The Value of Restoration

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A report by Terraformation and Frontier Economics

frontier economics   Terraformation

"Our partner network is currently on five continents and growing. I invite landowners to read this report and join us."

FOREWORD

By Yishan Wong, founder and CEO of Terraformation

This is the decade for climate action.

The remaining window of opportunity to avoid dramatic climate distortion is short, but we know what we need to do: slash fossil fuel emissions and draw carbon back out of the atmosphere.

At Terraformation, we believe that forests are the easiest, safest, and most cost-effective way to achieve the latter. Among all options, they are also the most immediately scalable.

Forests are powerful carbon capture tools that already absorb nearly one-third of our global emissions. In addition to protecting existing forests, we can dramatically expand this carbon sink. Many studies estimate that about 2 billion acres of degraded land are available for restoration. Solar-powered desalination technology will unlock additional afforestation opportunities in arid and dryland ecosystems.

Here, we lay out the compelling investment case for native forest restoration and explain how private and public stakeholders can get involved. While challenges of this scale often fall to governments, this is not the case for forests. Individuals and families, companies, and other organizations own swaths of land that could be restored to forest ecosystems.

Massive global reforestation represents the largest investment opportunity of our time. Unlike many other proposed carbon capture solutions, the money spent on land restoration is not simply consumed, but is rather an investment that will pay off hugely in material terms. The models in this report chart the growth of just some of those benefits – the marketable forest products – over the first decades of a restoration effort. In particular, the continued rise in carbon prices makes these projects even more attractive financial investments. Further, the conversion of undervalued, degraded land into thriving, productive ecosystems represents the largest global real estate opportunity in human history.

This report is just one of the ways we are advancing forest restoration in 2021 and beyond. Our partner network is currently on five continents and growing. I invite landowners to read this report and join us. Together, we can reverse climate change.

Yishan Wong

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EXECUTIVE SUMMARY

This report examines a well-known but undervalued opportunity: native ecosystem restoration. Restoring native ecosystems on degraded land can stabilize the climate, recharge local ecosystem services, and restore biodiversity while also generating private returns for landowners and communities.

The confluence of several recent developments, including new technology, the growth of carbon markets, and an increased global focus on restoring degraded lands, presents an opportunity for accelerating restoration this decade. This restoration would benefit landowners and surrounding rural communities, as well as the climate.

This report outlines a business case for restoring native forest ecosystems on degraded land, examining the financial costs and benefits for landowners involved in the restoration of different forest types and under various revenue scenarios.

Forests, like any ecosystem, are complex and encompass a huge diversity of life and relationships. Alongside the intrinsic value of biodiversity, trees and forests provide people with a wide array of products and services, including food, medicine, building materials, fiber, shade, recreational space, water filtration, flood risk reduction and, importantly, climate regulation through carbon sequestration.

Large areas of previously forested land are currently degraded to a level at which they no longer provide these services. The Food and Agriculture Organization estimates that 20%–25% of global land is degraded, defined as land that no longer supports a balanced ecosystem.

Although land classified as "degraded" may be less productive compared with its native ecosystem potential, local communities often continue to rely on these landscapes. Sustainable restoration efforts must take into account existing land use to avoid negative impacts on local livelihoods.

The unique characteristic of restoration is that it can create societal and monetary value. The societal values described above (e.g., biodiversity, water filtration, flood risk reduction, carbon sequestration) can be realized alongside new income for landowners and local communities. Restoration can restore lost productivity while sequestering carbon.

It is impossible to put a true value on restoration. Many studies have tried to estimate the value of the benefits that flow from restoration and have all come to a similar conclusion: it is very high. Some estimates suggest that the cost of lost ecosystem goods and services as a result of land degradation amounts to trillions of dollars per year (e.g., $6.3 trillion lost annually, as estimated by the World Resources Institute). The International Union for the Conservation of Nature (IUCN) conservatively estimated that meeting the 2030 Bonn Challenge to restore 350 million hectares of degraded land would create in excess of US$170 billion in net benefits annually.

Based on conservative estimates of the total available land for restoration, we calculate the net present value of potential new revenue streams from restoring all degraded tropical and temperate forest ecosystems to be **approximately US$1 trillion.** This is based on 80 years of cash flows, and does not include the value of restored ecosystem services.[1]

An individual landowner's potential revenue varies considerably based on the local environment and what is possible in that context. Illustrative analysis suggests that **the net present value of returns from *tropical* forest restoration could range from $5,000 to over $20,000 per hectare,** depending largely on the price of carbon credits and the number of workers required to maintain the forest and harvest its products.

A similar analysis suggests **that *temperate* forest returns can have a net present value ranging from $3,000 to $8,000 per hectare,** depending on similar assumptions.

In both cases, the point at which landowners "break even" on their investment depends on the price of carbon and of forest products or crops. At high prices, landowners can break even within the first decade; at more conservative prices (e.g., carbon prices at around US$10 per ton of CO_2), landowners can break even within about 25 to 30 years.

These private returns accompany considerable social value.

In practice, the actual returns depend on several factors, including:

1. Nature: The speed of carbon sequestration, opportunity to grow other products alongside trees, and natural availability of water and other inputs.

2. Policy: Public willingness to pay for wider forestry services, such as reduction in flood risk, advancement of carbon markets (e.g., through the Paris Agreement and the upcoming UN climate negotiations), local land ownership rights, and planning decisions.

3. Market developments: The costs of forestry products, new trade agreements, local cost of labor and certification of sustainable timber, and global markets in ecosystem services (like carbon credits).

4. Technological advances: The development and deployment of lower-cost seed banks, plant nurseries, water filtration systems, and related technologies that support land restoration.

Individual landowners and managers will need to evaluate local conditions to determine the business case for restoration in their circumstances. But growing recognition of the value of restoration is increasing the likelihood that such appraisals will show that restoration will yield positive returns to both local landowners and surrounding communities. Ensuring that mechanisms exist to provide local stakeholders with options to restore land would deliver global benefits to nature, climate, and society.

"Based on conservative estimates of total available land for restoration, we calculate the net present value of potential new revenue streams from restoring all degraded tropical and temperate forest ecosystems to be approximately US$1 trillion. This is based on 80 years of cash flows, and does not include the value of restored ecosystem services."

1. THE ECONOMIC VALUE OF RESTORATION

Forests, along with all natural ecosystems, are very complex. **The interactions among the unique elements of individual ecosystems have led to the evolution of a huge diversity of life occupying nearly every imaginable niche on Earth.** Alongside the intrinsic value of this diversity, trees and forests provide people with products and services: food, medicine, building materials, fiber, shade, recreational space, water filtration, flood risk reduction and, importantly, climate regulation through carbon sequestration.[2]

1.1 The services provided by forests

Large areas of previously forested land are degraded to a point that they no longer provide these services. The Food and Agriculture Organization estimates that 20%–25% of all land falls into this category and can be considered "barren" or degraded.[3]

Revitalizing these areas would provide the intrinsic values described above as well as important services and potential sources of revenue, such as improved agricultural production via soil restoration and agroforestry (see table on page 9).[4]

There are scientific, social, and political challenges to restoring forests at scale. In addition, public funding for restoration can often be inadequate or difficult to sustain.

This paper focuses on the business case for restoration in the absence of payments for wider public services, such as flood risk reduction or recreational services.

1. Based on estimates of total land available for restoration from Bastin, J et al. 2019, "The global tree restoration potential," Science. https://science.sciencemag.org/content/365/6448/76

2. Diaz, S et al. 2018, "Assessing nature's contribution to people," Science. https://www.researchgate.net/publication/322582117

3. See: http://www.fao.org/3/i1688e/i1688e03.pdf

4. This report focuses specifically on the possibility of restoring the land through forestry. It is widely recognized that other restoration options are available – for example, creating wild meadows and other forms of productive "scrubland" (e.g., https://hub.jncc.gov.uk/assets/39590874-8927-4c42-b02a-374712caccd6). This report is not suggesting that all marginal land be restored to forest, but that, when ecologically appropriate, it is an option that can generate a wide range of valuable services in many parts of the world using tools and techniques now available.

1.2 The value of forest restoration

Quantifying the value of potential restoration is difficult. There is a wide range of estimates, but they have one thing in common: they are large.

Some estimates suggest that ongoing land degradation represents an annual opportunity cost of trillions of US dollars. For example, research from the UN University estimated that land degradation costs US$6–10 trillion annually (about 10%–17% of global GDP).[5] Similar research by the World Resources Institute estimates an annual cost of US$6.3 trillion as a result of "soil erosion, salinization, peatland and wetland drainage, and forest degradation" over the past 50 years.[6]

On the other hand, there is near-immediate value from restoring degraded land. The International Union for the Conservation of Nature (IUCN) *conservatively* estimated that meeting the 2020 Bonn Challenge to restore 150 million hectares of degraded and deforested landscapes would sequester 47 gigatons of CO2 or equivalent emissions, helping to reduce the emissions gap between existing pledges made by countries and the objective of the Paris Agreement to limit global temperature rise to 2°C above pre-industrial levels.[7]

At the same time, this restoration would create about US$84 billion in *net financial returns annually*, assuming a conservative price of CO2 offsets. Of this, over $64 billion per year would come from the sale of sustainable wood products, $8 billion per year from the sale of non-wood agricultural or forestry products, and the balance from carbon credits. This provides new income alongside the wide range of broader climate and ecosystem services.

The subsequent extension of the Bonn Challenge to 2030 aims to restore a total of 350 million hectares and could generate annual net benefits in excess of $170 billion per year.[8]

The table to the right describes the range of benefits provided by forest ecosystems, emphasizing that the precise combination of benefits, and their magnitude, varies depending on local climatic, human, and ecosystem conditions.

5. See: https://www.sciencedaily.com/releases/2015/09/150915090404.htm
6. World Resources Institute 2017, "Roots of Prosperity," https://www.wri.org/publication/roots-of-prosperity
7. See: IUCN Policy Brief, https://www.iucn.org/downloads/policy_brief_on_forest_restoration_1.pdf
8. See: https://newclimateeconomy.report/2014/wp-content/uploads/sites/2/2014/08/NCE-Global-Report_web.pdf

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The table below describes the range of benefits provided by forest ecosystems. The table emphasizes that the precise combination of benefits, and their magnitude, varies depending on local climatic, human, and ecosystem conditions.

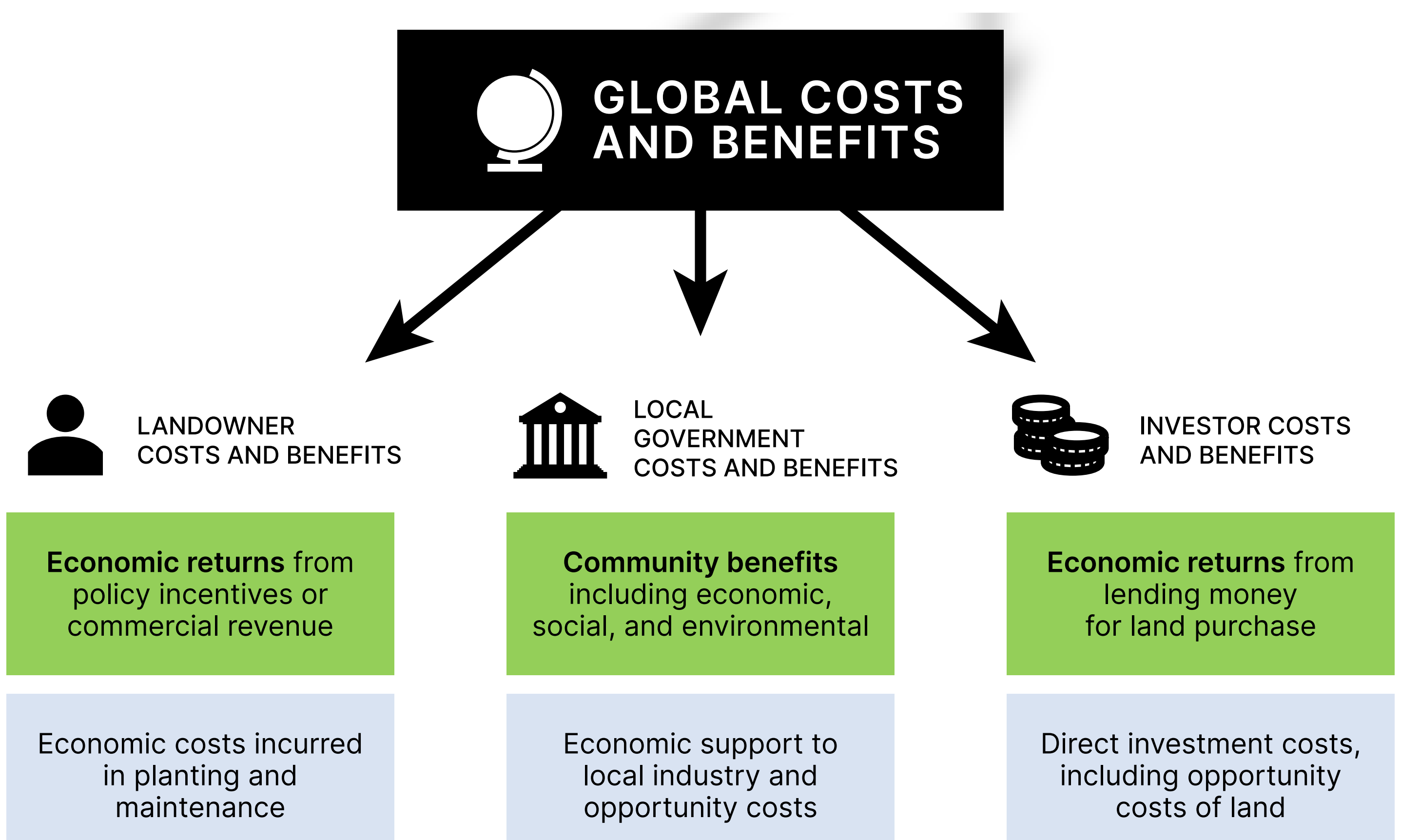
Benefit Type	Influencers
Carbon sequestration: Carbon is absorbed by new trees.	Tree type, land type, land use, and area of trees planted; time scales also relevant.
Reduction in soil erosion: Forests can stop soil and wind erosion, protect from sandstorms, etc.	Land type and area; tree type also relevant.
Flood defenses: Forests are a form of natural flood management.	Land type, area, location, natural climate, and likelihood of flooding; tree type also relevant.
Biodiversity and habitat maintenance: Forests can improve water quality and provide nutrient and water cycling, soil formation, and a habitat for pollinators.	Tree type, location, climate, and area of new forest.
Resources produced by forests: These include trees for timber and wood fuel, and agroforestry products.	Tree type, new forest area, and length of time to maturity.
Creation of forest industry: New forests generate industry (e.g., labor, equipment, production, tourism).	Size of area to be forested, natural climate area, land type, tree type, and length of time to maturity.
Research benefits: Increased biodiversity provides opportunity for research and scientific advancement.	Type, location, and size of forest.
Cultural benefits: Forests are aesthetically pleasing and can be used for education and recreation.	Type, location, and size of forest.

Forest ecosystems can produce returns for landowners, local governments, and investors, as illustrated below. But restoring forest ecosystems also incurs two broad categories of costs:

- ***Direct costs:*** Costs associated with planting and maintaining the trees and other parts of the ecosystem, including labor, irrigation, desalination, energy, and related costs.
- ***Indirect costs:*** Sometimes called "opportunity costs," which include the costs of not being able to use forested land for other purposes, like agriculture.

Like the benefits, the size of these costs varies considerably depending on the location, size, and condition of the land.

The next section seeks to quantify the benefits and costs of restoration for landowners.



1.3 Approaching restoration

The Ten Golden Rules for reforestation outline core principles for sustainable landscape restoration (see box below). Central to these rules is that projects should be anchored by local stakeholders. Projects must be done in very close partnership with local communities, and the benefits of restoration projects should flow to these communities.

Restoration in this framework needs to satisfy not just ecological but also technical, political, and civil concerns. Several tools for executing restoration with local communities have begun to emerge. We return to this set of options in the concluding section.

The benefits to local landowners and surrounding communities from earning revenue creates a financial incentive for the local communities to maintain the forest instead of replacing it. For initiatives to succeed over the long term, private opportunities need to exist alongside wider social opportunities from restoration.

TEN GOLDEN RULES FOR REFORESTATION

Di Sacco et al. (2021), working with global experts spanning Kew Gardens in the UK, the Department of Forest Sciences in Brazil, the World Agroforestry Centre in Kenya, the Forest Restoration Research Unit in Thailand, and others developed the following ten golden rules for forest restoration.

1. **Protect existing forests first:** it is hard to compensate for deforestation
2. **Work together**: involve local communities
3. **Aim to maximize biodiversity:** deliver on multiple goals
4. **Select appropriate areas:** only target previously forested land
5. **Use natural regeneration where possible**
6. **Select species to maximize diversity:** always plant a mixture of species
7. **Use resilient plant material:** pay attention to provenance
8. **Plan ahead for infrastructure:** use local infrastructure and supply chains and use seed standards suitable for local areas
9. **Learn by doing:** perform trials and adapt accordingly
10. **Make it pay:** ensure the project's economic sustainability

2. THE VALUE OF RESTORATION TO LANDOWNERS

The “Ten Golden Rules” (see box in Section 1.3) emphasize an approach to restoration that recognizes local conditions and rewards local participants. This section focuses on **the potential financial returns to local landowners, as well as potentially non-local investors, from restoring land through forestry.** Such restoration provides opportunities to limit climate change, improve the ecosystem, and produce new revenue streams for landowners and communities.

The actual returns earned by any particular landowner will depend on the specific combination of a wide range of local circumstances. The calculations in this section are intended to provide illustrative values.

2.1 The total value

The total monetary value of restoration to landowners comes from two main sources: financial incentives from local, national, or international governments (e.g., revenue from carbon offsets, local payments for flood resilience, etc.), and monetary value from existing private markets (e.g., from selling timber and other forest products). The table on the next page provides an overview of these revenue streams.

Generating these revenues requires some initial set-up costs, including the direct costs to plant and maintain the forest and the indirect costs of alternate uses, which are often captured in the price of the land itself. These are described in more detail in the table on page 14.

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Economic Benefits	
Type of Value	**Influencing Factors**
Policy interventions: There may be gains to the landowner from any government policies designed to create incentives for reforestation, afforestation, and tree-based restoration.	The nature and scope of government support, including tax credits, subsidies, and revenue from trading credits. Impact can vary greatly depending on time scales and level of support.
Future revenue generated by the forest: The forest could provide a sustainable source of food, natural products, and in some areas, potential tourist revenue.	The forest type, area, and location. The current productive potential of different forest types (assuming sustainable levels) may point to the potential size of these benefits.

> **The “Ten Golden Rules” emphasize an approach to restoration that recognizes local conditions and rewards local participants.**

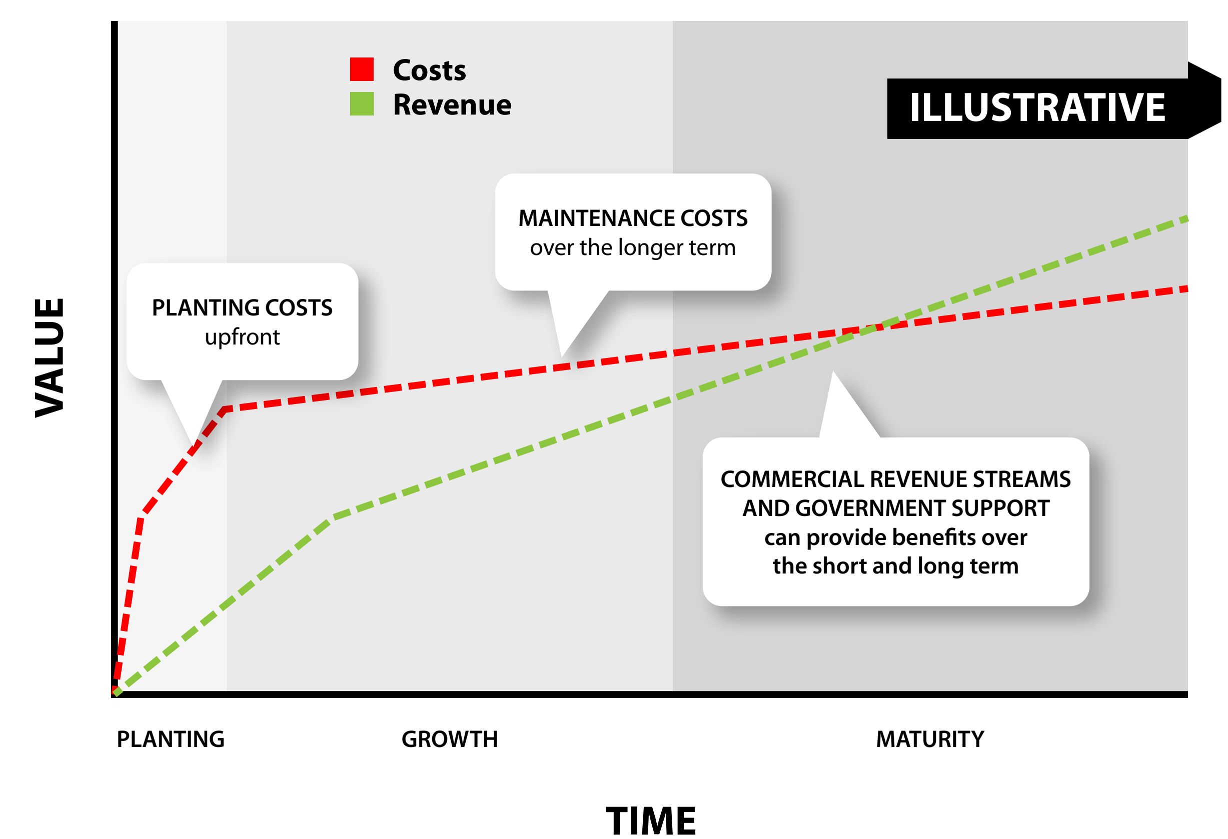
Direct (Monetary) Costs	
Cost Type	**Cost Influencers**
Planting costs: Includes the initial cost of seeds, land preparation, protection (fencing, security), labor, equipment, water, and energy.	Factors that influence planting costs per hectare include: • Land type, climate, and area • Tree type • Labor and equipment prices • Energy/water prices and availability • Skillset of labor force
Forest maintenance costs: Includes cost of watering and upkeep. Could include the costs of water and energy used in the desalination process if needed.	Similar influences as above, though these costs may be spread over a longer time frame than upfront planting costs.
Indirect (Monetary) Costs	
Alternative uses of land and resources: Includes the potential revenue/profit to the landowner for using the resources for a different purpose (e.g., agriculture, urban development).	The opportunity costs will depend mainly on: • Land type • Land location • Area of land Restoration activities often focus on land with few alternative uses. In those cases, the opportunity cost may be low.

In most restoration activities, the costs are mainly upfront and include land preparation and planting. Revenues start to flow only after forest establishment. Planting other crops alongside the trees can provide more immediate revenue while waiting for the forest to grow.

While suitable land may earn a positive return over time – say, over a 25- or 50-year period – the landowner will experience the return in three stages:

- Upfront "losses" while they restore the forest
- A gradual reduction in annual losses transitioning to annual profit that does not yet compensate for the upfront costs
- Steady annual profits that more than offset the cumulative costs.

The figure below illustrates this timeline. Clearly, there are many possible versions of the cost and revenue curves: they may be steeper or shallower, they may cross over earlier or later and, indeed, they may not rise and fall uniformly (e.g., a natural disaster might require re-planting even after maturity is reached).

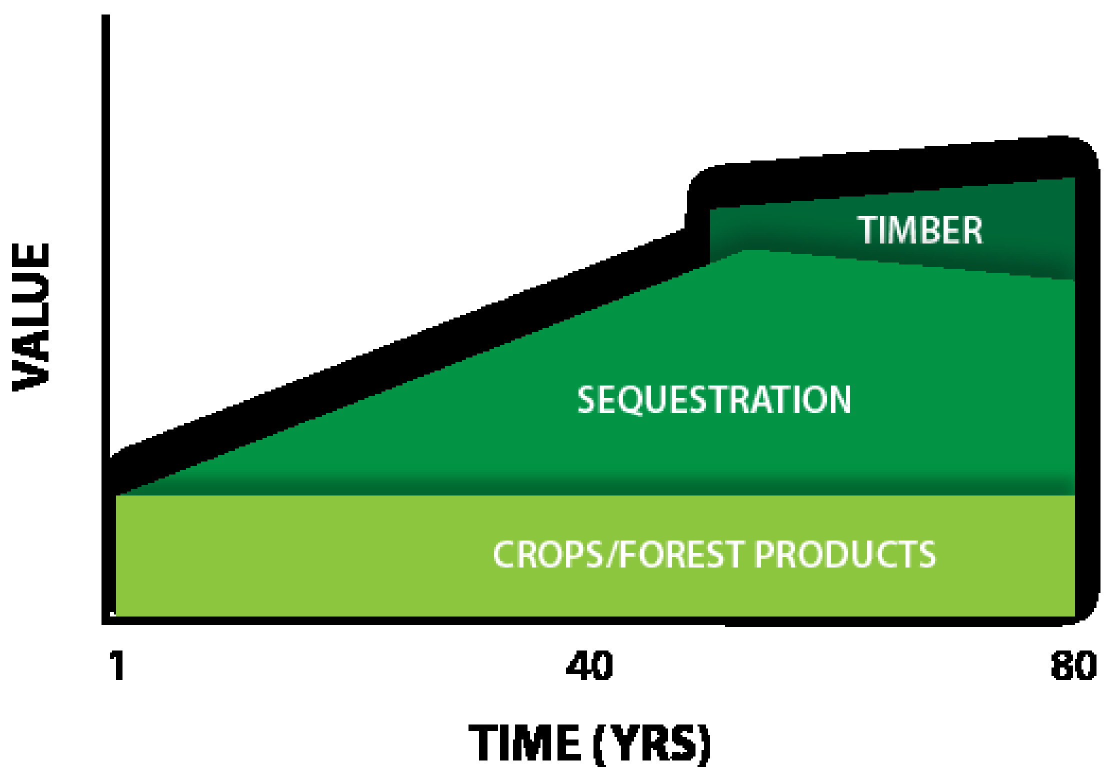


Restoration projects can benefit from multiple revenue streams, as illustrated below. The ability to capitalize on more than one revenue stream at a time is a key determinant of the revenue curve shape and the speed at which profits emerge.

The importance of individual revenue sources varies over time. In practice, this means that landowners can start earning some revenue from crops or other forest products (e.g., seeds) very early in the restoration process. The size of that income depends crucially on the type of crop and prices, which represent the main source of revenue at the beginning of the project.

Over subsequent years, cash flow from carbon credit revenues supplements, and can even surpass, those generated by agricultural products as the forest matures. At maturity, sustainable logging emerges as a third potential source of revenue. Timber tends to produce revenue in discrete, periodic spikes when wood can be harvested and sold. The size and nature of the products and the revenue from timber depend on the type of forest, its location, and the ecosystem, but provide revenue in later years, after carbon offsets stabilize.

Different sources of revenue from forest restoration (illustrative)



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2.2 The determinants of total value

Many factors affect the financial benefits of restoration to landowners, including both international and local policies and markets; factors may include carbon credit and forest resource prices as well as local labor costs. In this section we assess them in greater detail.

2.2.1 Carbon credits

The single largest source of revenue for landowners seeking to restore forests on their land in the coming years will likely be from payments for sequestering carbon. Carbon price forecasts show rising carbon prices as governments try to meet the objectives set out in the Paris Agreement and companies honor their carbon neutrality pledges.[9] The emergence of high-value, stable carbon payments depends on a number of factors, such as the outcome from the upcoming United Nations Climate Change Conference (COP26) negotiations in November 2021.

These are still relatively new markets, and they are evolving as more participants enter them. Currently, there is no single global price of carbon. Instead, there are multiple local markets and schemes with varying prices. The World Bank's carbon pricing dashboard tracks, as of this publication, more than 60 different carbon pricing initiatives across the globe and 8 sub-national jurisdictions, each with a different carbon price (see figure on next page).[10] Individuals and companies can also voluntarily buy offsets through third parties, creating an even greater range of products and prices.

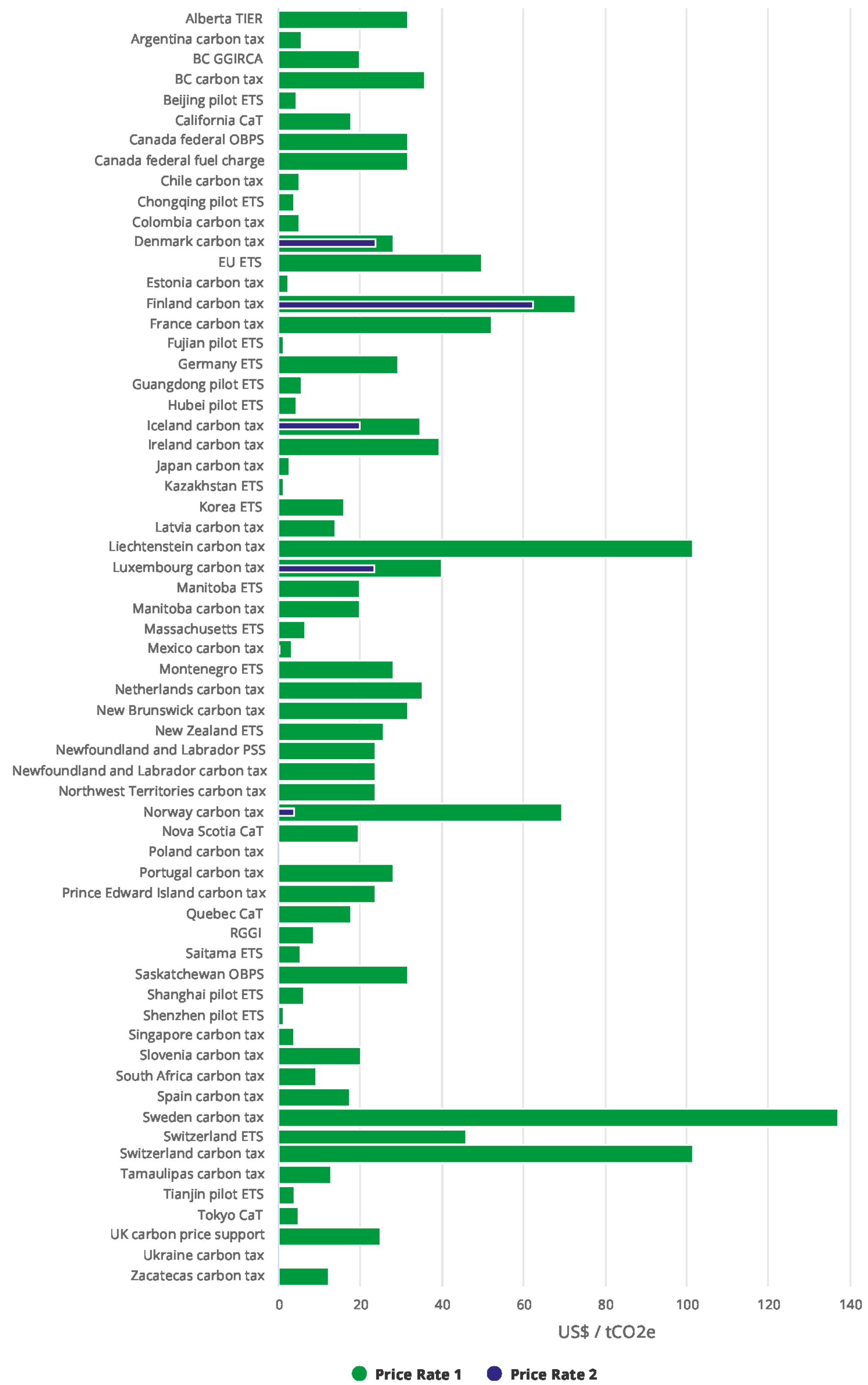
Over time, as the market matures, these smaller markets will likely converge into a single global market with a single global price, like most commodities. That process may take years, or possibly decades.

Modeling returns to landowners relies on assumptions about the price of carbon credits over time. There is significant uncertainty around the price today and into the future.

9. For example, the Bank of England recently warned businesses and banks to prepare for rising carbon prices: https://www.bloomberg.com/news/articles/2021-01-14/bank-of-england-says-prepare-for-carbon-prices-to-triple-to-100

10. See: https://carbonpricingdashboard.worldbank.org/map_data

Variability in global carbon prices



Source: World Bank Carbon Pricing Dashboard, downloaded September 20, 2021.
See: https://carbonpricingdashboard.worldbank.org/map_data

2.2.2 Agricultural and forestry revenue

Agroforestry and layered food systems can provide tremendous value and revenue to landowners. Unlike carbon credits, the prices for timber and agricultural products are relatively uniform across the world. Longstanding liquid markets ensure that similar-quality kilograms of coffee, cork, or oak planks cost the same regardless of which market they are traded in, excluding transport costs.

Timber and agricultural revenue will still vary from plot to plot because different crops, forest products, and timber species grow in different places. In keeping with the Ten Golden Rules (see Section 1.3), local landowners should grow locally appropriate products to generate revenue while preserving local biodiversity. The table on the following page lists examples of local plant types for several regions that could generate unique revenue sources appropriate for each region.

2.2.3 Labor and related costs

Costs, like revenues, vary by location. For any given site, the speed at which local landowners earn a positive return depends on the costs of restoration and maintenance. In most areas, the most important cost item will be labor, which varies widely around the world. Other important cost categories include set-up and maintenance costs (e.g., access to seed banks, nurseries, and/or water sources if locally constrained) and potentially the land itself.

Region	Possible Planting Schemes	Possible Sources of Income
Argentina	Anadenanthera colubrina (cebil)	Silvopasture, carbon credits
Australia	Eucalyptus sp. (hardwood), Acacia aneura (mulga), Syzygium luehmannii (riberry), Macadamia integrifolia (macadamia nut), Actinidia chinensis (kiwi)	Agroforestry, carbon credits
Brazil	Piper nigrum (pepper), Coffea arabica (coffee), Paubrasilia echinata (Pernambuco), Anacardium occidentale (cashew)	Agroforestry, carbon credits
East Africa - Malawi, Tanzania, Zambia	Acacia sp., Sclerocarya birrea (Marula), Tylosema fassoglense (Tamani berry), Parinari curatellifolia (Mobola)	Agroforestry, wildlife corridors, carbon credits
India	Pinus roxburghii (Chir pine), Quercus leucotrichophora (banj oak),Tectona grandis (teak), Shorea robusta (Sal), Dalbergia sp., Azadirachta indica (neem)	Timber silviculture, carbon credits, silvopasture, wildlife corridors, carbon credits
Indonesia - Kalimantan	Artocarpus sp. (jackfruit, breadfruit), Dipterocarpus sp. (hardwood sp.), Nephelium lappaceum (rambutan)	Agroforestry, wildlife corridors, carbon credits
Spain	Quercus suber (cork), Pinus sp. (pine), Prunus dulcis (almond), Olea europaea (olive), Prunus domestica (plum), Sambucus nigra (elderberry)	Agroforestry, timber silviculture
United States - Southern California	Persea americana (avocado), Prunus dulcis (almond), Pinus ponderosa (ponderosa pine), Pinus lambertiana (sugar pine), Pinus jeffreyi (Jeffrey pine)	Timber silviculture, agroforestry, carbon credits
United States - Texas	Prosopis sp. (mesquite), Populus deltoides (cottonwood), Sapindus saponaria var. drummondii (Western soapberry), Celtis occidentalis (common hackberry)	Silvopasture, timber silviculture, carbon credits
United States - Wisconsin	Betula alleghaniensis (yellow birch), Acer saccharum (sugar maple), Corylus americana (hazelnut), Juglans cinerea (white walnut), Malus domestica (apple), Prunus sp. (apricot), Rubus occidentalis (black raspberry), Rubus sp. (blackberry)	Agroforestry, carbon credits

2.3 Returns to landowners

Combining relevant local costs and revenue for a particular project proposal provides a framework for understanding future returns. Here we provide some illustrative examples based on possible combinations of cost and revenue streams.

To develop illustrative examples, we assess the costs and benefits of restoration in different scenarios. The scenarios combine several forest characteristics, summarized in the box on the following page.

Inputs into modeling the returns to landowners

Several factors determine the returns from restoring forests. To simplify, we focus on two very broad forest types: tropical and temperate. While these represent a wide range of climates, we make the following assumptions:

- **Amount of carbon sequestration:** We cite Brunori et al. (2017)[11] and Proietti et al. (2016)[12] for the temperate scenarios and Wheeler et al. (2016)[13] for the tropical scenarios. The total values reported include sequestration by plants above and below the ground.
- **Price of carbon:** We use relatively conservative values of US$5 to US$15 per ton of CO2, growing 20% annually from years 1–75, to account for increased demand, and holding flat from years 75–80, assuming the global price stabilizes as more competitors enter the market. Meeting the Paris Agreement objectives and pledges by countries and enterprises would likely lead to significantly higher carbon credit prices over time.
- **Revenue from forest products and/or agriculture:** See Section 2.2.3 for a range of crops that can grow in a forest ecosystem. In our model, we use a single agricultural crop in our agroforestry scenarios to illustrate potential revenues. For tropical forests, we model global coffee prices, and for temperate forests we model cork.
- **Timber silviculture:** We modeled revenue from sustainable timber harvest scenarios, compatible with carbon credit maintenance, based on research from carbon credit issuing bodies (https://verra.org/wp-content/uploads/2018/03/VCS-Guidance-Harvesting-Examples_0.pdf).

- **Costs**

1. Local labor costs: We base these on different scenarios for the number of workers required to maintain and harvest, with average local wage rates from a basket of countries.

2. Set-up costs for seed banks, nurseries, and planting: We use estimates for typical requirements based on evidence collected by Terraformation.

3. Cost of land: We assume zero opportunity cost of converting the area (i.e., no value or purchase price) because this study focuses on marginal land that is not currently used for agriculture or other production.

4. Cost of credit verification: We use Kerchner et al. (2015)[14] for the verification cost estimates and divide them by the size of the average reforestation project in Verra to find a per-hectare value.

- All values are discounted at a social discount rate of 3.5% over an 80-year period.

Based on these models, the value of new potential revenue streams from forest restoration, incorporating estimates of the available degraded land in tropical and temperate areas, may be $1 trillion over the coming decades.[15]

2.3.1 Tropical forest returns

The analysis suggests that **the net present value of returns from tropical forests could range from about $5,680 to $20,750 per hectare.** This includes revenues from carbon offsets, sustainable timber silviculture, and crops or other forest products. The actual return depends on the size and value of each revenue stream but is particularly sensitive to the price of carbon credits and the number of workers required to maintain the forest and harvest its products. Depending on those factors, **landowners break even on their investment after 25 to 30 years** at moderate offset prices of around US$10/ton; they could break even within as few as five years if carbon offset, forest product, and crop prices are high. The figures on page 23 illustrate the relatively steady earnings available from carbon offsets and coffee compared to more variable and periodic earnings from timber. In all cases, earnings depend on the prices available and achieved in local and global markets.

Based on these models, the value of new potential revenue streams from forest restoration, incorporating estimates of the available degraded land in tropical and temperate areas, may be $1 trillion over the coming decades.

As noted in our description of the inputs to the model, we have used relatively low values for the revenue earned per ton of carbon sequestered ($5 to $15). These reflect current prices but will likely rise as countries seek to meet their pledges under the Paris Agreement. A rising carbon price would further increase revenue along with the present value of returns to restoration. The profile of returns is illustrated below for the two ends of that range. Revenue and costs see a "step-up" when sustainable timber harvesting begins.

The net present value of returns from tropical forests could range from about $5,680 to $20,750 per hectare.

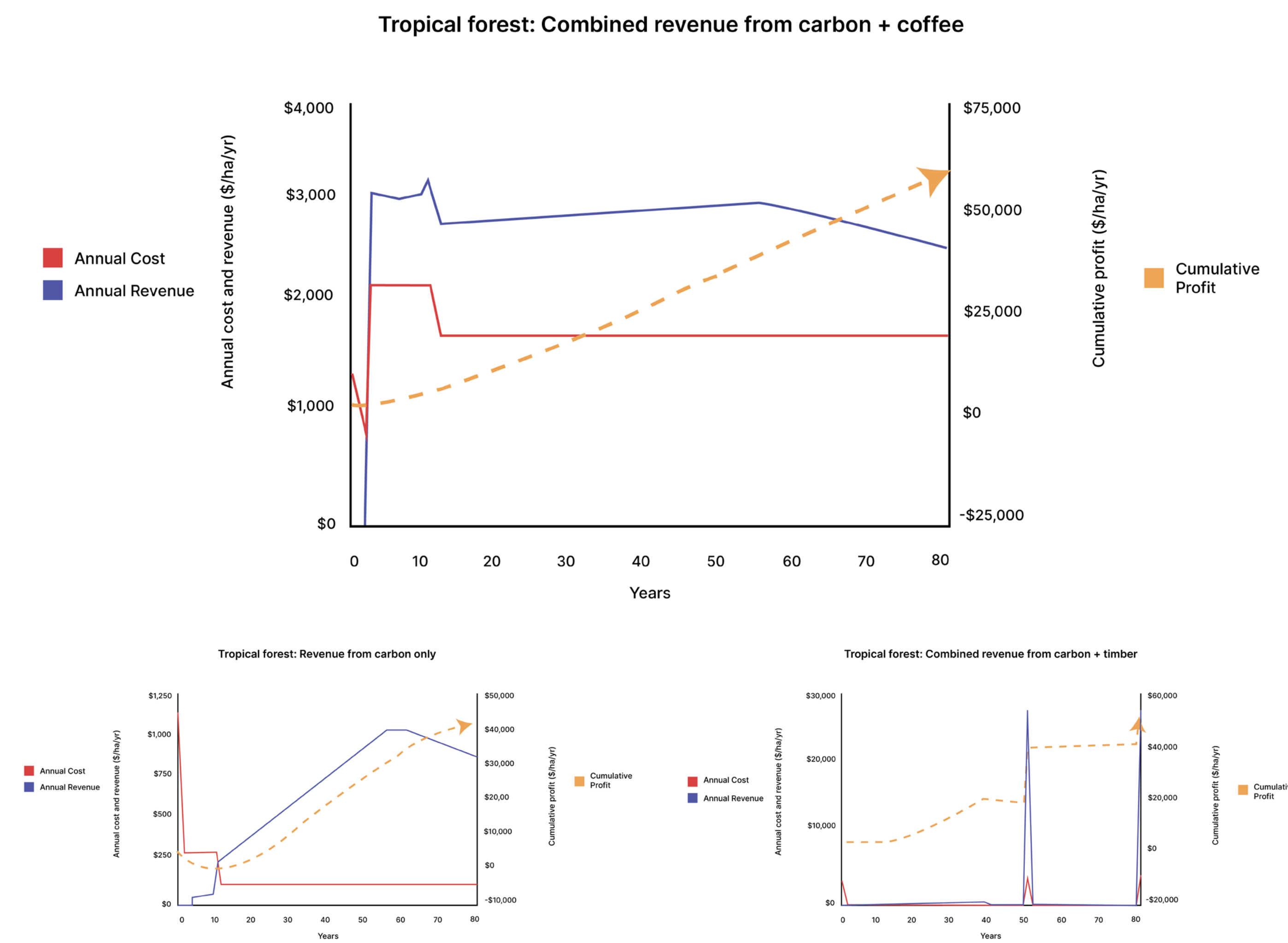
11. Brunori, A et al. 2017, "Carbon balance and life cycle assessment in an oak plantation for mined area reclamation," Journal of Cleaner Production. https://www.sciencedirect.com/science/article/abs/pii/S0959652616321795

12. Proietti, P et al. 2016, "Assessment of carbon balance in intensive and extensive tree cultivation systems for oak, olive, poplar and walnut plantation," Journal of Cleaner Production. https://www.sciencedirect.com/science/article/abs/pii/S0959652615013906

13. Wheeler, C et al. 2016, "Carbon sequestration and biodiversity following 18 years of active tropical forest restoration," Forest Ecology and Management. https://www.sciencedirect.com/science/article/pii/S0378112716301906

14. Kerchner, C and Keeton, W 2015, "California's regulatory forest carbon market: Viability for northeast landowners," Forest Policy and Economics. https://www.sciencedirect.com/science/article/abs/pii/S1389934114001531

Profiles of earnings to landowners from restoration of illustrative **TROPICAL FOREST**



Note: Cumulative profit is the sum of annual profits over 80 years (in real terms), undiscounted; see main text for present-value, discounted figures. Revenue from carbon drops after year 60 because we assume that the price will drop as more suppliers enter the market.

2.3.2 Temperate forest returns

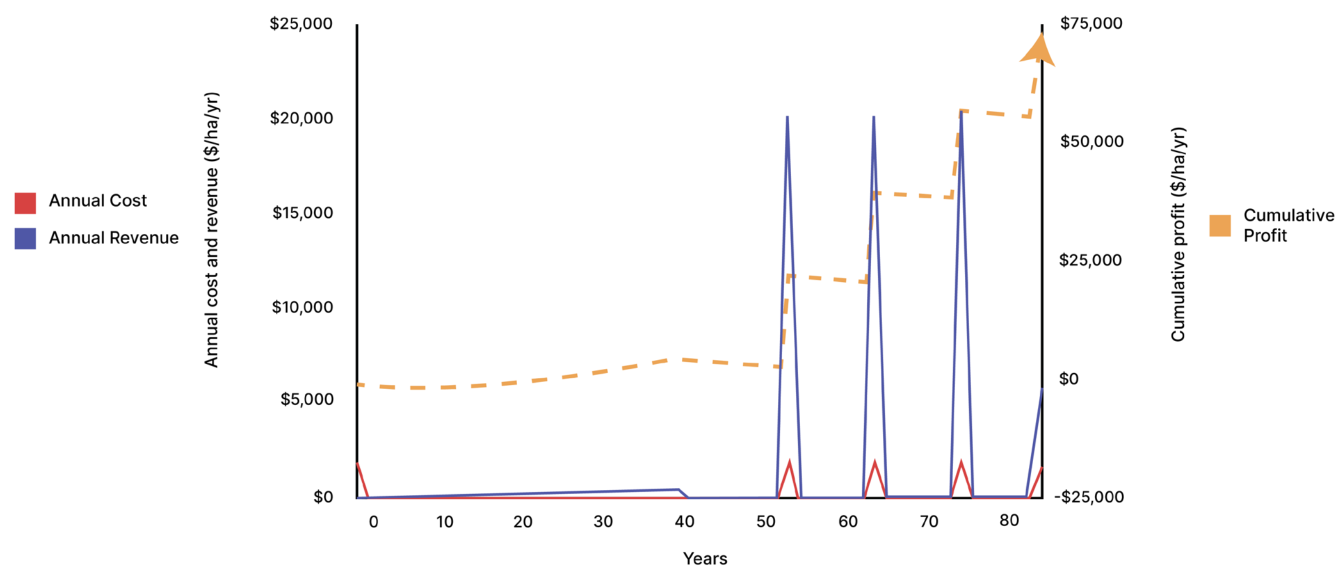
The returns from temperate forests are also significant. **Temperate forest returns have a net present value of about $3,700 to $8,250 per hectare** over 80 years, depending on the price of carbon sequestration and the cost of labor. Labor costs play a significant role in the returns from temperate forests, and the different shape for the profit curve below illustrates the impact of labor costs at the point where it becomes possible to harvest timber.[16]

15. Based on estimates of total land available for restoration from Bastin, J et al. 2019, "The global tree restoration potential," Science. https://science.sciencemag.org/content/365/6448/76

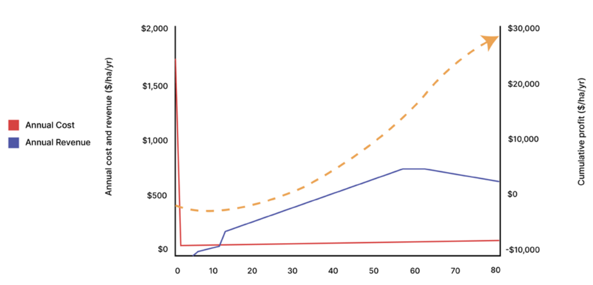
16. In some countries, labor costs are sufficiently high that significant investments may be made in machinery to replace people in timber harvesting. The impact of that substitution has not been analyzed and would vary considerably from country to country.

Profiles of earnings to landowners from restoration of illustrative
TEMPERATE FOREST

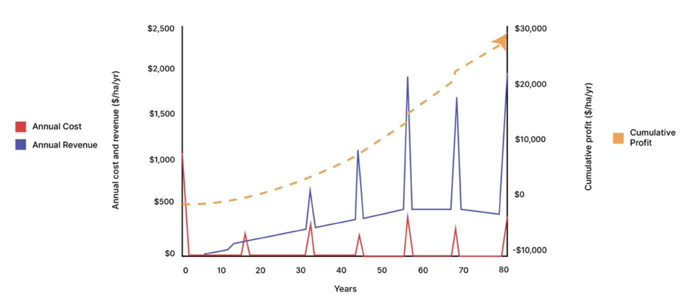
Temperate forest: Combined revenue from carbon + cork



Temperate forest: Revenue from carbon only



Temperate forest: Combined revenue from carbon + timber



Note: Cumulative profit is the sum of annual profits over 80 years (in real terms), undiscounted; see main text for present-value, discounted figures. Revenue from carbon drops after year 60 because we assume that the price will drop as more suppliers enter the market.

> **Temperate forest returns have a net present value of about $3,700 to $8,250 per hectare.**

3. CONCLUSION OF INVESTMENT CASE

Restoring **marginal, highly degraded land** has the potential to create a very wide range of benefits. Estimates suggest that **up to 25% of all land on Earth might fall into this category, and the value of restoration could amount to trillions of dollars per year.**

Restoring forests on degraded lands would provide a combination of public and private benefits. It can provide significant returns to owners of previously low-value land through multiple possible revenue streams like agriculture and forestry products, carbon credits, and sustainably cut wood.

In total, the present value of restoring land ranges from approximately US$3,000 to over US$20,000 per hectare, depending on the location of the land. The existence of multiple revenue streams allows for some immediate sources of revenue (crops) while other, potentially larger, sources develop (e.g., carbon credits and timber silviculture).

Alongside these private revenues, restored land offers a broad range of wider services, such as shade, recreational space, water filtration, flood risk reduction, and climate regulation, above the value monetized through carbon credits. While it is difficult to place a single monetary value on these services, the value flows to communities, towns, and the world. It sits alongside the private value to the landowner. This report highlights the dual nature of the value of restoration: to the landowner and to society more broadly.

Realizing the private and social values of restoration depends on many other factors that should form the basis for future work. They include:

- **Developing appropriate local policies:** National and regional governments have an important role to play in facilitating land restoration. The incentives for landowners to restore their property often depend on local policies, such as clarity of ownership, payments for ecosystem services (e.g., flood prevention), and local planning decisions.
- **Implementing global carbon markets:** Significant value is available from carbon sequestration, but international carbon markets are nascent. One potentially important step could be taken at the upcoming UN global climate summit (COP26), where successful negotiations to implement Article 6 of the

Paris Agreement would help enable global carbon markets to take off.

- **Using global trade agreements to lower barriers to trade for a wider set of forestry products:** Global and bilateral trade agreements could facilitate the trade in forestry products that form another important aspect of value. Increased trade in such products could create further incentives for landowners to restore land and realize the wider benefits.
- **Funding research and development into land restoration:** This report highlights that a series of new developments (seed banks, ability to improve access to water, plant nurseries, etc.) helps lower the cost of restoration and improve outcomes from restoration efforts. Funding research and development for natural restoration should be considered alongside more traditional forms of research funding that often target manufacturing, life science, and other industries.

4. APPENDIX

A holistic approach to native forest restoration.

By Jill Wagner, Head of Forestry at Terraformation, Director of the Hawai'i Island Seed Bank, Founder of Future Forests Nursery

4.1 Native species are key for restoration success.

Nearly half of global tropical and subtropical forest restoration commitments are for monoculture commercial tree plantations.[17] These plantations provide short-term benefits to local economies, making them attractive restoration options. But they do not deliver the climate benefits of multi-species native forests.

Monoculture stands support a much narrower band of biodiversity than native forests. They are also less resilient against weather events, making their carbon storage less reliable.[18] Inadequate native seed supply and low knowledge of local ecology drive much of the reliance on monoculture restoration plans. But native forests have considerable advantages, including:

- ***Native forests optimize carbon sequestration*** Native tropical and subtropical forests hold much more carbon per hectare than single-species plantation forests.[19] In striving to meet the Bonn Challenge's restoration goal of 350 million hectares of land,

17. Lewis, S et al. 2019, "Restoring natural forests is the best way to remove atmospheric carbon," Nature. https://www.nature.com/articles/d41586-019-01026-8

18. Osuri, A et al. 2020, "Greater stability of carbon capture in species-rich natural forests compared to species-poor plantations," Environmental Research Letters. https://iopscience.iop.org/article/10.1088/1748-9326/ab5f75/pdf

19. See: https://www.sciencedaily.com/releases/2018/10/181004143905.htm

20. See: https://www.bonnchallenge.org/

restoring to native forest could sequester some 42 petagrams of carbon (PgC) by 2100, while the same area restored exclusively to plantation stands of commercial trees would sequester only 1 PgC, or about 2.5% that of the natural forest pathway.[20]

- ***Species-rich forests are more resilient to weather and environmental fluctuations***
  Native forests are more resilient against pests, disease, and extreme weather conditions than single-species tree plantations.[21] This means that not only is the sequestered carbon more secure in natural forests as compared with plantations, but also that the rate of carbon capture is more consistent. This is particularly true in drought conditions, during which the rate of carbon capture in plantation forests can be nearly 30% lower than in natural forests.[22]
- ***Native plants support biodiversity***
  According to the Millennium Ecosystem Assessment, more than half of the world's terrestrial plant and animal species live in forests.[23] Plantation forests have a fraction of the biodiversity of native forests. Native plant species richness declines by 65% in plantation forests compared with primary forests.[24] Loss of native-species biodiversity in changes to other land types – such as for agriculture – can be even more dramatic.

Shifting the global mix of restoration plans to a heavier emphasis on native forest restoration will require solving project operational bottlenecks, as described below, as well as creating adequate incentives or revenue to support local restorationists.

21. Osuri, A et al. 2020.

22. Osuri, A et al. 2020.

23. Brockerhoff, E et al. 2008, "Plantation forests and biodiversity: Oxymoron or opportunity?" Biodiversity Conservation. https://www.fs.fed.us/research/publications/misc/63353_2008_Biodiv%20Conserv %20Brockerhoff% 20et%20al.pdf

24. Bremer, L and Farley, K 2010, "Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness," Biodiversity and Conservation. https://link.springer.com/article/10.1007/s10531-010-9936-4

THE INVESTMENT CASE FOR RESTORATION, Frontier Report 2021

4.2 Overcoming the bottlenecks to scale

Restoring billions of acres of degraded land will require a coordinated physical effort at a scale that is difficult to comprehend, perhaps bigger than anything humans have attempted before. We need to take a hard look at the challenges these lofty missions face in order to have a chance at success.

Restoration projects regularly face five operational bottlenecks: lack of sufficient water, training, tools, seed supply, and funding. These are sticking points that slow progress or even collapse efforts altogether. And they go hand in hand with pitfalls like inadequate social, political, and economic engagement.

If we are to achieve massive restoration in the next decade, we need to give climate workers access to the resources they need for success.

Bottleneck #1: Training

Restorationists need three kinds of expertise: botanical, ecological, and horticultural. For reforestation projects to scale, we need to make high-quality field training in these three areas accessible to anyone who wants to join in this work.

To meet this need, Terraformation is creating training programs in seed banking and nursery management. The courses will speed education on the most important techniques and protocols for doing the work. These certificate programs will be accessible to people all over the globe via web-based video series and regular video conferencing with Terraformation trainers. These courses are a first step in meeting the need for massive information dissemination to solve this restoration roadblock.

In addition to training, restorationists need easy access to data about their local environments, like local botanical and soil histories, which determine what would and should grow in their forests. This information access is growing thanks to efforts like the Crowther Lab's restoration maps, but we need to expand further.

Bottleneck #2: Seed supply

We need to massively increase seed supply if we are to meet large-scale restoration goals. All too often, restoration projects let seed availability drive restoration plans, rather than determining the correct native plant balances and collecting seed with that intention. The resulting stands are flimsy, poor copies of complex systems. Monocultures and small, generic species choices do not make healthy plant communities – they're much less likely to survive the drought and storm events sure to occur over time.

Restorationists need the knowledge and tools to collect and safely store diverse native seeds. They also need access to public and private lands that contain healthy ecosystem fragments, which provide valuable native seed sources.

Bottleneck #3: Water

Lack of water supply is a key limiting factor in dry tropical forest restoration, and this can slow or even defeat efforts.[25] Forest restoration programs in arid regions can have adverse impacts on regional groundwater, at least in the short term, when the water uptake of new vegetation is not taken into account.[26] This can negatively impact the local economy and human health.

But over the last five years, something really important happened – the cost of solar power dropped below that of coal and gas.[27] And this has unlocked an opportunity to do what couldn't be done before: sustainably reforest desertified regions via solar-powered desalination.

25. Fajardo, L et al. 2013, "Restoration of a degraded tropical dry forest in Macanao, Venezuela," Journal of Arid Environments. https://www.researchgate.net/profile/Laurie-Fajardo/publication/256941445_Restoration_of_a_degraded_tropical_dry_forest_in_Macanao_Venezuela/links/5e5c2445299bf1bdb84abe7c/Restoration-of-a-degradedtropical-dry-forest-in-Macanao-Venezuela.pdf

26. Lu, C et al. 2016, "Ecological restoration by afforestation may increase groundwater depth and create potentially large ecological and water opportunity costs in arid and semiarid China," Journal of Cleaner Production. https://www.researchgate.net/profile/Chenxi-Lu/publication/300408322_Ecological_restoration_by_afforestation_may_increase_groundwater_depth_and_create_potentially_large_ecological_and_water_opportunity_costs_in_arid_and_semiarid_China/links/5af2b4310f7e9ba3664987ef/Ecological-restoration-by-afforestation-may-increase-groundwater-depth-and-create-potentially-large-ecological-and-water-opportunity-costs-in-arid-and-semiarid-China.pdf

Bottleneck #4: Equipment

Unreliable tools and equipment breakdowns delay projects for weeks or more, wasting human energy and wearing teams down. In contrast, crews with the right equipment can spend their energy on the specialized, delicate work that only human hands can do. And that efficiency is key to scaling up.

Terraformation has developed several modular, off-grid equipment solutions to support forest restoration projects around the globe. Our modular seed banks are the only mobile, self-sustaining seed labs in the world. They contain all the equipment necessary to process and store up to five million seeds, all within a standard 40' (12 m) container that can be shipped anywhere in the world. The bank is entirely solar-powered, so it can function at sites around the globe.

Bottleneck #5: Funding

Almost every restoration project around the world is undervalued and underfunded. Too often, grassroots organizations are given little training and a trickle of resources. This sets them up with rudimentary resources to tackle complex problems alone. To achieve large-scale reforestation, we will need to start valuing restoration projects for the planet-saving work they are.

27. See: https://www.businessinsider.com/solar-power-cost-decrease-2018-5

About Terraformation

Terraformation's mission is to turn degraded land into three billion acres of forest, restoring vital ecosystems, drawing carbon out of the atmosphere, and stabilizing our climate.

The company empowers locally led forest restoration with tools, training, financing, and other support. It has developed modular and open-source solutions to the biggest barriers to mass tree-planting, including solar-powered desalination systems, seed banks to process and store millions of seeds, and open-source software to streamline restoration progress. In particular, Terraformation's team built and now operates the world's largest off-grid, 100% solar-powered desalination facility, located on the Big Island of Hawaiʻi, proving that off-grid, solar-powered desalination makes it possible to grow forests on desertified land.

Terraformation works with public- and private-sector landowners, respecting customary land tenure and institutions. It co-develops multi-year restoration projects by collaborating with local partners from initial project planning through long-term project maintenance.

Margaret Morales

VP of Marketing and Communications

margaret@terraformation.com

About Frontier Economics

Frontier is an economic consultancy with energy, imagination and flair. Now one of the largest economic consultancies in Europe, we started Frontier Economics in 1999 wanting to do things differently. Owned entirely by our staff, our business attracts the best people and the most interesting work. Our principles remain. Our work covers economic analysis spanning climate, policy, infrastructure, competition and strategic issues. Visit www.frontier-economics.com for more.

Matthew Bell

Director

matthew.bell@frontier-economics.com