723.5	29.5	54.5
26	245	56.6	167.8	3880.4	29.2	59.4
27	241	58.1	170.5	4034.7	29	64.9

28	238	59.7	173	4188.5	28.8	69.6
29	234	61.1	175.4	4338.3	28.4	74.5
30	230	62.6	177.6	4486.1	27.9	79.3
31	225	63.9	179.7	4629.6	27.3	85.1
32	221	65.3	181.6	4773.6	26.7	90
33	217	66.6	183.5	4915.8	26.1	94.8
34	213	67.9	185.3	5056.5	25.5	99.5
35	209	69.1	186.9	5195.8	25	105.1
36	204	70.3	188.5	5330.2	24.2	110.1
37	200	71.5	190	5466.4	23.5	114.7
38	196	72.7	191.4	5601.3	22.8	119.2
39	192	73.8	192.8	5735	22.2	124.8
40	188	74.9	194.1	5867.4	21.5	129.4
SI=65 ft	**Density**	**Dominant height**	**Basal Area**	**Volume**	**Pulpwood**	**Sawtimber**
Age	Trees/ac	ft	sq.ft/ac	cu.ft./ac	tons	tons
1	284	2.6	0	0	0	0
2	284	5.8	0	0	0	0
3	284	9.1	0	0	0	0
4	284	12.4	0	0	0	0
5	284	15.7	0	0	0	0
6	284	19	38.5	334.1	4.6	0
7	283	22.2	52.2	544.3	10.1	0

8	283	25.3	65.4	783.8	14.8	0
9	282	28.3	77.6	1039.4	18.3	0.1
10	281	31.3	88.7	1302.2	21.2	0.8
11	280	34.1	98.8	1565.8	23.5	2.3
12	279	36.9	107.9	1826.3	25.9	5
13	277	39.5	116.2	2081	27.7	8.7
14	276	42.1	123.7	2329.1	29.3	12.8
15	274	44.6	130.5	2569.3	30.4	17.4
16	272	46.9	136.7	2801.7	31.6	22.8
17	269	49.2	142.3	3025.9	32.1	28.2
18	267	51.5	147.4	3243.4	32.9	33.8
19	264	53.6	152.1	3453.1	33.1	39.5
20	261	55.7	156.4	3656.4	33.3	45.1
21	258	57.7	160.4	3853.6	33.3	50.5
22	255	59.6	164.1	4045.2	33.4	56.7
23	251	61.5	167.5	4230.4	33.1	62.6
24	247	63.3	170.7	4410.7	32.7	68.3
25	243	65	173.6	4586.6	32.4	74.7
26	239	66.7	176.3	4758.4	31.9	80.4
27	235	68.3	178.9	4926.5	31.3	85.9
28	231	69.9	181.3	5091.2	30.7	91.3
29	227	71.4	183.5	5252.8	30.2	97.7
30	222	72.8	185.6	5408.8	29.3	103.4

31	218	74.3	187.6	5564.7	28.6	108.7
32	213	75.6	189.5	5715	27.8	115.2
33	209	77	191.2	5865.9	27.1	120.4
34	204	78.2	192.9	6011	26.1	125.8
35	200	79.5	194.5	6157.6	25.3	130.8
36	195	80.7	195.9	6298	24.4	137.2
37	191	81.9	197.4	6440.5	23.6	142.1
38	187	83	198.7	6581.3	22.8	146.9
39	183	84.1	200	6720.3	22.1	152.8
40	179	85.2	201.2	6857.7	21.3	157.6
SI=75 ft	**Density**	**Dominant height**	**Basal Area**	**Volume**	**Pulpwood**	**Sawtimber**
Age	Trees/ac	ft	sq.ft/ac	cu.ft./ac	tons	tons
1	284	3.4	0	0	0	0
2	284	7.5	0	0	0	0
3	284	11.7	0	0	0	0
4	284	15.9	0	0	0	0
5	284	20	0	0	0	0
6	284	24	46.5	513.7	8.8	0
7	283	27.8	61.2	809.1	15.5	0
8	282	31.5	75	1133.1	20.4	0.1
9	282	35.1	87.4	1469.1	24.2	0.7
10	281	38.5	98.6	1805.4	27.3	2.6

11	279	41.8	108.7	2134.7	30.1	6.1
12	278	44.9	117.6	2453.6	32.5	10.7
13	276	47.9	125.7	2759.3	34.2	16.1
14	274	50.7	133	3051.4	35.7	22.4
15	272	53.5	139.5	3329.9	36.7	28.7
16	270	56.1	145.4	3595.6	37.3	35
17	267	58.6	150.8	3848.1	37.9	42.2
18	264	60.9	155.7	4089.3	38.1	48.9
19	261	63.2	160.1	4319.9	38	55.5
20	258	65.4	164.2	4541.1	38.1	62.6
21	254	67.5	168	4752.2	37.7	69.4
22	251	69.5	171.4	4957	37.4	75.6
23	247	71.4	174.6	5153.2	37	82.8
24	243	73.2	177.6	5342.8	36.4	89.3
25	238	75	180.3	5524.5	35.4	95.9
26	234	76.7	182.9	5702.9	34.7	102
27	229	78.3	185.3	5874	33.8	109.3
28	225	79.9	187.5	6043.2	33	115.3
29	220	81.4	189.6	6205.6	31.9	121.4
30	215	82.8	191.5	6363.9	30.9	128.4
31	211	84.2	193.4	6522.1	30	134.1
32	206	85.6	195.1	6673.6	28.8	139.8
33	201	86.9	196.7	6821.7	27.8	146.5

34	197	88.1	198.2	6971.2	26.9	151.9
35	192	89.3	199.7	7113.5	25.7	157.4
36	188	90.5	201.1	7258.1	24.8	162.4
37	183	91.6	202.4	7395.1	23.7	168.9
38	179	92.7	203.6	7535.1	22.8	173.9
39	175	93.7	204.8	7673.1	21.9	178.6
40	171	94.7	205.9	7809.1	21.1	184.7

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