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Comparative global timber investment costs, returns, and applications, 2020[1]

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ABSTRACT

Keywords

timber investments, benchmarking, internal rates of return, capital budgeting, planted forests, carbon mitigation

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We estimated stand level timber investment returns for a range of 16 countries and 47 planted species/management regimes in 2020, using capital budgeting criteria, at a real discount rate of 8%, without land costs. Plantation management financial returns were estimated for the principal plantation countries in the Americas—Brazil, Argentina, Uruguay, Chile, Colombia, Ecuador, Paraguay, Mexico, and the United States—as well as for China, Vietnam, Laos, Spain, New Zealand, Finland, and Poland. South American, New Zealand, and Spain plantation growth rates and their concomitant investment returns were generally greater, with the exception of some pulpwood regimes, with real Internal Rates of Return (IRRs) of more than 11%. Southeast Asia had the highest timber prices and highest calculated stand-level IRRs in the world, at more than 20%. Temperate forest plantations in the U.S. and Europe returned less, from 3% to 7%, but those countries have less financial risk, better timber markets, and more infrastructure. These timberland benchmarking research efforts can be used by the private sector for considering timber investments in different countries and regions in the world, or by government and nongovernment organizations to estimate their management costs and returns, or for providing government incentives for the provision of ecosystem services such as forest carbon storage.

INTRODUCTION

Timberland investment returns are important for practitioners, investors, government and nongovernment organizations, and researchers. For institutional investors and for most private forest landowners, the prospective returns for making investments in buying and managing forests are crucial. These investors usually focus on the production of timber or other tangible market commodities, which determines the demand for forest land and tree planting, as well as timber rotation ages, stand management, and harvesting activities. Chudy and Cubbage (2021) report that there were more than $100 billion dollars of investment funds already made by new timberland investors in the last three to four decades. Demands for timber and forest biomass investments could triple in the future, and the value of carbon storage could scale up forestry as an asset class to more than $1-1.5 trillion. These forest investments are being favored by broad interest in corporate Environmental, Social, and Governance (ESG) components, as well as "net-zero" investing to ensure that corporations do not contribute any additional greenhouse gases or carbon emissions that accelerate global warming (Brancalion and Chazdon 2017, Chudy and Cubbage 2021).

Timber production costs and returns also are fundamental for government and nongovernment organizations that own and manage forests for multiple market and nonmarket goods and ecosystem services. A broad set of ecosystem service payments may influence forest private land management, through government subsidy, incentive, education, and technical assistance programs, such as for carbon storage, water quality or quantity, biodiversity, or amenity values (Prokofieva 2016). Efforts to plant or restore forests for direct timber investments or for public goods and benefits all will require major expenses to establish planted forests or renovate degraded forests.

However, there is extremely little public information available about comparative world forest management costs and returns at an individual stand level or for an aggregate scale. Forest investment returns data are a first step in private landowner investment decisions, or for public program expenditures. As a recurring contribution to this information gap, in this paper we present the results from a long-running timber investment research data series, which we have compiled since 2005. The purpose of the paper is to provide a readily accessible summary of the methods, data, and results of our research about tree planting and management costs and investment returns as of 2020 for many of the major commercial species and industrial forest regions in the world. This can be useful for timber and forest land investors, who are interested growing mostly industrial wood fiber for profit by corporations, timber investment management organizations (TIMOs), community forests, family, small owner / outgrower, indigenous, individual, or other organizational entities. It also is important for national, state, or local government and nongovernment organizational (NGO) owners, who seek to make profitable investments as well, to fund multiple use forest benefits and their broader government and conservation programs and services.

Forest establishment and management costs also are important for consideration in major proposed national and international efforts to plant trees and restore forests to store carbon, prevent more forest carbon emissions, offset other land or industrial carbon emissions, and mitigate global warming. This includes assessments of massive global tree planting programs such as the Trillion Trees[2] to grow, restore, and conserve one trillion trees around the world by 2030. This effort and similar broad regional or country efforts have focused attention on forest planting or restoration as a major vehicle for carbon storage to mitigate global warming. Many other multilateral and national efforts have been promulgated to plant forests for carbon storage, reduced carbon emissions, or improved forest management. All these efforts

[2] Trillion Trees: https://trilliontrees.org/

will require initial information on forest planting, establishment, and management costs for planning, budget estimates, and seeking sufficient capital before they can begin.

METHODS

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, which varied slightly based on reporters and contacts available in selected years. The selections of the species included depended on their importance in each the country forest sector and on the availability of data in each country.

For our research in 2020, we calculated global timberland investment benchmarks for 16 countries, and 47 species and different management regimes. The costs, prices, and investment returns were collected in or converted to U.S. Dollars ($) in each country. Previous global timber investment publications have described the data collection, discounted cash flow, and capital budgeting methods employed as methods for this research (Cubbage et al. 2020, 2014, 2010, 2007). Various forest economists, including Klemperer (2003) and Wagner (2012), describe standard forestry capital budgeting approaches. For briefer World Bank Technical Reports in Spanish or English that align with our approach, see Cubbage et al. (2011, 2013), or for a shorter book chapter, see Cubbage et al. (2016).

Capital budgeting

For reference, we provide a brief written summary of capital budgeting, drawing from Cubbage et al. (2013). The Net Present Value (NPV) converts a series of recurring revenue streams into a single number that can be used to compare mutually exclusive investments at a given discount rate (cost of capital). For single accept/reject investment decisions, positive NPVs indicate that one would accept the investment; for selecting among multiple projects (termed capital budgeting), one would choose the investment with the greatest positive NPV.

The Land Expectation Value or Soil Expectation Value (LEV or SEV) calculates the present value of an infinite series of projects (rotations). The LEV is applied the same as NPV in making investment decisions—individual alternatives that have positive LEVs are acceptable, while negative LEVs would mandate rejection of the project. Similarly, the greatest LEV would be the preferred alternative in a capital budgeting situation, or to select among different forest rotations.

The Internal Rate of Return (IRR) is defined as the discount rate that makes the present value of project revenues equal the present value of project costs. For individual investments, the IRR is usually compared to any alternative rate of return. Alternative projects with an IRR greater than the rate of return are considered acceptable alternatives. Higher IRRs are preferred in capital budgeting among many projects.

We calculated IRR, NPV, and LEV at a base real (excluding inflation) discount rate of 8%, which we have applied for all analyses and all countries since this research began in 2004. In theory, with a given, known discount rate, NPV or LEV are taught as the best capital budgeting criteria. However, the actual discount rate is seldom known with certainty, and usually varies depending on the country, individual project, or other factors. In addition, common discussions of investments from Wall Street (e.g., Damodaran 2012) to major investment corporations (e.g., BlackRock, Vanguard) to pension funds to small owners rely almost exclusively on annual rates of return for comparing different investments and asset classes, so timber investment IRR is most useful in order to make similar comparisons. In fact, annual returns and "basis points" are a common unit of measure for returns as interest rates and other percentages in finance. A 1% change in an investment annual rate of return equals a change of 100 basis points (Investopedia 2022).

Input costs and timber prices

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. 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 and 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 data quality and consistency.

The 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%. We used the three capital budgeting criteria of IRR, NPV per ha, and LEV per ha for this summary of each global timber investment in 2020, which provide estimates of returns for individual stands. As noted above, we used IRR as the key metric for discussing these benchmarking comparisons here, similar to almost all other investment organizations and public discussions. NPV and LEV are included in the inputs and results summarized in Tables 1 and 2 for reference—if readers prefer to know value per ha instead of an IRR for comparison, or to estimate total costs and returns for tree planting and forest management programs. For larger investments or public programs, one could scale up the stand investments by the appropriate number of hectares, or include temporal analyses such as harvest scheduling of such investments and programs over the extended time periods required to plant, manage, maintain, and harvest forests.

The base investment returns did not include the price of land, which varies substantially in the amount per country and within most countries, and indeed one cannot buy land outright in the relevant Asian countries of China, Vietnam, and Lao PDR. This also is similar in other countries in Asia and Africa at least, but sufficiently long term land leases can be obtained in many countries from the national government, from local communities, or via industrial timber outgrower programs. Our analyses do not include reforestation subsidy payments either. However, we did collect land purchase prices or annual rental prices for most countries. Many of the investments by private landowners and by public programs occur where owners already have land tenure, and land may not be a relevant cost and need not be included, similar to our analyses. For new land purchases and investments, the land prices could be entered into the analyses and then used to calculate overall forest, timber, and ecosystem value payments if desired.

This research summarizes the most recent efforts for our selected countries, which collected data and estimated timber investment returns in 2020. These management cost, timber stumpage price, and return data may be extended somewhat to provide approximate estimates of forest restoration costs. However, those costs, inputs, and timing are more speculative, but our data could at least provide a first order estimate of those costs. We did not include the prices for added returns from ecosystem services such as carbon, or for carbon prices alone in lieu of timber prices. Those too could be modeled with most of the same spreadsheet models and approaches described here.

INVESTMENT RESULTS

Overall, the timber investment returns for each species in each country were determined by the tree species growth rate and yields; the operational timber rotation; the timber thinning and harvest timing; the establishment and management costs; the timber product prices; and the given discount rate of 8%. For the best investment returns, or indeed for the most cost-efficient use of public funds for forest carbon reduction programs, the objective usually would be to minimize costs, maximize growth rates and value by timber product class, and optimize discounted stumpage price return values. Table 1 summarizes the input cost data for each species and country, and Table 2 summarizes the results of the capital budgeting calculations. Attachment B summarizes these data in an Excel spreadsheet for easy access and use by readers.

Table 1. Tree planting management regimes, establishment costs, and timber stumpage prices by country and species, 2020.

Country	Species	Rotation Age (yrs)	MAI m3/ha/yr	Establishment Costs ($/Ha) Site Prep	Planting	Tot Yr 0-5	Land Cost ($/Ha)	Prices per m3 ($) (at small end diameter) Biomass (~5 cm)	Pulpwood (~15 cm)	Medium (~25 cm)	Large (~30 cm+)	Veneer (~36 cm)
Argentina	Pinus taeda - Misiones	18	32	330	415	1235	2000	4.00	10.00	12.00	15.00	17.00
Argentina	Eucalyptus grandis - Average	13	25	144	227	667	2150	1.27	5.62	12.05	17.86	20.96
Brasil	Pinus taeda sawtimber	21	30	181	271	1004	6000	2.92	2.92	11.40	18.04	18.04
Brasil	Eucalyptus urophylla pulpwod, W-Cen	7	38.5	144	318	746	7000	2.80	9.00	11.50		
Chile	Pinus radiata Sawtimber - Good Site	22	30	362	261	983	6533	5.70	13.80	33.30	55.50	70.50
Chile	Pinus radiata - Pulpwood - Poor Site	16	20	412	241	823	2650	5.70	13.80	33.30	55.50	
Chile	Eucalyptus globulus pulpwood	16	25	497	345	1088	5200	9.20	27.30			
Chile	Eucalyptus nitens pulpwood	14	30	497	332	1075	5200	8.00	16.50			
China	Eucalyptus sp. - Pingxiang, Guangxi	6	20	659	1469	2787			91.00			
China	Pinus massoniana	30	6.9	562	1131	2033			75.76	89.39	104.55	
Colombia	Eucalyptus grandis	7	35	256	744	1805	1800		10.00			
Colombia	Pinus patula sawtimber	18	18	248	560	1441	1500		10.00	29.54	37.98	
Colombia	Pinus patula pulpwood	12	18	248	560	1557	1500		10.00			
Colombia	Pinus tecunumanii	16	28	297	628	1813	1500		10.00	29.54	37.98	
Ecuador	Tectona grandis	20	18	340	404	1720	2500	2.00	8.00	100.00	248.00	
Ecuador	Eucalyptus globulus (4 cutting cycles)	38	22	180	443	1423	4500	2.00	18.00	33.00		
Ecuador	P. radiata / P. patula - 80%/20%	20	18	180	310	1130	3500	1.00	8.00	32.00	45.00	
Finland	Picea abies	63	6.5	482	936	1418			21.24		68.04	
Finland	Pinus sylvestris	66	7.5	624	1111	1735			17.49		59.73	
Lao PDR	Eucalyptus sp. Industry	7	33	441	318	1119		10.59	31.84	103.00		
Lao PDR	Eucalyptus sp. Outgrower	7	15	363	288	1159		10.59	31.84	103.00		

Lao PDR	Tectona grandis, Fast Growth	18	12.4	256	257	778			88.49	132.74	176.99	
Lao PDR	Tectona grandis, Slow Growth	24	9.3	140	276	811			88.49	132.74	176.99	
Mexico	Pinus gregii	20	15	389	400	1554	1333		12.00	15.00	34.00	62.00
Mexico	Eucalyptus grandis	8	30	395	414	1279	1329		25.00			
New Zealand South	Pinus radiata	28	30	320	707	1708	4500	11.00	11.00	43.00	47.00	80.00
Paraguay	Eucalyptus grandis/urograndi clones	12	25	613	665	1311			20.36	29.33		
Poland	Quercus Sp. State Forest/Private	120	8	1049	125	1595	8200	33.29	36.72		178.84	
Poland	Pinus sylvestris State Forest/Private	100	9.3	196	599	1148	8200	12.31	25.71		53.31	
Spain	Populus	15	22	578	2057	3452		7.01		29.19		95.75
Spain	Eucalyptus globulus	12	19.8	1463	870	3629			39.70			
Spain	Eucalyptus nitens	13	30.3	1463	870	3629			30.94			
Spain	Pinus radiata	30	17	934	1039	2849			21.02	25.69	37.37	
Uruguay	Eucalyptus smitthii	10	22	420	710	1430	2500		31.00			
Uruguay	Eucalyptus dunnii	10	22	420	660	1380	2500		23.50			
Uruguay	Eucalyptus grandis pulp	10	25	366	689	1355	3500		25.00			
Uruguay	Eucalyptus grandis sawtimber - faster	16	27	400	450	1240	2200		18.00		20.00	32.00
Uruguay	Eucalyptus grandis sawtimber - slower	21	24	400	450	1240	2200				17.00	26.00
USA	Pinus taeda / South-Wide Avg Growth	25	11.3	662	630	1293	2500	3.78	11.97	19.53	28.73	
USA	Pinus taeda / Upper 1/6 South Growth	25	14.2	662	630	1293	3000	3.78	11.97	19.53	28.73	
USA	Mixed Hardwoods, Even Age, Plant	60	6.2	710	1500	2210	2000		7.56		31.50	47.88
USA	Pseudotsuga menziesii Site I	40	13.4	215	894	1646	2347		60.67	64.00	67.33	67.33
USA	Pseudotsuga menziesii Site III	45	12	215	894	1646	2347		60.67	64.00	67.33	67.33
Vietnam	Acacia Smallholder Northeast	7	13.5	84	332	1035			43.50	43.50	52.00	60.80

Vietnam	Eucalyptus urophylla Northeast	7	12.8	84	400	1106	8.50	45.50	45.50	55.00	62.80

Table 2. Tree planting investment capital budgeting returns by country and species, 2020.

Country	Species	Capital Budgeting Criteria		
		NPV	LEV	IRR
		($/Ha@8%)		(%)
Argentina	Pinus taeda - Misiones	-126	-167	7.4
Argentina	Eucalyptus grandis - Average	2100	3323	20.6
Brasil	Pinus taeda sawtimber	939	1171	11.8
Brasil	Eucalyptus urophylla pulpwod, W-Cen	37	89	8.6
Chile	Pinus radiata Sawtimber - Good Site	1808	2216	14.1
Chile	Pinus radiata - Pulpwood - Poor Site	653	922	11.5
Chile	Eucalyptus globulus pulpwood	1757	2482	14.9
Chile	Eucalyptus nitens pulpwood	828	1255	12.3
China	Eucalyptus sp. - Pingxiang, Guangxi	4055	10964	28.6
China	Pinus massoniana	-121	-134	7.7
Colombia	Eucalyptus grandis	-594	-1426	2.2
Colombia	Pinus patula sawtimber	933	1244	11.0
Colombia	Pinus patula pulpwood	-976	-1619	0.2
Colombia	Pinus tecunumanii	2380	3361	14.2
Ecuador	Tectona grandis	2027	2581	11.4
Ecuador	Eucalyptus globulus (4 cutting cycles)	1410	1490	11.7
Ecuador	P. radiata / P. patula - 80%/20%	-420	-535	6.5
Finland	Picea abies	-1281	-1291	4.4
Finland	Pinus sylvestris	-1575	-1585	4.2
Lao PDR	Eucalyptus sp. Industry	1835	4406	20.9
Lao PDR	Eucalyptus sp. Outgrower	2750	6603	32.2

Lao PDR	Tectona grandis, Fast Growth	6028	8040	21.2
Lao PDR	Tectona grandis, Slow Growth	3691	4383	16.2
Mexico	Pinus gregii	1546	1968	11.8
Mexico	Eucalyptus grandis	1986	4321	21.0
New Zealand South	Pinus radiata	2858	3233	11.2
Paraguay	Eucalyptus grandis/urograndi clones	2535	6754	22
Poland	Quercus Sp. State Forest	-3316	-3316	2.7
Poland	Quercus Sp. Private (lower management costs)	-2080	-2081	3.7
Poland	Pinus sylvestris State Forest	-2816	-2817	1.2
Poland	Pinus sylvestris Private	-1591	-1592	2.9
Spain	Populus	1376	2010	9.9
Spain	Eucalyptus globulus	1585	1891	10.6
Spain	Eucalyptus nitens	999	1580	10.3
Spain	Pinus radiata	-581	-645	6.0
Uruguay	Eucalyptus smitthii	1318	2456	14.6
Uruguay	Eucalyptus dunnii	604	1125	11.6
Uruguay	Eucalyptus grandis pulp	1125	2086	14.1
Uruguay	Eucalyptus grandis sawtimber - faster	1278	1805	12.4
Uruguay	Eucalyptus grandis sawtimber - slower	-988	-1232	4.3
USA	Pinus taeda / South-Wide Avg Growth	-811	-950	4.8
USA	Pinus taeda / Upper 1/6 South Growth	-393	-460	6.6
USA	Mixed Hardwoods, Even Age, Plant	-2438	-2462	2.9
USA	Pseudotsuga menziesii Site I	-876	-919	6.7
USA	Pseudotsuga menziesii Site III	-1396	-1441	5.8
Vietnam	Acacia Smallholder Northeast	1578	3789	26.0
Vietnam	Eucalyptus urophylla Northeast	1209	2904	21.9

Input costs, timber, and land prices

Stand establishment and management costs, which are spent mostly in the first five years, and timber prices are the other factors determining overall investment returns. It is not possible to generalize about comparative establishment costs by region or species. The average establishment cost was $1,534 per ha; the median cost was $1,355 per ha. South America and Asia had some less expensive establishment costs, but not exclusively. The northern hemisphere establishment costs were slightly more expensive, but not always.

Timber prices were more varied by region. The average medium size sawtimber stumpage price was $53 per m^3 (with a small end log diameter between 26 and 30 cm), and the median was $46 per m^3. Asian countries had the highest sawtimber prices, along with Chile and the U.S. Pacific Northwest and New Zealand, which all export to China, which has high demand. The average unweighted global pulpwood stumpage price was $27 per m^3; the median was $25 per m^3. China had the highest pulpwood prices by far at $91 per m^3 for *Eucalyptus* and $76 per m^3 for *Pinus*. This large demand also raised prices in Vietnam and Laos, which export extensively to China. Poland and Spain also had high pulpwood prices. Pulpwood prices were the least in the U.S. South and in South America, which is a bit surprising given the many large pulp mills in those regions.

We did not use land prices in our investment calculations this year, but we collected the data when available for each country. The results were quite variable. Forest land prices averaged $3,400 per ha; had a median price of $2,500 per ha; and there were some land prices of more $5,000 per ha. Surprisingly, the United States had some of the lowest land prices for forest land; South America and Poland had some of the highest prices. This is probably because the land in South America is often of a higher quality; it has a better year-round tree growing climate; and potential alternative grazing or crop land uses have higher prices. Land also is a store of value and a hedge against inflation in less stable economies typical in several countries in Latin America. In Poland, the price of the forestland is greater than the cash flow analysis might justify. High land prices there are likely due to a small number of available properties for sale; an increasing number of people who want to live in forested areas; and available forest subsidies (e.g., European agricultural fund for rural development). In addition, the timber market is controlled by State Forests having a right of first refusal, and prices are set by forest owners based on average prices of arable crop land. The forest land in the southeastern U.S. often occurs on less fertile formerly cleared crop land with shallow soils, and is not as profitable for agricultural crops.

Timber investment returns

As shown in Table 2, one can observe that the highest stand level IRRs, not including land prices, were for fast growing *Eucalyptus sp*.—in Lao PDR (21%-32%), in China (29%), in Vietnam (22%), and Argentina, Paraguay, and Mexico (21%). Various *Eucalyptus* species also had high rates of return ranging from 16% down to 10% in Chile, Uruguay, Colombia, Ecuador, and Spain. *Acacia sp.* had high IRRs in Vietnam of 26%; Teak (*Tectona grandis*) had high rates of return, with IRRs of 16% to 21% in Laos and 11% in Ecuador. The softwood species in Colombia (*Pinus tecunumanii*, 14%; *P. patula*, 11%), Chile (*P. radiata*, 14%), Brazil (*P. taeda*, 12%), Mexico (*P. gregii*, 12%), and New Zealand *(P. radiata*, 11%) all had pine IRRs that exceeded 10% *Populus sp.* in Spain had an IRR of 10%.

Softwood and hardwood species in temperate forests in the Northern hemisphere, as well as a few *Eucalyptus* species with lower growth rates or lower prices in the southern hemisphere, generally had lower IRRs, including *Eucalyptus* pulpwood in Brazil (9%) and Colombia (2%). Softwood species returns were usually less (*P. massoniana* of 8% in China, *P. taeda* in 7% in Argentina, *Pseudotsuga menziesii* in the western USA and *P. taeda* in the U.S. South of 7%, and *P. radiata* (6.5%) in Ecuador). Other northern countries with slow growth and long rotations had IRRs of 5% or less, including poor site *P. taeda* in the U.S. South (5%), *Picea abies* (4.4%) in Finland; *P. sylvestris* in Finland (4.2%) and Poland (1.2%-2.9%); and mixed hardwoods (*Quercus sp*.) in Poland and the U.S. South (2.7% -3.7%).

Examining returns by timber growth rates showed that the lowest MAIs of less than 10 m^3/ha/year (yr) 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. tecunumanaii* (Colombia) had intermediate growth rates between 18 and 35 m^3/ha/yr, and intermediate returns, except for Argentina, which had poor timber prices. *Eucalyptus* usually had fast growth rates of 20-30 m^3/ha/yr, leading mostly to its higher IRRs, except for pulpwood in Brazil, which had the highest growth rate of all species, but high costs and low prices. *Eucalyptus, Tectona,* A*cacia* roundwood in Asia had the highest stumpage prices in the world by far, based on the high demand in China and India for Tectona at least.

From a silviculture perspective, is interesting to observe that growth rates, rotation ages, and native (autochthonous) versus exotic species had substantial effects on timber investment returns. In general, faster growth rates and shorter rotations did lead to greater returns, except when stumpage prices were exceptionally low. Pulpwood management regimes usually had lower returns than integrated pulpwood and sawtimber regimes. There were no native species with rotations of less than 18 years; these longer rotations usually generated lower IRRs.

DISCUSSION

This periodic research effort has provided estimates of timber investment returns at a stand level in many countries since 2005, based on estimates led by experts in each country or region. We obtain input data on forest management systems, timber growth, costs, and prices from practitioners, forest consultants, different scales of forest companies, or government reports. Returns are estimated for representative forest stands in each country. Countries, regions, and species that have the most planted area and have the most active timber markets, (i.e., the U.S. South and Northwest, Brazil, Chile, New Zealand, Argentina, Uruguay, Finland, and Poland) have returns based on the deepest data sets and most operational forest plantation data. Other countries with smaller or emerging markets, at least for individual species, may have good growth and cost data, but less published or broad-based market prices (i.e., Spain, Mexico, Ecuador, Colombia, or Vietnam).

Investment returns for the remaining countries in our data set are based on either experimental research trials, limited private timber markets, or newly developing species plantings and areas, so are less robust (i.e., China, Paraguay, Lao PDR). They may be more optimistic because they are based on trials or early returns with small supplies, and prices have not been compressed by large fiber inventories and broader competition among many timber producers compared to a small number or wood fiber consumers.

Overall, these data and methods provide accurate estimates of operations or prospective forest investment returns. 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 here 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 also can 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 as deemed appropriate for their situation.

Preferred capital budgeting criteria

We presented the capital budgeting results for IRR, NPV, and LEV for all the country and species combinations examined, as shown in Table 2. Our discussion of comparative results focused on IRR, which aligns with the annual rates of return used by investors and investment organizations. As noted before, finance and forest economic theory, however, recommend using NPV and LEV for selecting the highest NPV/LEV for exclusive investment options. This is a discrepancy between almost universal practice—which relies on easily understood rate of return and basis points metrics common for all asset classes—and theory—which assumes that discount rates are known and all alternatives can be ranked precisely.

We followed the IRR or annual rate of return convention commonly employed by investors in the discussion here since it is easiest to understand differences even among the 47 forest management regimes, as well as among different asset classes. We also present NPV and LEV in Table 2 for reference. Overall these relative IRRs and LEVs are highly correlated on average, with a Pearson correlation coefficient of r=0.9185. So the rankings may vary slightly between IRR and LEV, but they are quite similar. And of course, by definition, all the investments with a positive LEV have an IRR greater than 8%, and vice versa. Last, the rankings made here are for benchmarking and informing decision making, not an absolute final decision, so intuitive ease of understanding is more important than dogmatically following theory.

In addition to the lack of comparability to other investment classes, LEV depends substantially on the discount rate used. We have used 8% real discount rate for all analyses for almost two decades, which is a judgment-based composite of lower developed and higher developing country rates. Lower discount rates might change the timber investment rankings somewhat as well. Having unique discount rates for each country and species would lead to even more variable results. All of these approaches, however, would be even less consistent and informative estimates of timber investment returns for benchmarking purposes or for comparison with other assets. So overall, our approach of comparing and discussing IRRs will be more practical and useful for investors to help identify most promising financial returns. They can perform more detailed analyses on their own subsequently, and also consider many other country markets, risk, land area, politics, and institutions that help determine an investment’s merits.

Regional timberland comparisons

Northern Hemisphere and Oceania

In general, in Northern Europe and the United States, mostly native species of pine or hardwood trees are planted. This includes 27 million ha of planted forests in the U.S., and 86 million ha in Europe (Korhonen et al. 2020). The U.S. South has the largest number of pulp and paper mills in the world, as well as many expanding sawmills, and the U.S. West is a leading global sawtimber and roundwood producer and exporter. Scandinavia is the largest pulp and paper producer in Europe, with a substantial export in the EU and elsewhere.

Plantations of native forests in these regions have slower growth rates and lower timber stumpage prices, albeit excellent forest technology and a relatively active, plentiful, and open land markets. The U.S. South has large wood fiber inventories, relatively low housing starts, increased plantation productivity, and continual incremental improvement in mill fiber recoveries. These large supply increases, and increasing manufacturing efficiency, have reduced stumpage prices, and reduced returns in the U.S. The U.S. and EU have lower but fairly predictable returns, and the least amount of investment risk.

There are 4.4 million ha of exotic pines and native eucalyptus planted species in New Zealand and Australia (Korhonen et al. 2020). There are 1.6 million ha of radiata pine forest in New Zealand and around 1 million ha in Australia. In New Zealand, this species grows much faster than the native hardwoods or softwoods. The pine plantations are intensively managed and much of the current production is exported to China as logs or chip. New Zealand has a small amount of Eucalyptus plantations (around 21,000 ha) and Australia around 1.2 million ha. Both countries have intermediate forest investment returns. These regions complement their medium level of financial returns with among the least financial, political, and export risks in the world.

South America

Commercial forest plantations in South America rely mostly on exotic species and have the fastest growth rates in the world. South America has excellent technology and very good timber prices until recently, which have led it to have the greatest increase in industrial timber plantations in the world in the last five decades or more, reaching 15 million ha of mostly industrial timber plantations currently (Korhonen et al. 2020). In addition, it has had the greatest expansion of industrial pulp mill establishment and output during that period, including several of the largest pulp mills in the world. Technology and high manufacturing capacity have led to stable and relatively high returns in areas with good timber markets due to well-established forest products markets.

Countries in the Southern Cone of South America have had the most rapid increases in industrial planted forest area and productivity, based on extensive research and genetic improvement, and excellent forest management techniques. Brazil, Chile, Argentina, and Uruguay have had the largest planted forest areas and substantial expansion for pulp and paper and wood fiber boards and lumber production. In Brazil, one major new pulp and paper mill has been opened in each of the several years. A total of R$ 57.2 billion in forestry investments by 2024 have been announced or are already underway since 2020 (IBÁ 2021).

South America generally also has a substantial amount of land that could be used for additional tree planting programs, and these expansions have driven their large increase in planted area and industrial output, with major investments by domestic and foreign capital. However, successful expansion of tree planting into new areas usually requires permits from the government, social acceptance, time, and caution.

New greenfield independent forest plantings are also betting that future manufacturing expansion will follow and locate near the planted forests, which has been less certain. Tree planting programs exclusively for carbon storage may avoid this problem, but mixed-use planted forests or forest restoration efforts still require timber markets for private landowner financial success. South America also has more national political restrictions on foreign investments, and greater issues with land tenure, land titles, social equity, indigenous rights, environmental restrictions, and major shifts in politics and the business environment, with the notable exception of Uruguay, which make at least foreign direct investments in South America more difficult or risky than in the U.S. or EU.

Asia

Driven by the large number of people, rapidly expanding economy, and high wood products demand in China, Asia has the highest wood fiber demand in the world. China has about 135 million ha of planted forests (Korhonen et al. 2020), although a very small portion of that is industrial wood fiber plantations. Asian countries have significant factors that limit supply, such as less well-developed planted forest technology; less advanced timber harvesting and trucking equipment and systems; poor rural roads and infrastructure; and small planted forest areas. Conversely, it has the highest population and demand in the world. These supply and demand interactions lead to the highest timber stumpage prices in the world.

Forest growth rates in Asia are usually moderate—less than South America—but more than Europe or the United States. China reports that it has planted more trees than any other region in the world in the last 20 years—more than 50 million ha—but most of these have focused on conservation and environmental purposes, not wood production (Zhang et al. 2022). However, two timber programs have been implemented—the Fast-growing and High-yielding Timber Plantation Base Construction Program in 2002 and the National Timber Strategic Storage and Production Bases Construction Program in 2012. The goal of fostering carbon neutrality, such as possibly promoting wood structure buildings, could lead to greater demand for wood in China (Zhang et al. 2019). However, China also has many small land rights owners, who may have tenure rights to areas as small as one ha or less, which make administration costs high for large-scale operations.

Vietnam has more than 4 million ha of planted *Acacia* and *Eucalyptus* species (Korhonen et al. 2020), and exports most of its production to China and Japan. Lao PDR has large area of land that has potential for reforestation, but government policies and approval for these efforts have developed slowly. Each of these countries retains national or local government control over forest land, so new commercial forest plantings must assemble government leases or small fixed-term land use rights of 25 to 50 years to develop new forest plantations. Or forest products companies may rely on many small farmers with land tenure rights to grow wood for it (often termed outgrowers) to provide wood fiber (Vincent et al. 2021). Overall, Asia has the highest stand-level timber investment returns in the world on paper, but finding large amounts of land to develop large scale operational wood production forests would be extremely difficult, especially for foreign direct investment.

Africa

Africa is of course the next frontier for planted forest investments, has lots of land, albeit with tenure, political, and precipitation challenges at the very least. In West Africa, Ghana and Sierra Leone have had some private investors who plant *Gmelina sp., Eucalyptus sp.,* and *Acacia sp.* Mozambique has had private, government, church investors who have trials of *Eucalyptus*, *P. maximinoii*, and *P. tecunumanii*. South Africa has about 1.8 million ha of intensively managed exotic *Pinus* and *Eucalyptus* forests, and Ethiopia reports more than 1 million ha of plantations (Korhonen et al. 2020). Kenya and Tanzania also have some commercial government and private forest plantations. Expansion of these nascent planted forests will require advances in technology, forest products mills and demand, and resolution of land tenure issues, among other factors.

Short run comparison of returns

We can compare IRRs calculated in 2020 as reported in this study to the IRRs from 2017 (Cubbage et al. 2020) for 12 country/31 species combinations that were collected in both years. Overall, the changes in investment returns during the three year period were relatively small, with 23 of the 31 species having net changes of 1.2 percentage points or less in either direction. Twelve country/species combinations had investment return declines, of up to 3 percentage points (3%), and 19 had increases. The IRR declined more than 2% in Brazil for *Pinus taeda* sawtimber, *Eucalyptus* sp. and in Pingxiang, Guangxi in China. More than 1% declines in IRR were found for *Pinus sylvestris* forests for state and private in Poland, Average *Pinus taeda* growth in the U.S. South, and *Pseudotsuga menziesii* high Site I in the US. Most of the other countries and species had small decreases in IRR, within the limits of accuracy for our data reporting and collection. However, in the U.S., the timberland returns measured by IRR declined systematically across all the different species.

Table 3. Comparison of timber investment internal rates of return (IRRs) in 2020 and 2017 for selected species.

Country	Species and management regime	Difference 2020-2017	IRR, 2020 (Co-Authors)	IRR, 2017 (Cubbage et al. 2020)
		(%)	(%)	(%)
Argentina	Pinus taeda – Misiones	0.9	7.4	6.5
Argentina	Eucalyptus grandis – Average	13.1	20.6	7.5
Brasil	Pinus taeda – sawtimber	-2.5	11.8	14.3
Brasil	Eucalyptus urophylla pulpwood – West Central	0.5	8.6	8.1
Chile	Pinus radiata Sawtimber - Good Site	1.1	14.1	13
Chile	Pinus radiata - Pulpwood - Poor Site	0.3	11.5	11.2
Chile	Eucalyptus globulus - pulpwood	0.6	14.9	14.3
Chile	Eucalyptus nitens - pulpwood	0.1	12.3	12.2
China	Eucalyptus sp. - Pingxiang, Guangxi	-2.9	28.6	31.5
China	Pinus massoniana	-0.2	7.7	7.9
Finland	Picea abies	0.1	4.4	4.3
Finland	Pinus sylvestris	-0.1	4.2	4.3
Lao PDR	Eucalyptus sp. - Industry	-0.8	20.9	21.7

Lao PDR	Eucalyptus sp. - Outgrower	20.4	32.2	11.8
Lao PDR	Tectona grandis - Slow Growth	3.2	16.2	13
Mexico	Pinus gregii	0.5	11.8	11.3
Mexico	Eucalyptus grandis	0.9	21.0	20.1
Poland	Quercus Sp. - State Forest	0.3	2.7	2.4
Poland	Pinus sylvestris - State Forest	-1.2	1.2	2.4
Poland	Pinus sylvestris - Private	-1.6	2.9	4.5
Spain	Populus	0.0	9.9	9.9
Spain	Eucalyptus globulus	1.0	10.6	9.6
Uruguay	Eucalyptus grandis - pulp	3.7	14.1	10.4
Uruguay	Eucalyptus grandis sawtimber – fast growth	0.6	12.4	11.8
USA	Pinus taeda - South-Wide Avg Growth	-1.1	4.8	5.9
USA	Pinus taeda - Upper 1/6 South Growth	-0.5	6.6	7.1
USA	Mixed Hardwoods - Even Age, Plant	-0.3	2.9	3.2
USA	Pseudotsuga menziesii - Site I	-1.2	6.7	7.9
USA	Pseudotsuga menziesii - Site III	-0.1	5.8	5.9
Vietnam	Acacia Smallholder - Northeast	3.3	26.0	22.7
Vietnam	Eucalyptus urophylla - Northeast	1.2	21.9	23.1

The largest increases of 13.1 percentage points in IRR were found for *E. grandis* in Argentina and 20.4% for *Eucalyptus sp*. for outgrowers in Lao PDR. Furthermore, IRR for *Tectona grandis,* Slow Growth in Lao PDR increased by 3.2%; 3.7 % for *Eucalyptus grandis* pulp in Uruguay; and 3.3 % for *Acacia* Smallholder Northeast in Vietnam. Increases of more than 1% were found for *P. radiata* Sawtimber - Good Site in Chile and *E. urophylla* Northeast, Vietnam.

Our previous research indicates that timber investment returns in most countries increased from 2005 to 2008; were relatively stable from 2008 to 2011; decreased slightly in 2014; and dropped most markedly in 2017. This trend is similar to the trend in timber prices during this period, which peaked in the U.S. South in 2008 at the time of the major recession, and dropped significantly after that. Other countries in the world were less affected by the U.S. recession and housing crash, but still slowly began to experience slower declines in timber prices until 2017 (Cubbage et al. 2020).

Research applications

Private sector timberland investments

As noted, one can use these timberland investment research results in the private sector for scoping possible forest investments by region and country and species. They also can be used to compare forest investments—with or without carbon sequestration and other ecosystem services—with other investment asset classes. Chudy and Cubbage (2020) summarized the timber investment returns research from 11 secondary sources like our benchmarking series, which included 29 countries, and about 70 country/species/management intensity scenarios. The IRRs and results complemented our findings regarding regional average returns, with Asia usually having the greatest IRRs of up to or more 20%; South America falling at the next level between 10% and 20%; Oceania and Spain next at about 8% to 10%; and Northern Europe and the U.S. having the lowest IRRs of about 4% to 8%.

Chudy et al. (2022) examined the performance of private equity timberland funds managed by Timberland Investment Management Organizations (TIMOs) in the United States between 1985 and 2018. The reported results represented interim IRRs, and it was found that annual investment returns achieved by TIMOs (4% to 6%) were close to those of U.S. bond markets (3.4% and 7.6% for 3-Month U.S. Treasury bill and U.S. Treasury 10-year bond, respectively) and much less than U.S. BAA Corporate Bonds (9.7%) and U.S. stock markets (12.6%).

Beljan et al. (2022) examined 48 publicly traded forestry companies in the world that had some type of forest ownership or leasing coupled with forest products manufacturing in order to assess forest sector investment returns. These comparisons examined financial reports for companies from the forestry sector versus other sectors. They concluded that: “Taking the last 10-year comparison of the world’s most common capital market benchmarks, the highest return was achieved by the U.S. S&P 500 (13.8% on average) followed by forestry companies (9.1%), U.S. Treasury bonds (4.4%), and gold (3.0%).”

One could also compare our timberland investment IRRs with current annual rates of returns for other sectors. Recent Vanguard (2022) performance data[3] provide a useful comparison (Table 4). Without land prices, our 2020 average and median global timberland investment was about 11% IRR. Including the cost of land would reduce the returns about 4 percentage points (400 basis points) in the U.S. and 6 percentage points in Brazil (Cubbage et al. 2020). So the 2020 net average timber with land IRR of 3% to 6% in the

[3] Vanguard (2022) performance data: https://personal.vanguard.com/us/funds/tools/benchmarkreturns

U.S., or up to 10% in Brazil, would be greater than bonds and some index funds over the last five years; less than stocks for the last five year average; and greater than most stock indexes in the last year. This comparative ranking is similar to the aggregate findings from Chudy et al. (2022).

Table 4. Selected comparative investment returns, 2022.

	Annual return to 30 April 2022 (includes inflation)	
Selected index benchmark	One year (%)	Five years (%)
U.S. S&P 500	0.2	13.7
U.S. Russell 3000	-3.1	13.0
U.S. S&P Midcap 400	-7.0	9.3
S&P Smallcap 600	-8.5	8.9
U.S. Government Money Market	0.03	0.7
Spliced Total World Stock	-5.8	9.6
U.S. S&P except U.S. Global Property	-8.7	2.4
Spliced Energy Index	22.4	-0.4

Source: Vanguard (2022).

In order to examine the financial risks of timber investments, Chudy et al. (2020) used our same methods to examine the main factors that influence internal rates of returns (IRRs) in several global timber plantation investment opportunities, excluding the price of land. Species and regions included loblolly pine on the U.S. Atlantic coastal plain; Douglas-fir plantations in the western U.S.; loblolly pine and eucalyptus plantations in Brazil; radiata pine and eucalyptus plantations in Chile; and pine and oak stands in Poland. Biological growth and timber prices were the most influential variables that impacted the IRRs across global timberland investments. In addition, some country-specific factors, such as planting costs (Chile) and management costs (Poland and the U.S.), were identified as crucial when considering timberland investments in these countries. Investments in South America's pine plantations are characterized by the same level of returns as eucalyptus opportunities, but with lower risk. The same was found for Douglas-fir investments in the Pacific Northwest compared to loblolly pine in the U.S. South.

These comparisons of various annual investment returns indicate that timberland is a viable asset class. Its downside risk is small, and negative returns are not common. It is particularly useful as part of portfolio, and has considerable upside for institutions and small owners. Furthermore, timber and forest investments inherently bring newly emerging environmental, social, and governance (ESG) benefits to a portfolio of investments, which are widely promoted and sought by most large firms and investment funds throughout the world (Klinger et al. 2022).

Forest investments provide diverse ecosystem values such as carbon offset contributions, water filtration, cleaner air, and often positive social impacts, when properly managed (Ovando et al. 2019, Nocentini et al. 2022). For example, Yao et al. (2021) applied the spatial tool called Forest Investment Framework for valuing the multiple benefits provided by the existing production forest estate (1.75 million ha) in New Zealand. They found that although timber was the primary reason for establishing the production forests, timber only accounted for approximately 20% of the ecosystem values while the nonmarket ecosystem services such as carbon sequestration, avoided erosion, and avoided nitrogen leaching accounted for the rest of the value.

Local to international tree planting

As noted, there have been many national and international tree planting programs proposed in the last decade. Foremost among these is the One Trillion Trees (1TT) proposal made in 2020 at the annual World Economic Forum in Davos, Switzerland[4]. Others include the New York Declaration on Forests[5], which was first endorsed at the United Nations climate summit in 2014; and the Bonn Challenge[6], which is a platform to achieve multiple restoration targets under one initiative. In addition, The African Forest Landscape Restoration Initiative[7] (AFR100) aims to restore 100 million ha by 2030; the Initiative 20x20[8] planned to bring more than 20 million ha of degraded land in Latin America and the Caribbean into restoration by 2020; and the Asia-Pacific Economic Cooperation (APEC[9]), which set a goal for 2020 to increase forest cover by 20 million ha, which is almost met by today.

Also, the World Wide Fund for Nature's Living Forests Report[10] projects that around 250 million ha of new planted forests would be established globally between 2010 and 2050 under a scenario involving expanded wood use in the bioenergy sector. Carbon emission reduction or offset programs, such as the

[4] One Trillion Trees: https://www.1t.org/
[5] New York Declaration on Forests: https://forestdeclaration.org/
[6] Bonn Challenge: http://www.bonnchallenge.org/
[7] The African Forest Landscape Restoration Initiative: link
[8] Initiative 20x20: https://initiative20x20.org/
[9] Asia-Pacific Economic Cooperation: https://www.apec.org/
[10] World Wide Fund for Nature's Living Forests Report: link

California Air Resources Board (CARB[11]) program, and the U.N. REDD+[12] program also include significant opportunities for tree planting, forest restoration, improved forest management as part of their opportunities.

Prior research on cost estimates

Despite the long list of major tree planting efforts, there are few modern estimates of the costs of such large tree planting programs. Several authors have examined the costs of reforestation programs to sequester carbon as means to reduce climate change. An early effort by Moulton and Richards (1990) examined costs of sequestering carbon through tree planting and forest management in the United States. They found that reductions of 20% of U.S net emissions would involve 138 million acres (55.8 million ha) of planted forests, of a cost of $4.5 billion per year. This would compute to be $80 per ha per year.

Paul et al. (2016) examined 1,491 tree planting projects in Australia of up to 15 years in age. They found that with proper spacing and species selection, tree plantings in Australia would sequester carbon, increase biodiversity, and minimize the loss of agricultural land. In an extensive field trial in Southeast Brazil, de Morais et al. (2020) measured growth and carbon yield for 15 forest species. All species could increase carbon on degraded forest areas, and pioneer species contributed more to carbon storage than non-pioneer species. In research on costs, Summers et al. (2015) used a spatial model to examine reforestation in Australia for environmental and carbon plantings, using seedlings, manual planted tubestock, or machine planted tubestock. Costs for planting carbon projects ranged from $1,763 to $6,396 per ha; environmental plantings cost from $1,703 to $9,097 per ha.

Wade et al. (2019) estimated the potential area for forest land expansion or improved forest management for the U.S., by using geographic information systems and biophysical and economic data, using an econometric model with more than 20 independent variables. They predicted and mapped the spatial distribution of possible new planted forests to reach about 155 million acres (63 million ha) of new plantations in the U.S. Austin et al. (2020) examined forest expansion opportunities and costs at a global level using econometric analyses of forest and agriculture land markets and potential market responses of forest expansions based on carbon storage price scenarios ranging from $5–$100/tCO2 for four abatement activities across 16 global regions. Based on these prices, their model projected "0.6–6.0 $GtCO_2$ yr−1 in global mitigation by 2055 at costs of 2–393 billion USD yr−1…Forest area increases 415–875 Mha

[11] CARB: https://ww2.arb.ca.gov/

[12] U.N. REDD+: https://www.un-redd.org/

relative to the baseline by 2055 at prices \$35–\$100/tCO_2, with intensive plantations comprising <7% of this increase."

Tree planting to store carbon could be planted on private ownerships or public lands. Public lands usually would not incur added land purchase costs. Private land may or may not require purchase or payment for the land. Regardless, substantial new funds would need to be appropriated and provided to public or private landowners. In addition, substantial administrative costs would be required to implement tree planting programs. And for private landowners, some type of incentive payments surely would be required to carry out large land use change and tree planting or restoration programs. It is also can be noted that even if the economics of planting were sorted out and programs created to make large scale tree-planting economically feasible, tree planting must be extremely carefully planned and implemented to achieve desired outcomes (Holl and Brancalion 2020).

Our Example Planting Cost Calculations

For an example of large private or public planting programs, we calculated the costs that it would take for planting various areas of trees at the approximate average establishment costs that we have collected in our research. These range from 5,000 ha as a moderate but still large operational project to 100,000 ha as a large project, to 1 million ha or more as major national or international efforts (Table 5). The mean establishment costs per ha in our data set was \$1,500 per ha, without major program overhead costs, with a standard deviation of \$700. We used the \$1,500/ha average, as well as a \$2,000/ha estimate, which might account for an assumed 33% in program overhead. This planting rate would assume that there were about 1,000 trees planted per ha, which can be the compared to the Trillion Trees goal or other metrics to calculate the area needed.

Table 5. Potential costs for tree planting projects of different scales, 2020.

Forest area planted (ha)	Total establishment cost at \$1500/ha (\$)	Total establishment cost at \$2000/ha (\$)
5,000	7,500,000	10,000,000
100,000	150,000,000	200,000,000
1,000,000	1,500,000,000	2,000,000,000
10,000,000	15,000,000,000	20,000,000,000
1,000,000,000	1,500,000,000,000	2,000,000,000,000

These initial calculations demonstrate the magnitude of the costs that local to global tree planting programs might incur, not including the price of the land. A modest size timberland planting program of 5,000 ha could cost $7.5 to $10 million. As another industrial example, a major pulp mill might require 3 million tons of wood per year, or about 2.5 million m^3. At an excellent growth rate of 25 m^3 per ha per year, a ten-year rotation would yield a final harvest of 250 m^3 per ha; and the area needed to furnish the pulp mill would be 100,000 ha; and the plantation establishment costs would be $150 million to $200 million. Some extra land area would be needed for roads, infrastructure, operational losses or shortfalls, or insurance for operational losses. And land purchase costs might be required as well for vertically integrated forest products firms or for greenfield timber investors who might supply a mill, but perhaps not for small famers or outgrowers who already have available land.

A national or international tree planting project of 1,000,000 ha of new forests would cost $1.5 to $2.0 billion to establish the planted forests at a minimum. The much larger scale of planting the hypothetical trillion trees (about 1 billion ha, or a 25% increase in the world's forest area), would cost $1.5 to $2.0 trillion.

The average, marginal, and total costs would of course increase substantially as less fertile, more remote, scarcer, or more productive and expensive land areas were sought for suitable tree planting and growth. These initial calculations are indeed only approximate, but indicate the level of costs that would be the base level for such major tree planting programs. If the land were needed to be purchased as well—at costs ranging from $2,000 to $6,000 per ha for forest land, or more for current agricultural land—total costs could be double to quadruple the cost of tree stand establishment alone.

Comparisons to prior research

Such calculations are not academic. In the USA, 1TT was endorsed by President Trump in his 2020 State of the Union speech and in an Executive Order that established the 1TT Interagency Council (Trump 2020). Various USA goals are being discussed, ranging from 15 to 60 billion seedlings (e.g., 15 to 60 million ha at 1,000 trees per ha). In comparison, from 2012 to 2018, the annual U.S. tree seedling production averaged 1.236 billion per year. The annual tree planting area averaged 2.35 million acres, or 1 million ha. Certainly, major new policies and investments will be needed to achieve such ambitious new global or national tree planting or forest restoration goals (Guldin 2020).

For comparison with other carbon offset literature, recall that Summers et al. (2015) estimated that tree planting for carbon programs in Australia cost from $1,763 to up to $6,396 per ha. This would amount to $1.7 trillion to $6.4 trillion to plant the aspirational trillion trees/billion ha, without land costs. In addition, planting costs for environmental plantings cost somewhat more. There is not available literature on costs for restoration of natural forests or degraded stands, but their rough stand conditions and scattered stocking would suggest that their restoration costs would be greater than planting of monocultures on site prepared and planted land, and the average growth rates would be less than evenly stocked forest plantations. On the other hand, passive or assisted natural regeneration does cost less than active planting, but active replanting is apt to increase the present value for the greater wood fiber benefits it produces (Vincent et al. 2021).

Austin et al. (2020) approached the question of carbon storage with payment incentives from $5 to $100 per tCO_2, and estimated program costs using a global timber model projections until 2055 with forest area increases ranging from 415 to 875 million ha. They found an optimal allocation of outcomes for carbon mitigation with avoided tropical deforestation (30% to 54% of the total); intensive plantations with less than 7%, and the balance being rotation and forest management changes in temperate and boreal forests (Austin et al. 2020). One could derive their projected costs per ha or per program for this combination of activities, which would range from the low of payment costs of $4.82 per ha per year to the high of $449 per ha per year. Cumulatively then for 35 years and the preceding area increases, these costs would range from $70 billion ($169 per ha) to $13.8 trillion ($15,720 per ha). This very broad span of costs for a mix of land conversion reductions, forest management changes, and sparse tree plantation areas range from about one-tenth to ten times our planted forest establishment costs per ha, and one-tenth to twice as much as that of Summers et al. (2015) lower and higher planting costs per ha. The Austin et al. (2020) economic modelling would include lower cost initial land retention in the tropics and range up to more expensive forest planting, and does include land rent costs, so this broader range could reasonably bracket our cost levels with land purchase costs.

CONCLUSIONS

This periodic timber investment costs and returns series provides 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 relatively unique information on forest establishment costs, timber prices, and investment returns. The data help compare timber investment returns among countries, and assess the relative merits of planted forest timber growth, establishment costs, timber prices, 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.

One must also blend our stand level returns with institutional, policy, macroeconomic, risk, and other factors to consider the aggregate merits of any individual investment in a species or country. These data can complement other data about land availability, timber supply and demand, exports and imports, country laws and regulations, country politics, stability and risk, and more in making forest investment or forest carbon storage decisions. They also can be used to compare forest planting with other public programs such as forest restoration, improved forest management, or forest retention as means to gain the benefits of forests, either for commodity production, carbon storage, biodiversity, or other possible forest goods and nonmarket ecosystem services.

Our timber investment returns research can be used for comparison of forest returns with other asset classes. This review of other literature indicates that forest investment returns are moderate, averaging somewhat more than government bonds, but less than long-run stock investments (Chudy et al. 2022, Beljan et al. 2022). Our limited comparison with other tree planting cost estimates (Summers et al. 2015) or econometric global timber modelling (Austin et al. 2020) indicates that there is a huge span of estimates for the costs of tree planting establishment cost and carbon mitigation program costs. Accordingly, this subject of carbon mitigation costs certainly bears further examination.

Our research is limited to focus on the financial aspects of tree planting. Important components of social and environmental complexity related to the topic are critiqued well by Holl and Brancalion (2020). There are host of factors other than deterministic input costs, growth and yield, and timber prices that influence tree planting programs, social acceptance, success, and investment returns. Possible variability in the inputs and outputs that we used here is of course important (e.g., Chudy et al. 2020).

A wide variety of research efforts could build from the methods and results we report on here, such as Monte Carlo and risk simulation of input costs and timber prices; applications to other growth, productivity, or management intensities; calculation of different discount rates for different countries and species; effects of different global timber portfolios; or effects of timber as one component of a portfolio with other assets. These extensions were beyond our scope and time, but of course have merit in the future if possible. Indeed our research methods, data, and results provide a foundation for these type of analyses by ourselves or other users who are interested in making or analyzing individual timber investments or developing public programs such as carbon storage. That is indeed the point of this research.

Risks from human, biotic, and abiotic threats—ranging from conversion to other land uses, fires, or insects and diseases—are important factors affecting all forests (e.g., Siry et al. 2018). Monoculture planted forests may be more susceptible to damage from fires, insects, and diseases than native forests, which are considered to have more resilient and diverse species and age structures. Planted forests, especially of exotic species, may have positive or adverse environmental and ecosystem impacts (e.g., Bauhus et al. 2010). Social and political criticism, and perceived or actual "land-grabbing" from or other exploitation of poor local or indigenous populations are equally important issues with forest plantation programs (e.g., Kröger 2014). We recognize the importance of these issues, but cannot cover all these subjects in this production economics and financial investments research.

These comparative forest investment returns in key countries and species in the world do provide a wealth of compact commercial forest management information for planted forests. This forest management and production economics approach is well grounded with detailed inputs, biology, silviculture, operations, yields, and economics of forestry. This method provides representative and reasonable estimates of the forest investments in key countries with industrial planted forests. The data, results, and comparisons are quite interesting. The results can be used in forest finance deliberations and portfolio analyses, and form the basis for and be compared with analyses and projections made using econometric or statistical approaches. We will continue this line of research in 2023, and look forward to more feedback, other contributors from new countries, and continual applications to forest finance and economics.

ATTACHMENTS

A. Global Timber Investments, 2020 – Excel Template

B. Plantation Investment Analysis Summary for Selected Species and Countries, 2020 - Excel

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