

Integrated timber investment returns, wood fiber stumpage costs, and forest carbon costs for global planted forests, 2023

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ABSTRACT

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benchmarking, capital budgeting, forest carbon costs, internal rate of return, planted forests, timber investments, wood production costs

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This article summarizes our research on integrated timber investment returns, wood stumpage costs, and forest carbon production costs in 2023 for a representative selection of 15 countries, across 44 planted and 1 natural species/management regimes, using capital budgeting criteria, at a real discount rate of 8%, without land costs. Despite a large amount of disparate research, few, if any, studies have provided integrated estimates of investments, wood fiber costs, and forest carbon costs for CO₂ offsets using fundamental primary data and production economics approaches. We expanded our prior research that estimated present values and internal rates of return for timber investments, using planted forest growth and yield, input management costs, and timber products prices by selected countries and species. We extended the production economics and forest investment calculations to estimate average stumpage costs for wood fiber per cubic meter per rotation. In addition, we calculated the costs to produce forest carbon for offsets in terms of carbon dioxide equivalent. Timber investment returns by country and species were the largest in tropical Asia and smallest in the Northern Hemisphere (including the United States and Europe), and South America had calculated returns between the two regions. Based on prior research, more developed countries had less investment risk, and had land markets that were more open for foreign investments. Wood costs and forest carbon production cost outcomes by country and species differed substantially from timber investment returns. The discounted wood costs per m³ were generally cheapest if the establishment costs and management inputs were minimized, or for long rotation planted stands. Forest carbon costs had similar rankings to wood costs, and even similar numbers, but were using a different metric—dollars per tCO₂e. The calculated forest carbon costs are certainly among the cheapest of all types of typical carbon offsets. They were equal to or much less than the six primary developed country compliance market prices. However, they were higher than the current depressed public voluntary market prices. These results can be used for private, government, or nongovernment investments and for public policy intervention considerations.

INTRODUCTION

Forests provide a wealth of ecosystem services, including market and nonmarket goods. These goods and services depend on natural or planted forest stocks, ecosystem processes, and markets, and may be affected by human management, exploitation, or protection. As scientists and authors, we have cooperated periodically for about 20 years in making estimates of the market investment returns of planted and some natural forests for selected countries and species (Cubbage et al. 2007; 2010; 2014; 2020; 2022).

This research article expands that cooperative research to include the base year of 2023 for estimating the costs of timber production for that year, as well as the cost to produce the nonmarket good of forest carbon storage to offset CO₂ emissions. To our knowledge, this research calculates the first integrated global estimates by species and country for these investments and costs. This provides novel and useful information for forest investment benchmarking integrated with industrial wood production and forest carbon storage opportunities.

METHODS

Per Cubbage et al. (2022), we have cooperated periodically since 2004 in estimating and publishing timber investment costs and returns for selected countries in the world. These data were collected for different species and different countries every three years, initially in the United States and South America, and then expanding to a number of key countries throughout the world. The selection of the species included depended on their importance in each country's forest sector and on the availability of research cooperators and data in each country.

Similar to our prior efforts, in 2023, we calculated global timberland investment benchmarks for 15 countries, with 44 different planted species and management regime combinations, as well as 1 natural stand. The typical management regimes and rotation ages were identified and selected by the researchers who developed the spreadsheets for each country, in consultation with colleagues and practitioners. The costs, prices, and investment returns were collected in or converted to 2023 U.S. Dollars (\$US) in each country. Previous global timber investment

publications have described the data collection, discounted cash flow, and capital budgeting methods employed for this research in detail (see Cubbage et al. 2022).

These estimates of forest returns were made for the costs and returns of producing stumpage—producing wood fiber standing in the woods, not including timber harvests. These relevant costs include individual forest stand establishment, management, protection, and administration, without the cost of land. Similarly, returns for timber investments were estimated as sales of stumpage. Production costs for wood fiber and for forest carbon were calculated as separate goods and services, respectively. Jointly producing all three outputs, or producing other forest market products or ecosystem services or social benefits, were not considered, which can increase income and social welfare in many situations.

In many cases, private and public landowners already own and manage the land, so its purchase prices are irrelevant. In addition, excluding the price of land makes comparisons among forest productivity and management costs much more accurate, since land costs may vary more than stand management even within a given country. Last, several countries we report on have significant restrictions on selling land, and customarily only make new forest investments or leases on existing government or community lands (e.g., Mexico, China, Vietnam, India). We also collected data on land prices in 2023 when available, and they are reported here, but not analyzed in the capital budgeting calculations.

To summarize, in contrast to earlier efforts focused mostly on planted forest investment IRRs and LEVs, this study introduces two additional output metrics:

1. Integrated wood fiber production costs in dollars per cubic meter,
2. Forest carbon production costs in dollars per tonne of CO₂e.

Wood production costs were calculated as the present value sum of all stand establishment and management costs per cubic meter for one rotation, discounted to year zero (\$/m³). Forest carbon production costs were calculated as the sum of the same costs for one rotation, discounted to year zero, in \$/tCO₂e. Carbon production is expressed as a metric tonne of carbon dioxide equivalent (tCO₂e) in the general form for all offsets, which is often just termed as tCO₂ for wood. The forest carbon costs do not include any additional carbon offset costs for feasibility and design, data and verification, or offset registry.

We used an Excel spreadsheet template to calculate the discounted cash flow analyses for all three components of the research. The slightly neater template that we used with methodological notes and sample calculations are provided for one U.S. species in Attachment A.

Capital budgeting

Various forest economists, including Klemperer et al. (2023), Wagner (2012), and Cubbage et al. (2016), described standard forestry capital budgeting approaches. In brief, these discounted cash flow calculations provide a means to estimate the profitability of a forest or other investment. Net present value (NPV) calculates the discounted value of a series of annual or periodic costs and revenues for a fixed time period at a given discount rate. Land expectation value (LEV)—also called the Soil Expectation Value or the Faustmann formula—calculates the present value for the same set of costs and returns in perpetuity. Per accepted forest economics theory, the LEV indicates the amount that one could pay for a tract of land at the given discount rate. While not discussed here, an annual equivalent income (AEI) calculates the discounted annual income that a series of perpetual annual cash flows will generate.

An internal rate of return (IRR) calculates the unique annual percentage return for an investment. In forestry, the IRR provides an interest rate that makes all the discounted establishment and management costs exactly equal to the value of the subsequent discounted returns (e.g., wood fiber tree planting or forest carbon planting). The greater the calculated NPV, LEV, or AEI at a given discount rate, the better an investment will be. Similarly, the largest IRR would indicate the best investment if it exceeds the known discount rate or alternative rate of return.

In theory, NPV and LEV criteria at the discount rate are superior to IRR as a criterion with a given, known discount rate. However, the actual discount rate is seldom known with certainty, and varies depending on the country, individual project, or other factors. In timberland investing, the discount rate represents the expected minimum return on acquisitions; however, the realized return often exceeds or falls below the expected discount rate.

In addition, common discussions of comparative investments—from Wall Street (e.g., Damodaran 2019), to timber investment and management organizations (TIMOs), to international forest carbon storage policy efforts, to small forest landowners—rely almost exclusively on annual rates of return for comparing different investments and asset classes. Thus, calculating forest investment

IRRs is the most useful in order to make similar comparisons. We do use IRRs here in our written discussion, but provide NPVs and LEVs as well for reference in the primary results table.

Wood fiber production costs

The input data we collected provided a means to calculate costs for producing wood as stumpage at the given discount rate. Drawing from Cubbage et al. (2010), we calculated the NPVs of wood production in \$US by discounting regeneration and management costs to the initial year of analysis. Then the total discounted cost of all the costs per hectare (ha) was divided by the entire volume of wood production per ha throughout the entire rotation—all thinnings and the final harvest—to determine average production costs per cubic meter at a selected given discount rate of 8% (Equations 1 and 2).

1. Discounted Total Cost (\$/ha) = Sum of all discounted costs for each year from 0 to the end of the rotation (r),
2. Cost of wood production per m³ (\$/m³) = Discounted Total Cost (\$/ha) / volume produced in rotation (m³/ha).

We used a uniform 8% real discount rate to estimate returns for all species in all countries, for timber investments, wood fiber costs, and forest carbon costs. The exact discount rate for more than a dozen countries over more than a decade is not possible to determine. We have asked periodically about discount rates used for forestry investments in each country. They have ranged from as low as 6% in the Northern Hemisphere to 15% in the Southern Hemisphere. We selected 8% in 2005, and have kept that as the baseline for consistency for every year since that the research data have been collected. This fixed discount rate has allowed all investments to be compared on the same basis for two decades, without the cost of land, for the entire period.

Forest carbon costs

The forest carbon production¹ costs were calculated similarly to wood fiber costs, as the NPV in dollars of one rotation divided by total weight of carbon stored (Equation 3).

3. Cost of CO₂e production (\$/tCO₂e) = Discounted Total Cost (\$/ha) / weight of CO₂e in one rotation (tCO₂e /ha).

¹ For simplicity, forest carbon production costs for CO₂ offsets or other variations of the term will just be referred to as “forest carbon costs” usually henceforth. Their computation and cost factors included are described subsequently. Koirla et al. (2002) followed this convention as well.

This required a conversion from volume of wood (in cubic meters) to weight of CO₂ (in metric tonnes) before calculating the cost per tCO₂e. Hicks (2020) updates a clear article by Irland (2020) in Maine Woodland Owners magazine for providing the conversion and calculations for tCO₂e. An adaptation of that example is shown below in Table 1. The computations are described next.

Table 1. Calculations to obtain weight of CO₂ (tonnes) per m³ of wood, with examples.

Equation (row) number	Measurement	Calculation	Multiplier	Loblolly pine	Oaks, average	Douglas fir
4	Specific gravity	Obtained from Literature	-	.47	.75	.53
5	Dry weight Kg per m ³	Row 4 X 1000	1000	470	750	530
6	Carbon weight Kg per m ³	Row 5 x 0.5	0.5	235	375	265
7	CO ₂ weight kg per m ³ ²	Row 6 x 3.67	3.67	862	1376	973
8	Metric tonnes CO ₂ per m ³ (tCO ₂ e) ³	Row 7 / 1000	.001	0.86	1.38	0.97
9	U.S. (English) tons per m ³	Row 8 X 0.907	0.907	0.78	1.25	0.88

Source: Adapted from Hicks (2020), Irland (2020)

Table 1 indicates that the calculation starts with the dry weight of wood. This can be calculated as the Specific Gravity of the wood species multiplied by 1000. So the process we used in the research spreadsheets to calculate the cost per metric tonne of CO₂ (tCO₂e) was as follows. U.S. tons is

² For equation 7, the chemical weight of CO₂ is two oxygen atoms (atomic weight 16) and one carbon atom (atomic weight 12). So, two times 16, plus one time 12 equals 44. Thus for every tonne of carbon atoms in wood, there are 44/12 (or 3.67) tons of CO₂. This factor is unitless, so it can be used with metric or English units.

³ Equation 8 converts kg/m³ into tonnes/m³ of CO₂ by simply dividing by 1000 (Hicks 2020). Note also that this detailed conversion of wood volume (in cubic meters) into CO₂ weight in tonnes is more precise than simply dividing green weight or dry weight by one-half, which is commonly mis-used in some literature.

included just for reference. Metric tonnes is the global standard for measuring carbon weight stored.⁴

The relevant equations corresponding to the rows in the above table are listed next.

1. Specific gravity: entered by research investigator; usually available with an internet search, or with local measurements.
2. Dry weight (kg/m^3) = specific gravity * 1000
3. Carbon weight (kg/m^3) = dry weight * 0.5
4. CO_2 weight (kg/m^3) = carbon weight * 3.67
5. Tonnes CO_2e per m^3 = (7) / 1000
6. Tons of CO_2e per m^3 = (8) x 0.907 {Not used in this research; for U.S. reference only}

Applying the conversion resulted in numerical differences between the CO_2 weight in tonnes and the total volume of wood fiber production in m^3 . Importantly, note that these are different units of weight versus volume. Put simply, if the calculated metric tonnes of CO_2e per cubic meter exceeded 1.0, then costs would be cheaper for producing a tonne of CO_2e than producing a m^3 of wood, and vice versa. Heavier wood with more carbon per m^3 would generally have cheaper tCO_2e costs of production than lighter wood with less carbon per m^3 .

The calculation we used was for above-ground biomass production on the main tree stem only. Experience in the field suggests that pines and softwood trees usually have about 20% more volume in branches and tops, and hardwoods about 30%. Below-ground carbon biomass is also substantial, but the amount varies immensely by species, site, and soils, stand conditions, age, and relevant research, so we could not offer any accurate guide for that amount or percentage.

It should be noted that the forest carbon costs calculated in this study do not include the costs associated with developing approved offsets for regulated or voluntary carbon markets. An aggregator's verification and transaction fees (Koirala et al. 2022) were not taken into account, and can vary widely.⁵ The entire amount of forest carbon offset costs would include our production

⁴ Note that the table inputs and equations are numbered in sequence following from 1-3 above, not by row number in the table.

⁵ For example, past case studies in tropical settings showed variations in transaction costs from \$0.09 to \$7.71/t CO_2e (Pearson et al. 2013). A preliminary internet search in 2026 generated cost estimates for monitoring, verification, reporting, and legal fees ranging from tens of thousands of dollars to 10 million dollars or more depending on the size of the project and type of carbon credit, so we will not make any generalizations about administration costs per tCO_2e here. This is a rapidly evolving field of practice, and more research on the subject is warranted.

costs, and any additional costs for feasibility and design, data and verification, or offset registry. This is similar to our calculated stand-level timber investments and wood costs in that the overhead of organizational administrative, management, and consulting fees were not explicitly included in those returns and costs.

Input costs and timber prices

Just as in prior global timber investment analyses, the data we collected cover costs of forest practices—initial site preparation and tree planting, periodic stand treatments, and annual management costs per hectare (ha) at a stand level. To quote the description of input costs and prices directly from Cubbage et al. (2022, p. 94-95):

"The establishment costs were comprised of:

- Site preparation: (a) startup work (clearing, measurements); (b) plowing/shearing; (c) ripping/subsoiling; (d) grading/dozing - Year 0 (the first year)
- Planting: (a) seedlings; (b) plant maintenance; (c) fertilizer; (d) marking and digging; (e) plant distribution; (f) planting; and (g) replanting – Year 0 (the first year)
- Rotation: Timber cycle from planting to final clearcut harvest; may or may not have various harvest thinning as part of the rotation; coppicing was not considered
- Periodic stand treatments (as relevant): Occur at varying times or not at all, depending on species and rotation – These may include (a) ant control; (b) herbicide/cleaning; (c) fertilizer; (d) prescribed burning; (e) low pruning; (f) medium pruning; (g) high pruning
- Road system maintenance, property taxes, and administration costs (management overhead costs, but not corporate headquarters personnel, buildings, overhead expenses)

The data also include prices of timber as stumpage, standing trees "in the woods". These vary by the size of the timber harvested, as well as the species and country. The possible product breakdowns used for the price data included biomass fuel, pulpwood, chip-n-saw, small sawtimber, and veneer/large sawtimber. Silvicultural management prices per ha and timber stumpage prices per cubic meter represented the average of the more active markets by country.

We used these data in a standard spreadsheet template (see Attachment A) in order to estimate timber investment returns at the stand level for different species by country. Reporters for each country entered the tree establishment and forest management costs; the timber mean annual

increment (MAI) growth rate; the timber harvest output timing, quantities, and product specifications; and the relevant stumpage prices for the products used for each species. The spreadsheet then automatically calculated several capital budgeting criteria. The senior author then reviewed and provided feedback or suggestions for corrections on the spreadsheets if needed to ensure that the data were correct and consistent.”

The Excel spreadsheet calculated timber investment returns per ha for each species at a stand level in each country, using the base real discount rate of 8%. The spreadsheet inputs for calculating the net present value of wood production were the same as those used for calculating the timber investment returns. Instead of using both benefits and costs, only the costs and the total wood production for one rotation (not a perpetuity) were used to estimate the discounted average costs per cubic meter of wood. We used the 8% discount rate to estimate the net present value of those costs. In addition, note that we calculated the wood costs as a discounted value back to year zero—consistent with the timber investment and most capital budgeting analyses.

In contrast to our discounted cash value approach focused on here, Cubbage et al. (2010) calculated the wood costs as a net future value (NFV) at the end of the rotation, which was an accounting stance more like that used by integrated forest products companies and accounting principles, not capital budgeting. This is an important distinction, since the NPV of discounted costs will be smaller than the compounded NFV of future costs at the end of the rotation, at any positive discount rate. The implications of this are covered more in the discussion section.

RESULTS

Table 2 summarizes the input cost data for each species and country. Table 3 summarizes the results of the capital budgeting calculations for timber investments; the cost per m³ for producing wood fiber; and the cost per tCO_{2e} for carbon dioxide storage.

Attachment A shows an updated example template that each co-author or associated contributor used as the basis for calculating the investment returns for their species and country. Attachment B summarizes these input data and the results in one large Excel spreadsheet for easy access and use by readers.

Table 2. Tree planting management regimes, establishment costs, and timber stumpage prices by country and species, 2023.

Country	Species	Rotation Age (yrs)	MAI m3/ha/yr	Establishment costs (\$/Ha)			Land cost (\$/Ha)	Prices per m3 (\$) (at small end diameter)				
				Site Prep	Planting	Tot Yr 0-5		Biomass (~5 cm)	Pulpwood (~15 cm)	Medium (~25 cm)	Large (~30 cm+)	Veneer (~36 cm)
Argentina	Eucalyptus spp. - Corrientes	12	30	255	485	1406	3500	0.00	17.12	22.52	29.28	43.84
Argentina	Pinus spp. - Corrientes	18	20.5	205	373	743		0.00	6.00	11.00	16.00	22.00
Argentina	Pinus taeda - Misiones	17	27	160	385	1055	2500	0.50	2.00	10.00	18.00	25.00
Brasil	Eucalyptus spp.	6	36	1900	440	2550	4400		30.00			
Brasil	Pinus taeda sawtimber	17	30	1360	0	2040	3400	9.00	15.00	30.00	46.00	64.00
Chile	Pinus radiata Sawtimber - Good Site	22	30	420	352	1372	7500	8.00	11.80	19.80	36.80	53.80
Chile	Pinus radiata - Pulpwood - Poor Site	16	20	420	300	1170	2500	8.00	11.80	19.80	36.80	53.80
Chile	Eucalyptus globulus pulpwood	16	25	420	395	1190	4500	8.00	19.80			
Chile	Eucalyptus nitens pulpwood	14	35	420	365	1160	4800	8.00	13.80			
China	Eucalyptus sp. - Pingxiang, Guangxi	7	20	324	593	2560			111.43			
China	Pinus massoniana	30	6.9	500	236	1314				80.00		
China	Cunninghamia lanceolata	30	6.9	500	236	1314				85.71		
Colombia	Eucalyptus urograndis - Andes	7	45	488	576	1994	2350	0.50	0.50	35.00	35.00	35.00
Colombia	Eucalyptus pellita - Orinoquia	7	35	206	384	1447	470	10.50	10.50	10.50	10.50	10.50
Colombia	Pinus patula sawtimber - Andes	18	22	488	576	1994	1500	2.50	2.50	35.00	47.50	52.50
Colombia	Pinus tecunumanii - Andes	16	30	488	576	1994	2125	2.50	2.50	35.00	47.50	52.50
Colombia	Tectona grandis - Magdalena	20	7.3	982	528	3114	1580		6.00	112.50	167.63	
Colombia	Eucalyptus urograndis/pellita - Casanare	9	39.7	108	431	2395	lease 174	12.70	12.70	12.70	12.70	12.70
Finland	Pinus sylvestris	66	7.5	599	900	1499		3.72	22.21	0.00	30.16	77.32
Finland	Picea abies	63	6.5	659	1178	2332		3.72	24.57	0.00	33.85	80.78
India	Eucalyptus spp.	8	20	360	421	941	5975	10.00	34.00			
India	Casuarina	8	20	156	421	737	6939	20.00			39.00	
Mexico	Eucalyptus grandis	8	30	431	531	1586	2700	2.00		30.00	30.00	30.00
Mexico	Pinus gregii	20	15	509	524	2035	2700	2.00	5.00	10.00	15.00	30.00
New Zealand South	Pinus radiata	28	30	143	600	1423	6500	1.00	6.00	35.00	57.00	66.00
Paraguay	Eucalyptus grandis/urograndi clones	10	25	462	545	1645		2.00	5.00	10.00	15.00	30.00

Country	Species	Rotation	MAI	Establishment costs (\$/Ha)			Land cost	Prices per m3 (\$) (at small end diameter)				
		Age (yrs)	m3/ha/yr	Site Prep	Planting	Tot Yr 0-5	(\$/Ha)	Biomass (~5 cm)	Pulpwood (~15 cm)	Medium (~25 cm)	Large (~30 cm+)	Veneer (~36 cm)
Poland	Quercus Sp. Private	120	8.4	2383	880	4481	2513	28.79	58.94		309.80	
Poland	Pinus sylvestris Private	100	9.3	194	868	1656	2513	2.74	47.06		75.39	
Spain	Eucalyptus globulus	15	23	1237	1865	3439			39.35			
Spain	Eucalyptus nitens	12	30.3	1073	2091	3838			31.48			
Spain	Populus	15	20	1198	2971	4196		9.56		28.83		134.91
Spain	Pinus radiata	30	17	1057	1039	3036			22.48	28.11	50.59	
Spain	Pinus pinaster	35	13	1011	1125	3036			22.48	28.11	50.59	
Uruguay	Eucalyptus smitthii	10	18	520	810	1415	2700		29.00			
Uruguay	Eucalyptus dunnii	10	20	520	810	1515	2700		26.00			
Uruguay	Eucalyptus grandis pulp	10	25	433	866	1474	2750		24.00			
Uruguay	Eucalyptus grandis sawtimber - North	12	25	270	440	898	2500	3.50	16.00	18	26.00	45.00
USA	Pinus taeda Hi /Upper 1/3 South Growth	25	13.2	902	482	1383	3000	3.78	9.54	29.59	37.83	
USA	Pinus taeda / South-Wide Avg Growth	25	11.3	568	373	941	2500	3.78	9.54	29.59	37.83	
USA	Quercus spp., Even Age, Plant	60	6.2	325	284	759	2000		5.66		36.25	52.21
USA	Mixed Hardwoods, Natural	120	4.12	0	0	0	2000		5.66		36.25	52.21
USA	Pseudotsuga menziesii Site I	40	13.4	222	1086	1864	2223			60.00	73.33	80.00
USA	Pseudotsuga menziesii Site III	45	12	222	1086	1864	2347			60.00	73.33	80.00
Vietnam	Eucalyptus urophylla Northeast	7	21		1251	2103	2909	8.50	42.20	60.20		
Vietnam	Acacia mangium Smallholder Northeast	7	19.5		1134	1916	2909	8.50	42.20	60.20		

Table 3. Tree planting investment capital budgeting returns, wood fiber costs, and carbon dioxide storage costs by country and species, 2023.

Country	Species	Capital Budgeting Criteria @8%			Wood Costs		Forest Carbon Costs	
		NPV	LEV	IRR	NPV at Year 0	NFV at Rotation	Tree	Whole Tree
		(\$/Ha@8%)	(%)	(%)	\$/m3	\$/m3	\$/CO2e	\$/CO2e
Argentina	Pinus taeda - Misiones	689	1143	12.0	4.96	9.83	4.16	3.46
Argentina	Pinus taeda - Misiones	871	1162	13.3	2.24	8.04	2.52	2.10
Argentina	Eucalyptus grandis - Corrientes 1	190	261	9.0	3.73	8.50	3.12	2.60
Brazil	Eucalyptus spp. pulpwood	1101	2978	14.4	13.81	18.73	16.01	13.34
Brazil	Pinus taeda sawtimber	675	925	13.2	8.82	14.80	10.23	8.52
Chile	Pinus radiata Sawtimber - Good Site	1207	1479	11.6	2.65	11.30	3.70	3.13
Chile	Pinus radiata - Pulpwood - Poor Site	349	493	9.8	3.73	12.53	5.21	4.53
Chile	Eucalyptus globulus pulpwood	724	1023	11.3	3.05	10.19	3.35	2.92
Chile	Eucalyptus nitens pulpwood	911	1229	12.3	2.42	6.95	3.10	2.63
China	Eucalyptus	5725	13745	32.7	22.51	31.33	25.56	21.30
China	Pinus massoniana	1219	1354	11.5	6.73	63.89	8.15	6.79
China	Cunninghamia lanceolata	1382	1534	11.9	6.83	63.89	9.31	7.75
Colombia	Eucalyptus grandis	-167	-402	6.8	8.88	10.85	10.63	8.86
Colombia	Eucalyptus grandis	-114	-273	6.7	6.59	10.12	5.22	4.35
Colombia	Pinus patula sawtimber	-676	-901	6.3	8.56	20.12	8.33	6.94
Colombia	Pinus tecunumanii	551	779	9.3	6.91	14.23	8.10	6.75
Colombia	Tectona grandis - Magdalena	-326	-415	7.3	24.70	99.41	19.23	16.03
Colombia	Eucalyptus grandis	4	8	8.1	8.14	13.40	6.34	5.28
Finland	Pinus sylvestris	-992	-999	4.3	10.71	486.59	13.89	11.58
Finland	Picea abies	-1840	-1854	4.3	16.85	726.39	26.23	21.86
India	Eucalyptus spp.	1371	2982	18.4	7.77	10.89	6.52	5.43
India	Casuarina	2710	5896	26.6	5.56	8.53	5.83	4.86
Mexico	Eucalyptus grandis	2100	4569	20.4	7.46	12.23	6.77	6.16
Mexico	Pinus gregii	2110	2687	12.2	8.09	31.62	9.39	7.82
New Zealand	Pinus radiata, no pruning	30216	34178	10.2	2.65	14.61	3.56	2.97
Paraguay	Eucalyptus sp. clones	1410	2626	16.0	6.45	14.21	5.41	4.51
Poland	Quercus Sp. Private	-4682	-4682	3.5	4.84	45575.88	3.91	3.26
Poland	Pinus sylvestris Private	-1664	-1664	3.9	2.41	3917.89	2.92	2.44
NSpain	Eucalyptus globulus	-151	-221	7.5	12.84	31.62	12.28	11.16
Spain	Eucalyptus nitens	-264	-438	7.4	13.23	26.58	16.02	14.18
Spain	Populus	3008	4393	11.4	18.11	44.37	25.98	20.45
Spain	Pinus radiata	-266	-295	7.6	6.70	59.91	8.29	7.28
Spain	Pinus radiata	-2787	-2989	5.4	7.62	98.67	8.93	7.51
Uruguay	Eucalyptus smitthii	674	1256	11.9	9.69	16.97	12.64	10.53
Uruguay	Eucalyptus dunni	584	1088	11.3	9.12	16.35	11.91	9.92
Uruguay	Eucalyptus grandis pulp	1123	2093	14.1	6.62	12.73	8.88	7.40
Uruguay	Eucalyptus grandis sawtimber - slower	413	685	10.0	4.83	7.54	4.05	3.37

Country	Species	Capital Budgeting Criteria @8%			Wood Costs		Forest Carbon Costs	
		NPV	LEV	IRR	NPV at Year 0	NFV at Rotation	Tree	Whole Tree
		(\$/Ha@8%)	(%)	(%)	\$/m3	\$/m3	\$/CO2e	\$/CO2e
USA	Pinus taeda / HighYield & Intensity NC	-636	-745	6.0	6.62	28.71	7.68	6.40
USA	Pinus taeda / Medium Yield & Intns NC	-223	-261	7.1	5.36	22.81	6.22	5.18
USA	Quercus spp., Even Age, Planted, Clearcut	-1176	-1187	4.2	4.34	206.61	3.48	2.90
USA	Mixed Hardwoods, Natural	-579	-579	3.7	1.53	0.00	1.23	1.02
USA	Psuedotsuga menziesii Site I	-1327	-1391	6.3	5.91	75.56	7.32	6.10
USA	Psuedotsuga menziesii Site III	-1919	-1981	5.4	5.92	110.20	7.34	6.11
Vietnam	Eucalyptus urophylla High growth	1414	2909	18.8	21.69	24.52	17.91	17.56
Vietnam	Acacia Smallholder	1122	2694	17.6	20.74	24.06	20.93	20.52

Timber investment returns

As shown in Table 3, one can observe that the largest calculated stand level IRRs, not including land prices, were for fast-growing species, mostly in Asia—for exotic *Eucalyptus sp.* in China (33%), Vietnam (19%), and India (18%), as well as *Casuarina* (27%) in India. Mexico also reported a 20% IRR for *Eucalyptus*. The reports were based on a limited area of government land plantings or demonstrations for China, India, and Mexico, but are based on more widespread data from smallholder private landowners in Vietnam.

In South America, exotic *Eucalyptus spp.* are widely planted by vertically integrated forest products firms and by small private landowners or by timber investment firms. Those calculated returns ranged from the highest IRRs of 16% in Paraguay, 14% in Brazil, 11% to 12% in Chile, and 10% to 14% in Uruguay, and 9% in Argentina. Reported IRRs for *Eucalyptus* in Colombia ranged from 4% to 9%, and were about 7% in Spain. *Tectona grandis* had a 7% IRR in Colombia. Prevalent *Acacia sp.* plantings had high IRRs in Vietnam of 18%, and *Populus sp.* in Spain had an IRR of 10%.

The calculated softwood species IRRs in the southern hemisphere ranged from 10% to 14%. The widespread area of relatively similar lands and timber management methods in Brazil and Argentina generated IRRs of about 13% for exotic *Pinus taeda*. Returns for large areas of exotic *Pinus radiata* in Chile ranged from 10% to 12% IRRs. For exotic pines in Colombia, the return for *Pinus tecunumanii* was a 9% IRR, and *Pinus patula* was 6%. The IRR for native *Pinus gregii* in Mexico was 12%. The dominant exotic species plantings of exotic *Pinus radiata* in New Zealand had a 10% IRR.

Calculated investment returns for native and a few exotic species in the Northern Hemisphere usually had IRRs of less than 10%. Native *Pinus massoniana* in China had an IRR of 12%, as did *Cunninghamia lanceolata*. Exotic *Pinus radiata* in Spain had IRRs of 5% to 8%. *Pseudotsuga menziesii* and *Pinus taeda* in the U.S. had IRRs ranging from 5% to 7%. In Finland, *Pinus sylvestris* and *Picea abies* had IRRs of 4.3%, while in Poland, *Pinus sylvestris* and *Quercus spp.*, and *Quercus spp.* in the U.S. South had calculated IRRs ranging between 3.5% and 3.9%.

For the NPVs and LEVs, note that per the formula for these values, species and countries with IRR greater than the 8% discount rate had positive NPVs and LEVs, and vice versa for IRRs less than 8%. The countries that had positive LEVs at 8% earned that discount rate, plus would generate additional cash that represents the value of land for that species and management regime. Negative LEVs, and IRRs of less than 8%, indicate that one could not buy bare land and make the 8% discount rate by growing those particular planted forests. Furthermore, note that the estimated land prices in almost all countries with private land markets exceeded the LEVs. This means that despite positive investment LEVs at an 8% discount rate, they still did not earn enough to justify buying bare land for new investments.

Even the calculated positive LEVs/land values were usually modest, at less than \$3,000 per ha, with the exception of Eucalyptus in China and Mexico, Casuarina in India, Populus in Spain, and Pinus radiata in New Zealand. The first three countries do not sell much open market land, but have mostly community-based forest management or have some small areas of leased land. In fact, forest investments often would have to accept a lower discount than 8% to justify higher land purchase prices. Or existing owners may be treating land as a sunk cost, and only focus on returns to their existing properties, assuming they will hold the land regardless, at least in the short run. This research result would indicate that forest investments commonly earn less than the typical costs of capital in many countries. This may constrain attracting new investors seeking high short-run returns during profitable stock market/equity eras. For government-owned lands, such as in India and China, new external timber investors may lease land, or local owners may form cooperative ventures to lease or rent land in order to plant and manage production forests on government land.

As noted in our Cubbage et al. (2022) paper, returns by timber growth rates showed that the lowest MAIs of less than 10 m³/ha/year occurred for the northern species and countries that had the lowest

IRRs. Non-native pines such as *P. radiata* (Chile, New Zealand), *P. taeda* (Brazil), and *P. tecunumanii* (Colombia) had excellent growth rates between 18 and 35 m³/ha/yr, and intermediate returns. *Eucalyptus* usually had fast growth rates of 20 to 30 m³/ha/yr, leading mostly to its higher IRRs. *Eucalyptus*, *Tectona*, and *Acacia* roundwood in Asia had the highest stumpage prices in the world by far, based on the high demand in China and India.

Similarly, rotation ages, and native (autochthonous) versus exotic species had substantial effects on timber investment returns. In general, faster growth rates of exotic species and shorter rotations did lead to greater returns, except when stumpage price levels were exceptionally low or management costs were very high. Conversely, native species usually had lower growth rates and lower rates of return. Pulpwood management regimes usually had lower returns than integrated pulpwood and sawtimber regimes. There were no northern hemisphere species with rotations of less than 25 years except for Spain. These longer rotations usually generated lower IRRs.

Wood fiber costs

The discounted wood fiber costs for merchantable wood in the main stem by species and country at the 8% discount rate are also shown in Table 3. These total costs then just show the sum of the discounted costs for each year in one rotation. In general, the average costs per m³ were relatively cheap when discounted back to year zero. Thirteen of the average wood fiber costs were less than \$5 per m³; 22 were between \$5 and \$10 per m³; six were between \$10 and \$20 m³; and four were greater than \$20 per m³.

The average costs for wood fiber were very low in Argentina, Chile, Paraguay, India, New Zealand, Poland, and for U.S. South hardwoods. The next category included moderate costs for softwoods in China, most species in Colombia, softwoods in Spain in the U.S., and Eucalypts in Uruguay. Average wood costs of more than \$10 per m³ occurred with Eucalypts in Brazil and Spain, *Populus* in Spain, and softwoods in Finland. The highest average wood fiber costs of more than \$20 per m³ occurred with teak in Colombia, and both Eucalypts and *Acacia* in Vietnam.

These results indicate that a ranking of timber investments does not correspond well with a ranking of discounted wood fiber costs. The differences are attributable to the magnitude, timing, and discounting of when costs occur, as well of them not being "offset" by any returns.

The smallest total and average discounted costs will lead to the cheapest wood, *ceteris paribus*. Some of the very productive species and countries—e.g., Eucalypts in Brazil, both species in Vietnam, and Eucalypts in China—have high establishment and management costs, that occur in a very short rotation of 6 or 7 years. These higher costs could be attributed to large amounts of manual labor in Asia at least, even for the monoculture plant and clearcut systems we examined. Asia has large public natural forest ownerships; significant areas under communal forest ownership and management; as well as very small private ownership tracts, especially for plantations (e.g., a common measurement and ownership area of a mu (1/15 ha) in China) that must be aggregated for economical management and harvesting. In Brazil, high establishment costs of very intensive site preparation and chemical applications are required to control vigorous competing vegetation and aggressive ants. In a timber investment, these higher costs are offset by high growth rates and high stumpage prices, which generate high IRRs. Colombia perhaps had higher costs due to more expensive management costs for smaller tracts, spread more widely across limited areas of suitable land in the mountainous terrain.

Surprisingly, on the other hand, hardwoods in Poland and the U.S., as well as pine in Poland, have very low discounted wood costs because of moderate establishment costs, especially for natural hardwood stands, and the management costs occur decades into the future. Thus, even while the total costs are significant, their discounted costs to year zero with an 8% discount rate make them small.

Wood fiber costs for both individuals and forest product firms would be much higher if one were to include the price of land in the calculations—perhaps two to three times more, since land purchase costs in year zero will be two to three times more than the total discounted costs. Also, note that the species and countries with the lowest wood production costs may not always be the most profitable investments—high timber prices can make other investments worth more despite higher initial and annual costs.

On the other hand, cheap wood fiber prices as stumpage and at the mill are particularly good for vertically integrated forest products firms. In addition to their primary goal of growing wood fiber to guarantee supply for their mill, relatively cheap wood production costs may be one reason why most firms in South America are vertically integrated. By doing so, these companies make more profit throughout the entire timber value chain. There is also no existing natural forest inventory

of native species on other private or public lands, such as loblolly pine in the U.S. South or Douglas fir in the U.S. West, so they must grow much of their own wood fiber to ensure adequate supplies for their manufacturing plants.

As another approach to estimating wood costs, one could also use an accounting stance parallel to Generally Accepted Accounting Principles (GAAP). Instead of calculating wood costs as the NPV of all costs in year zero, one could “flip” the discounting to compounding, and calculate the accumulated costs at the given interest rate of 8% to the end of the rotation as a net future value (NFV), as done by Cubbage et al. (2010). This accountant's approach would be more like a book value of the costs including interest. This NFV approach will be used more by forest products firms, but is less consistent with traditional forestry stand management analyses that estimate a net present value, or net present cost of wood fiber in this case.

Obviously, the cost per unit of wood becomes much higher with this NFV perspective. For example, the first row of Table 3, Argentina *Pinus taeda* wood costs increase from \$4.96 per m³ in the capital budgeting approach, to \$9.83 per m³ under the GAAP approach. Brazil *Eucalyptus spp.* increases from \$13.81 to \$18.73 per m³. New Zealand *Pinus radiata* increases from \$2.65 to \$14.61 per m³. U.S. *Pinus taeda* increases from \$6.62 per m³ to \$28.71 per m³. And the long rotation U.S. Douglas-fir (*Pseudotsuga menziesii*) increases from \$5.92 to \$75.56 per m³. On the other hand, the short rotation Vietnam *Acacia* only increases from \$20.74 to \$24.06 per m³. The main point here is that long rotations and GAAP approaches of compounding costs to the end of the rotation usually result in far more expensive wood. In fact, rotations of more than 60 years led to wood costs of several hundred dollars per m³, which suggests why very few investors or forest products firms choose to make these plantation investments.

Forest carbon costs

The base forest carbon costs are derived from the discounted total costs and total volume of merchantable wood produced, just like wood costs. But their equivalent numerical dry weight of tCO₂e in tonnes is approximately their specific gravity of the dry wood in a cubic meter times the weight of their carbon and oxygen atomic particles (3.67).

Our results indicated that there were 15 species and countries with average forest carbon costs of less \$5 per tonne of CO₂e; 16 species and countries with average costs of between \$5 and \$10.00 per tCO₂e; nine combinations with between \$10 and \$20 per tCO₂e; and five with costs of more than \$20 per tCO₂e. Whole tree forest carbon costs would be about 20% less, increasing the distribution of average costs slightly in the cheaper categories.

Just like with wood fiber production, high discounted tCO₂e costs are associated with intensive forest establishment and management costs. In general, the same species and countries listed for expensive wood costs per m³ also will have expensive average tCO₂e costs, and vice versa. The numbers for forest CO₂e costs per tonne were generally close to wood costs per cubic meter. However, remember that the tCO₂e costs are a weight-based number; the wood fiber costs are a volume measure. These costs for tCO₂e production will be greater for lighter wood (low specific gravity), and smaller for heavy wood. Like in the case of wood volume, costs are cheaper if one includes the approximately 20% of the volume in tops and branches. Costs for both wood fiber and tCO₂e production also will be much higher if one were to include the price of land in the calculations—perhaps two to three times more. On the other hand, although the carbon stored in forest soils and in wood products are usually not accounted or paid for in carbon credits, they may be relevant from a sustainability and Environmental, Social, and Governance (ESG) investing and reporting perspective.

DISCUSSION

This research article summarizes our most recent investigations about global timber investments, which we have performed for almost two decades, and expanded it to make integrated estimates of wood fiber production costs and forest carbon storage costs. We collected forest management cost and return data as we have before, and extended the basic spreadsheet template that we used in the past in order to make calculations of wood fiber production costs per m³ and forest carbon costs per equivalent amount of carbon removed from the air, in tCO₂e.

These data and analytical methods provide integrated estimates of operational or prospective forest investment returns, wood fiber production costs, and forest carbon storage costs. The data and

results are useful for providing sound production economics calculations of typical forest management practices for many of the major industrial planted forest regions in the world. In addition, the methods and spreadsheet template that we have developed in this study can be used to analyze other private or public forest land investments or programs by expanding the costs and returns to larger land areas. They can also be used to model different stand growth rates and harvest schedules, or different input costs and prices as appropriate for different site productivity classes, different forest management practices, or different timber markets and prices. Users can adopt or modify the Excel timber investment template (Attachment A) as deemed appropriate for their situation.

Investment returns

The keys to high timber investment returns were fast growth rates, high timber market prices, and reasonable forest establishment and management costs. China, Vietnam, India, and New Zealand had the highest prices for wood due to the high population and timber demand in Asia, and very few planted industrial forests (e.g., little supply). The management costs in China, Vietnam, and India were relatively expensive, but high stumpage prices in Asia made the investment returns among the highest in the world, with more than 20% IRRs. On balance, the high population and wood fiber demand, small commercial forest land available, and low production levels drive up stumpage prices. Several Asian countries have programs to increase planted forests, but land limitations and business challenges for existing domestic landowners or for foreign direct investment are substantial.

South America has the largest area and fastest growing exotic planted forests, good timber markets, but relatively high planting costs in the subtropical and warm temperate regions. Despite the high costs of planting, their net investment returns are still excellent, ranging from lows of about 7% IRRs in Colombia—which has rugged terrain, disparate tracts, and high transportation costs—up to IRRs of 12% to 13% for the largest three areas of Argentina, Brazil, and Chile—with good soils, good timber markets, and intensive management. Uruguay has a broad range of moderate returns and has built three new pulp mills in the last 30 years. Paraguay and Mexico potentially have the highest returns, but the results are based on small areas of planted forests and no major pulp mills.

The Northern Hemisphere forests, including those in the United States and Europe, have slow growth rates, moderate forest management costs, and moderate timber prices in most places, except the U.S. South. Despite having many markets, the South has large areas of planted and native forests and high levels of forest inventories that depress stumpage prices. The Northern Hemisphere also has long rotations, of about 25 years in the U.S. South and 40 to 45 years in the U.S. Pacific Northwest, 60 years or more in Finland, to more than 100 years in Poland. This combination of factors makes timber investment returns modest to low in many northern countries, with IRRs from 7% at best for pines in the U.S. South to 4% for softwoods and hardwoods in Poland, Finland, and the U.S. South.

The benefits of high levels of investment returns, of course, accrue to forest landowners who are wood suppliers and producers, and higher stumpage prices indicate that forest products mills must pay higher prices due to strong market competition. Vertically Integrated Forest Products Firms (VIFPCs) own and produce the most wood fiber in South America, so they capture much of the profit from their high-yield forests, albeit with high input costs. There are also small forest owners and some timber investment and management organizations (TIMOs), who sell wood fiber in regional markets. Conversely, large pulp mills, fiber board mills, or sawmills must pay the higher prices for wood fiber when they do not have their own timberlands and fiber production.

As a brief complement for this 2023 data summary, we have long-run trends—just for timberland investments—for a few countries for the entire span of this research effort. Two key countries, for example, include the U.S., with 26.4 million ha of planted forests in 2015, and Brazil, with 7.7 million ha in 2015. These represent the countries with the second-largest planted area in the world and the ninth-largest, respectively (Korhonen et al. 2021). These two important industrial wood producing countries are leaders in the pulp and paper and solid wood forest products sectors in the world, so they are good examples of robust timber markets for timber investments.

Figures 1 and 2 show the trends in the IRRs for the selected timberland investments for key species in each of those countries. These trends are fascinating. IRRs for *Pinus taeda* in the U.S. were highest in 2005 and 2008, and declined sharply in 2011 and 2014; they have since increased and fluctuated at an IRR somewhat less than 6%. U.S. Douglas fir prices hovered between 8% and 7.4% from 2005 to 2017, and dropped below 7% since. For both *Pinus taeda* and *Eucalyptus* spp., Brazil

had very high IRRs of more than 20% through 2011, but also had major drops to 12% and 8% from 2014 to 2020, and good recoveries to 13% and 15% in 2023.

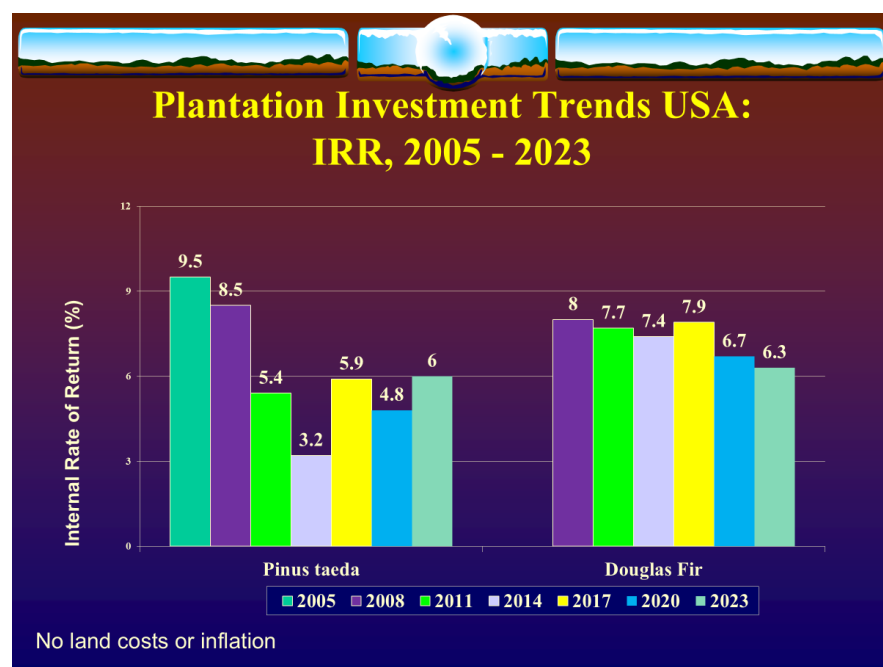


Figure 1. Trends in timber investment IRRs for species analyzed in the United States, 2005 - 2023.

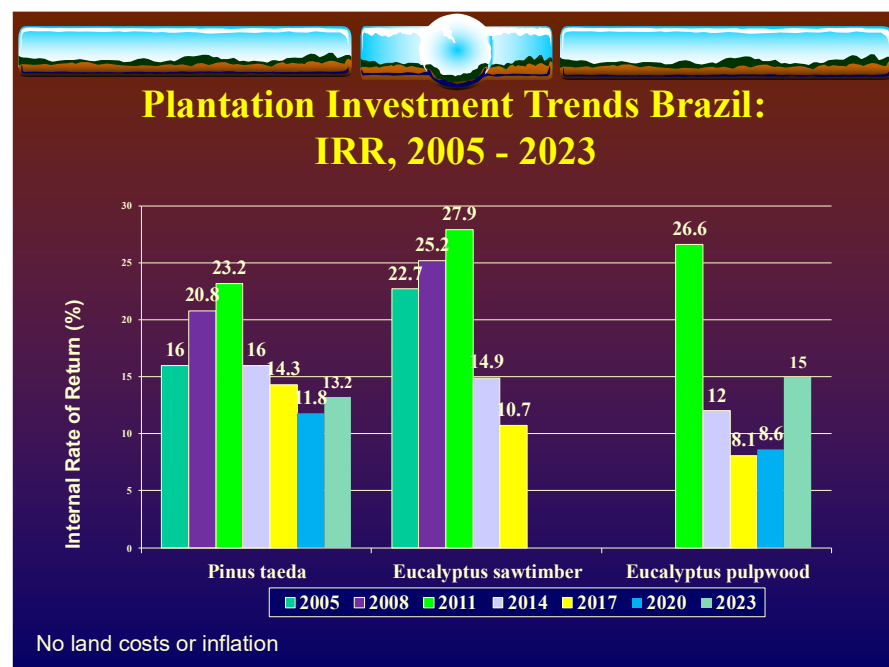


Figure 2. Trends in timber investment IRRs for species analyzed in Brazil, 2005 - 2023.

Wood production costs

Our calculated wood production costs are simply the sum of timber stand establishment and management costs, discounted annually to year zero at the 8% discount rate. Land also would be a cost for new owners, but we did not include that in the calculations. The spreadsheet template does provide a means to include that for users who want to. Establishment and management costs for the first five years of a plantation covered most of the costs, especially at an 8% discount rate. Those ranged from about \$750 per ha to \$2,700 per ha for most countries, except for much higher prices in Spain and Poland. This is a pretty broad range, but there are not likely many realistic opportunities for reducing them in any given country.

As noted in the results section, the average costs for merchantable wood fiber were less than \$5 per m³ in Argentina, Chile, Paraguay, India, New Zealand, Poland, and for U.S. South hardwoods. The next category from above included moderate costs for softwoods in China, most species in Colombia, softwoods in Spain in the U.S., and Eucalypts in Uruguay. Average wood costs of more than \$10 per m³ occurred with Eucalypts in Brazil and Spain, Populus in Spain, and softwoods in Finland. The highest average costs of more than \$20 per m³ occurred with teak in Colombia, and both Eucalypts and Acacia in Vietnam.

One surprise with these discounted wood costs calculations was that species and countries with very long rotations—Poland, U.S. hardwoods—had cheap wood production costs, which were caused mathematically due to the large discounting of distant future costs. The South American countries also had less expensive production costs per unit of timber, based largely on very high growth rates, although their establishment and management costs were moderate.

As noted, our default wood costs above assumed that the costs were calculated as the NPV of a discounted cash flow, consistent with the timber investment returns capital budgeting approach. One also could reverse the discounted costs to be the compounded sum of all costs as a NFV, computed to the end of the rotation. This approach would make them conform more with customary Generally Accepted Accounting Principles (GAAP) approach. Of course, compounding costs at 8% for a various rotations would make this accounting stance substantially increase wood production costs. *Ceteribus paribus*, the longer the rotation, the higher the wood costs would be.

The differences in timber investment returns, and NPV versus NFV wood costs bear noting. Long rotations consistently led to low IRRs, and similarly to high wood fiber costs based on NFVs. A

little surprisingly, longer rotations could lead to lower NPV-based per unit costs for wood fiber production, since the future costs were discounted more. These results suggest why most TIMOs do not invest in species with long, slow rotations in Northern climates. Instead, small forest owners, who can accrue other multiple use, familial, and land investment benefits, hold and manage much of these lands. And public forest ownership and management also is common in many Northern countries. Of course, Scandinavian and some EU countries have large areas of planted forests that are owned and managed by national pulp and paper or other firms. These were largely established based on widespread forests, scarce wood supplies, and high timber prices. Nonetheless, even those firms have pursued most of their forest expansion opportunities in more temperate or subtropical forest regions in the last few decades.

Forest carbon costs

As stated above, the results indicated that in the merchantable tree, there were 15 species and countries with average costs of less \$5 per tonne of CO₂e; 16 species and countries with average costs of between \$5 and \$10.00 per tonne of CO₂e; nine species/country combinations with costs between \$10 and \$20 per tonne; and five with CO₂e cost of more than \$20 per tonne. Average forest carbon costs would decrease about 20% for whole-tree-based volume calculations.

In general, these costs were relatively low, which would provide good opportunities to attract investment for forest carbon storage to offset global carbon emissions. These low costs, if forest carbon offsets are employed, would benefit society. The challenge is, of course, to have social acceptance and pressure for mandatory carbon storage in compliance markets or for carbon storage in voluntary markets. Figure 3 shows a snapshot of current carbon market prices as of July 5, 2025 (carboncredits.com 2025). This market is very dynamic, and changes often based on regulations and social demand. A similar table from April 2024 listed California as a Compliance Market, with a price of \$28.66 per tCO₂e (carboncredits.com 2024). California has since been dropped from the handy list, although the program still exists. Other compliance market prices listed there have changed somewhat from 15 months ago, but not that much for the Compliance Markets. The Voluntary Markets prices dropped by about 75%, and a Tech-Based Offset also was dropped from the list.

Live Carbon Prices Today



The widget displays live carbon prices from CarbonCredits.com. It features a dark blue header with the CarbonCredits.com logo and the title 'Live Carbon Prices'. Below the header is a table with three columns: 'Last', 'Change', and 'YTD'. The table is divided into two sections: 'COMPLIANCE MARKETS' and 'VOLUNTARY MARKETS'. The 'COMPLIANCE MARKETS' section lists prices for the European Union, UK, Australia (AUD), New Zealand (NZD), South Korea, and China. The 'VOLUNTARY MARKETS' section lists prices for Aviation Industry Offset and Nature Based Offset. Prices are shown in their respective currencies (EUR, USD, AUD, NZD, KRW, CNY). Changes and YTD percentages are shown in green for increases and red for decreases.

	Last	Change	YTD
COMPLIANCE MARKETS			
European Union	€71.50	-	-4.91%
UK	\$47.65	-	+30.98%
Australia (AUD)	\$35.50	-	-2.07%
New Zealand (NZD)	\$57.10	-	-8.64%
South Korea	\$6.17	-	-11.49%
China	¥74.08	-	-24.01%
VOLUNTARY MARKETS			
Aviation Industry Offset	\$0.19	-	+46.15%
Nature Based Offset	\$0.26	-	-55.17%

Carbon Prices by CarbonCredits.com Add this widget to your site

Figure 3. Selected global carbon prices (carboncredits.com 5 July 2025).

If carbon market prices were high, low forest carbon storage prices could be good for investors, for carbon offset buyers and programs, and for society. On the other hand, if social and political demand (e.g., demand) were very low, it would not matter much that forest carbon prices (supply) were low from a financial perspective. As Figure 3 shows, for compliance markets, the stand level forest carbon prices we calculated here would be less than all the country compliance program requirements of about \$34 to \$100 tCO₂e, except for South Korea's prices of about \$6 per tCO₂e. And there are some forest species and country species with prices that were less than South Korea as well. Current listed carbon prices in the voluntary markets were extremely low at \$0.50 or less per tCO₂e, and none of the greenfield forest wood costs we calculated would meet those levels. However, forest carbon vendors comment that there are many individual unlisted voluntary market cases and deals that have purchased carbon credits, and those have ranged from \$5 to \$12 USD per ton.

Regardless, forest carbon costs are certainly among the cheapest of all types of carbon offsets. The above-ground tree and stand forest carbon costs we calculated would be 20% to 30% less if they included tops and branches, as this demonstrably increases the amount of carbon included in the

sequestration estimates. And forest carbon storage increases even more if forest soils or carbon storage in wood products are included. In general, good forest management is a viable carbon emission offset practice. If carbon markets were robust, forests should be able to contribute well to meeting social goals to reduce or offset net carbon emissions, thus reducing climate change and its adverse impacts.

Recall that the sum of forest carbon production costs calculated in this study is not the full cost of developing an offset, because they do not include the administrative costs associated with regulated or voluntary carbon markets. Costs for tradable carbon offsets would include our CO₂e production costs, and any additional costs for feasibility and design, data and verification, or offset registry. These forest carbon costs often would be incremental to already existing forest management practices, or often joint products with timber or biodiversity production. So costs often may be small for a large project. On the other hand, they are unlikely to be financially or administratively attractive for forest carbon projects that are much less than 5,000 to 10,000 ha, unless various public or private incentive programs cover those costs.

Integrated investment, production, and ecosystem service portfolios

We calculated investment returns for timber, wood fiber production costs, and forest carbon costs as stand-alone economic production and cost functions. A forest may produce each of these goods as joint products, and investors and society may be able to manage for multiple benefits and returns. As noted, timber investment returns are not exactly correlated with wood fiber or forest carbon production costs. Other nontimber forest products can be produced in a forest, such as pine straw, ornamental or medicinal plants, or even livestock. Nature-based services, such as forest carbon, biodiversity, water quality or quantity, or recreation, can be jointly produced in production forests that produce timber, or just for conservation in multiple-use forests, communal forests, or other public and private forest lands.

These opportunities for joint products of market and ecosystem benefits and services can make forests more valuable in general, and for the single output scenarios that we calculated, by increasing the joint financial returns that forests may provide, for private investors and for public goods. Reforestation also can provide substantial local and global environmental benefits (Shyamsundar et al. 2022; Vincent et al. 2025). As a notable relevant example, timberland investment returns and forest carbon production can be increased by longer rotations, or different

planting densities and thinning and harvest regimes, with some reduction in timber volumes (Koirala et al. 2022; Mei 2023). Forests provide considerable opportunities for Environmental, Social, and Governance (ESG) investments, or for achieving Net Zero carbon targets. In fact, the returns from the individual species production and cost function calculations we made here can be increased for joint products—with only modest incremental management costs for the joint products—and produce more valuable total multiple benefits and returns.

CONCLUSIONS

This integrated timber investment costs and returns, wood fiber production costs, and forest carbon storage costs provide useful public information for private and public landowners, potential timber investors, forestry firms and consultants, government and nongovernment organizational personnel, and researchers. These data for many of the major timber-producing countries in the world provide a broad scope of relatively unique information on global forest establishment costs, timber prices, and investment returns. Extending the prior production economics and investment returns analyses to wood fiber costs and forest carbon storage offsets informs new policy and private and public investment decision-making.

The data and analyses help compare forestry opportunities among countries, and assess the relative merits of input factors and output prices to estimate discounted costs and returns and total returns to capital. They also provide sound empirical production economics calculations of forest management returns for use in other research applications, such as regional to global timber assessments. And last they help organizations assess the relative merits of and competition among production of different forest species and country opportunities, in addition to forest carbon as an ecosystem service.

The different criteria used for comparing investments and costs and their applications bear more explanation to understand their nuances. Our internal rates of return (IRR) calculations do not consider land purchase or lease prices. Thus, the results can be used to compare forest management and returns among all countries and private or public lands, and for existing owners who may not count their “sunk” land costs, as well as by prospective new investors. As such, the IRR is a

forestry investment return for a stand on a per hectare as a comparative index, pre-land cost. Our wood fiber production costs per cubic meter have the same assumption of excluding land, and follow the timberland analysis convention of being a cost as a net present value (NPV) at a given discount rate. Reversing these discounted costs to be compounded as a net future value (NFV) for a final wood production cost, as forest products firms usually do, would generate a higher wood cost, of course. Our carbon cost calculations per tCO₂e also discounted costs as a present value, like the other two approaches, which is consistent with most scientific and applied literature on the costs of forest carbon production, as well as for timberland investment analyses.

The results indicate that rankings of the best species and country for timber investments, wood costs, and forest carbon cost purposes differ. Thus, forest landowners, practitioners, and policy makers need to consider the objectives, input costs, and product or service returns to choose the best alternatives. Timber investments are the most complex, since they have costs and returns, which vary the most. Wood costs and forest carbon production are mathematically simpler, but have unique profitability requirements for wood costs, and usually unique country policy drivers and land retention and extended contact requirements for forest carbon production. As such, analysis and application of these methods and results will continue to require close examination of country, species, product or service, and site requirements, just as forestry has always required. Our models for analysis and spreadsheets presented here can help in those individualized efforts. In addition, expanding these investment analyses and subsequent practical applications to include the provision of joint products and services can help increase the investment returns and the private and public benefits and welfare generated by planted forests.

We did not include a wealth of additional literature on timber investments, risk, wood production costs, forest carbon, payments for environmental services, and social costs, which is beyond our scope. We do address risk explicitly in Cubbage et al. (2010, 2014), which has not changed too much by country. Based on that prior research, more developed countries had less investment risk, and land markets were more open for foreign investments. Most developing countries have improved financial risk in the last decade, but the lowest country risk ratings have not improved much.

As one example of climate risk, we did not consider the increasing impact of different disturbances on the mortality and growth of European forests (Pattaca et al. 2023), which could lead to

management to increase mixed forests and reduce plantations. Climate change has increased global uncertainty with problems of biotic and abiotic factors, such as forest fires, insect and disease pathogens, droughts, hurricanes, and typhoons, of course. Adverse impacts of increasing climate on human health and societies also are becoming more apparent. Issues with major and expensive storm damage to other assets, including homes, buildings, and civil infrastructure, exist, but are beyond quantification in this paper.

Overall, our production economics research here on global timber investments, wood fiber costs, and forest carbon costs does provide a comprehensive and valuable contribution to the literature on those subjects for investors, practitioners, policy analysts, and scientists. We welcome feedback on the research, and expect to continue this line of research in 2026.

ATTACHMENTS

- A. [Global Timber Investments, 2023 – Excel Template](#)
- B. [Plantation Investment Analysis Summary for Selected Species and Countries, 2023 – Excel](#)

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CONFLICTS OF INTEREST

The authors confirm there are no conflicts of interest.

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