Carbon Sources, Sinks and Offsets in Global Forest Investments

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Abstract: Global Forest Partners (GFP) is a forestry investment advisor that manages over 750,000 hectares of timberland around the globe on behalf of their investors. The primary objective of this analysis was to quantify GFP's annual net carbon footprint, including both carbon sequestration occurring through their forest assets as well as the emissions that are attributable to the company. Additionally, we will provide a modeling tool with which GFP can continue to monitor their carbon impact in the coming years. We structured our carbon footprint analysis based on the methodology established by the California Air Resources Board for use in the California cap-and-trade system and the methodology used in the Verified Carbon Standard for global voluntary carbon markets. After performing our carbon accounting analysis, we sought to provide a global perspective of carbon pricing mechanisms. Due to low carbon prices, historic volatility within global carbon markets, and impending large-scale changes within international carbon trading, it does not appear to be pressing for GFP to pursue a monetization of their carbon sequestration at present. In order to properly prepare for an impending phase of expansion and interconnectedness in the global carbon marketplace, we recommend that GFP begin considering the potential carbon additionality impacts of future acquisitions. GFP should also take steps during its asset evaluation process to determine whether undertaking a forestry carbon offset project in any of its existing forests would be feasible from a regulatory and financial standpoint. Key trends to anticipate include the establishment of a Chinese emissions trading scheme by 2020, a potential increase in carbon trading within the United States, and a potential increase in international carbon trading as a result of the 2015 Conference of Parties 21 talks. As a result of this project, GFP will gain a firm foundation of knowledge regarding the methods involved in calculating forest carbon sequestration, evaluating additionality, assessing the value proposition for forestry carbon offset projects, and understanding the operation and outlooks of major global carbon markets.

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1. Introduction

As the public discourse surrounding the issue of Earth's changing climate continues to grow, there is an increasing concern regarding anthropogenic contributions to global climate change. While the processes involved in driving global warming and climate change effects have been studied since the late 1800s, the topic was not considered a public concern until the 1970s. A 1988 testimony to Congress by then-NASA scientist James Hansen about the greenhouse effect and its direct contribution to global warming helped bring more visibility to the issue in the United States and abroad[1]. In 1988, the same year as the Hansen testimony, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC)[2] to review the evolving research and knowledge base surrounding climate change[3]. With contributions from thousands of scientists and 195 countries, the organization has since released an updated report every six years. The group's fifth assessment was released in 2014 and, supported by a consensus of global scientific research, stated with 95% certainty that humans have been the "dominant cause" of global warming since the 1950s[1].

Climate change has been accelerating due to human contributions to the greenhouse effect. The greenhouse effect is the process by which some gases, referred to as greenhouse gases (GHGs), increase the radiative forcing of the Earth's atmosphere. This means that GHGs allow incoming solar radiation to enter the Earth's atmosphere, but do not allow all of that radiation to leave, creating a net warming effect on the Earth's climate[4]. While carbon dioxide (CO_2) is not the most damaging greenhouse gas, it has become the gas of greatest concern to the international community due to the extremely high levels released by human activity each year. In 2010, more than 75% of total GHG emissions were carbon dioxide, with methane following at 16%, nitrous oxide at 6%, and fluorinated gases at 2%[5]. Due to the overwhelming share of total global GHG emissions attributable to carbon dioxide, global efforts to decrease GHG emissions have focused on this gas.

While curbing carbon emissions has been a large focus of international policy activity, there has been a smaller but critical emphasis placed on possible measures for sequestering atmospheric carbon. Sequestration is the removal of CO_2 from the atmosphere, either through natural processes or by artificial means. Plants are very effective at sequestering atmospheric carbon due to their use of carbon dioxide during photosynthesis, which results in carbon being stored throughout the plant[6]. The sequestration of carbon in plant biomass leads to the accumulation of large pools of stored carbon across a vegetated landscape. As long as there is continued plant growth, carbon will continue to be taken up and sequestered within the ecosystem. Once plants die, microorganisms colonize the dead plant matter and begin to break it down. As the microorganisms consume the wood, they release the stored carbon through respiration in the form of carbon dioxide[7]. As the ecosystem reaches its relative growth equilibrium, where plant mortality is equal to new growth, the level of sequestered carbon stored in the landscape will remain relatively stable until the biomass is removed or destroyed[8].

When assessing the carbon sequestration effects of different ecosystems, forests stand out as the most important, containing the greatest amounts of biomass and therefore sequestering the greatest amounts of carbon. This result is intuitive, as trees are the largest types of plant with exceedingly long lifespans. To put the importance of this terrestrial sequestration into perspective, the amount of carbon stored within all terrestrial biomes and soils is three times the amount of carbon dioxide currently in the atmosphere[6]. Studies have estimated that forests contain approximately 80% of all global aboveground stored carbon as well as 70% of global belowground carbon[9]. It has also been estimated that forests across the globe have offset up to 30% of the annual global anthropogenic CO_2 emissions since 1990[10]. Considering the large amount of carbon currently stored within forested systems and their great potential for increasing carbon storage, there has been an increasing focus on protecting and cultivating forests as a means for countering anthropogenic carbon emissions. This global importance placed on forests underscores the importance of understanding GFP's role on a global level and serves as motivation for the analysis within this report.

2. **Objectives of Project**

The four key objectives of this project are:

- Perform a carbon accounting analysis for existing GFP-managed assets, so that GFP can communicate this information internally, to their investors, and to other stakeholders.

- Provide a tool for GFP to monitor its carbon footprint on an ongoing basis and project the carbon sequestration benefits of new forest acquisitions or modified forest management techniques.
- Assess GFP's existing ability to monetize carbon sequestration and identify other potential opportunities in the near future.
- Provide a carbon policy context to the geographies that apply to GFP's assets and operations.

The main objective for this project is to provide a comprehensive organizational carbon footprint for GFP. This analysis will give GFP the tools to monitor and manage the carbon impacts of their global portfolio, informing the evaluation of future assets and contextualizing GFP's carbon sequestration potential within the broader scope of international carbon markets. Additionally, GFP will be able to inform its investors of its carbon impacts to further demonstrate its commitment to environmental and corporate sustainability.

Performing this type of analysis requires a thorough understanding of GFP's operations as well as primary international carbon accounting protocols. The significant amounts of sequestration considered within this analysis makes it an interesting case for carbon accounting, as carbon accounting is usually focused primarily on emissions. Forests naturally sequester carbon dioxide in various ways, each of which must be accounted for. We will be able to add additional value to this analysis by examining the results within the context of current and future global carbon market and political institutions.

3. Background

To build context around the international push to curb emissions, we will discuss the financial and institutional mechanisms that have been developed to aid countries in achieving their emissions reduction goals.

3.1. Global Carbon Pricing Mechanisms

There are two main financial mechanisms that countries have used to curb carbon emissions at a national or subnational level:

- Carbon Taxes
- Carbon Cap-and-Trade Systems

A carbon tax sets a fixed price on a given amount of carbon emissions generated by regulated entities, which typically include large corporations, manufacturers, and power producers. A tax has the benefit of mandating a fixed cost for emissions that regulated firms can use in their financial planning, but does not guarantee that a desired level of emissions will be met. For example, if the tax is set at a price at which it is less expensive for companies to pay the tax rather than taking action to reduce their emissions, there will be a limited effect on emissions reductions[11,12]. A successful example of a carbon tax can be seen in British Columbia, where the provincial government has enforced a tax of C$30/ton CO_2 (Canadian Dollars) since 2012. A 2015 review of the program conducted by Duke University researchers found that British Columbia has seen a 5-15% reduction in GHG emissions with negligible negative economic and social impacts[13]. The program is still young and it remains to be seen if there are other unintentional effects being felt, such as carbon leakage, or if the tax will withstand shifts in the political climate, but the tax program has shown success thus far.

A cap-and-trade system, also referred to as an emissions trading scheme (ETS), sets a fixed limit on the quantity of allowed emissions generated by a regulated sector and distributes permits or allowances among the regulated businesses within that sector that reflect the designated cap. This type of system has the benefit of generating a fixed amount of emissions reductions, but the financial incentives for involved firms can be highly variable depending on the design of the system, the initial allocation of permits, and the level of the cap[11,12]. An example of this can be seen in the European Union, which has traded carbon credits since 2005[16]. A discussion of the impacts that the European Union ETS has had to date can be found in Appendix C.

There has been debate over the merits of each method for reigning in emissions. On an academic level, economists have agreed on the advantages of emissions pricing but there remains a debate on whether a tax or cap-and-trade is the better option[11]. On a political level, taxes of any form have traditionally been unpopular among both businesses and the general electorate[14-16]. Recently, however, there have been more examples of businesses coming out in favor of a carbon tax. For example, in 2015, ten of the largest oil companies in the world showed their support for a carbon tax due to its simplicity and predictability in contrast to the complexity and volatility of cap and trade schemes[17]. Regardless of any arguments in favor of a carbon tax, trading schemes remain the dominant global pricing mechanism for greenhouse gas emissions. In 2015, approximately 70% of the estimated $50 billion value of global carbon pricing mechanisms was associated with emissions trading schemes[18]. Although the focus of international climate regulatory agreements within the United Nations may shift to the adoption of a tax on carbon in the future, the continuing global development of trading schemes is likely indicative of the importance that trading schemes will continue to have in the coming years and justifies the importance placed on emissions trading scheme protocols within this report.

3.2. Fundamentals of Emissions Trading Schemes

The successful U.S. sulfur dioxide trading program in the late 1990s has served as a prototype for many modern emissions trading schemes[19]. While there is disagreement over the reasons why the program was cost-effective, Schmalensee & Stavins (2012) estimated that the target for SO_2 reductions were met at between 15% and 90% lower costs than would have been incurred with a traditional regulatory approach[20]. Providing a cost-effective means for companies to reduce their emissions of a regulated pollutant is the fundamental purpose of any emissions trading scheme. There are two different types of markets where this type of trading can take place. Voluntary markets allow for organizations to offset their emissions through the purchase of offset credits despite having no legal obligation to do so, while compliance markets legally require participation from entities within a regulated sector in order to meet a desired reduction in emissions as a whole[21]. Once the cap on emissions is fixed, a corresponding amount of allowances (or permits) will initially be distributed by either auction to those within the sector being regulated or for free. When the initial permits are auctioned off, the proceeds can then be used by the regulating agency to invest in local emissions reductions projects. A prime example of this process was the California compliance market, where over $500 million was raised in the first year of state auctions and earmarked for projects aimed at further reducing carbon pollution[22].

There are two opportunities for companies to sell their initial allocation of permits. These include when a company is allocated more allowances than is needed to cover their total emissions, or when it is financially advantageous for the company to reduce their emissions beyond their mandated reductions and sell the permits corresponding to the incremental emissions reductions.

Companies whose emissions exceed the quantity of permits they are allocated must either purchase allowances from other regulated businesses or buy offset credits generated through a carbon offset project.

Certified offset projects result in a net reduction in atmospheric greenhouse gases, measured in tonnes of carbon dioxide equivalence (t CO_2e), through either a reduction of carbon emissions or an increase in carbon sequestration. The four characteristics of any offset project are as follows[23]:

- **Additionality**: The project must result in a net reduction of atmospheric GHGs relative to what would have occurred in the absence of the project.
- **Permanence**: The GHGs that the project activity keeps out of the atmosphere cannot be released at a later date.
- **Quantifiable**: The GHGs kept out of the atmosphere must have a measureable effect that can be quantified.
- **Verifiable**: The gains being made by the project must be verifiable by a third party.

If a project can meet these fundamental requirements, an interested party can pursue certification to become an official carbon offset project.

The most important component of a carbon offset project is the proof of additionality. The definition of additionality stipulates that the project must result in a greater net reduction of atmospheric greenhouse gases than what would have occurred in the absence of the project[23,24]. There have been issues concerning what constitutes as additional reductions when compared to the baseline level of emissions. Two examples of where credits were granted in areas that were not generating "additional" reductions in atmospheric GHGs are described below:

- [25] From 2005 – 2008, China's electrical generation capacity was increasing at an extraordinary pace. While the country expanded their coal power capacity, there were also large gains in hydro, wind, and natural gas generating capacity during this time, with many of the new facilities applying for accreditation under the Clean Development Mechanism. Based on the trend of the industry as a whole, it is believed that many of these projects would have occurred without the financial assistance that comes with the sale of the Certified Emissions Reductions generated from the project. Additionality was not demonstrated in this case.

- [26] In 2008, it was reported that landfills across the United States had been selling credits for the landfill gas they had already been capturing and selling for more than a decade. The existence of this practice prior to the landfill owners' participation in the Chicago Climate Exchange does not prove that any additional methane was kept out of the atmosphere than would have occurred in the absence of the program.

In the early stages of generating offset credits, these types of problems were very prevalent. A 2007 Öko-Institut study estimated that 40% of CDM projects registered by July, 2007, are unlikely or questionable to have proven additionality[27]. As programs continue to develop, restrictions over accepted projects will continue while governments attempt to ensure that more rigorous means of additionality verification are employed. This concern over allowing 'non-additional' projects dictates the types of programs that different trading schemes will allow.

All offset projects, regardless of trading scheme, have their roots in the Kyoto Protocol[23]. In 1997, the UNFCCC adopted the Kyoto Protocol in the hope of reducing greenhouse gas emissions by establishing a legally-binding set of emissions reductions targets for the largest industrialized nations in the world, referred to as Annex I countries[28]. This agreement established an initial commitment period of 2008-2012, which was later extended until 2020. The Clean Development Mechanism (CDM) was also established in this agreement to assist countries in meeting their targeted emissions reductions. Projects meant to decrease emissions could be registered with the CDM to earn Certified Emissions Reduction credits (CERs), and those credits could be sold to those seeking to reduce their emissions[28]. Whether a trading scheme uses CERs directly, such as the EU ETS, or they adapt their own methodologies to grant offset permits, the methodologies established by the CDM have served as a model for international carbon offset projects.

As discussed earlier in this report, terrestrial biomes and forests in particular are some of the largest global sinks for carbon dioxide. As more information becomes available regarding the carbon storage benefits offered by forests, as well as the large emission impact resulting from global deforestation, a larger importance is being placed on the preservation and growth of forested land. It is with this emphasis in mind that emissions trading schemes have recently been integrating more carbon offset projects based on forests into their schemes. Controversy remains surrounding the use of forestry projects as offsets, however, primarily due to the issue of permanence of the carbon being sequestered[29]. For example, if the company managing an accredited forestry plantation goes bankrupt, the sequestered gains may well disappear if the forest is allowed to degrade or a new owner harvests the forest and does not maintain the land as a forestry plantation. There is also doubt surrounding the “real” additionality of forest projects and the methods applied to verify them. With these reservations in mind, many global trading schemes, such as the EU ETS, have placed restrictions on accepted forestry projects. Due to the nature of our analysis, we will not address these issues surrounding additionality and verification. Instead, our analysis will establish a baseline carbon footprint for GFP which indicates the amount of carbon that GFP emits and sequesters on an annual basis in a ‘business-as-usual’ scenario. In the context of offset projects, additionality in the context of offset projects requires a change which would sequester additional carbon relative to the baseline value that we will be calculating. Appendix A of this report will discuss some common offset forestry projects accepted in various trading schemes that may be applicable to future GFP acquisitions.

4. Project Overview

This report seeks to present a well-researched and defended assessment of our findings regarding the current net carbon footprint of GFP. While GFP oversees over 750,000 hectares of timberland, our project concentrated on modeling roughly 450,000 hectares of managed forest plantations comprising twenty-eight assets. These impacts are characterized on an asset-by-asset level as “negative” carbon sequestration impacts and at the corporate/management company level as a “positive” carbon emissions footprint. These findings will clearly characterize the carbon impacts attributable to GFP in 2015 and projected forward. The results will be obtained through the creation of an Excel-based tool that can be used in ongoing monitoring by the client organization after the conclusion of this project. In addition to providing a summary spreadsheet detailing the results for the twenty-eight GFP assets that were considered in the project, we will also provide a detailed guide for using the Excel-based tool developed for the project in Appendix B. A separate Excel model will present the carbon emissions impacts of GFP and their affiliated forest management companies at a global and regional level. Lastly, this report will provide a review of the major types of carbon offset forestry projects in Appendix A and a prospective outlook on international carbon markets as well as global and country-level carbon policy in the short- to medium-term in Appendices C and D.

5. Methodology

In order to determine the net carbon footprint of Global Forest Partners operations in 2015, our team needed to assess both the amount of carbon sequestered by GFP's forest assets and the amount of carbon emissions resulting from their business operations. It was determined early in the analysis that the carbon sequestration impacts of forest cultivation would dominate the net carbon footprint of the GFP portfolio and so the bulk of our analysis was focused on quantifying the carbon sequestration impact of each forest asset. Silvicultural and administrative emissions attributable to GFP played a secondary role in our analysis, due to the minimal impacts they represented relative to the amount of carbon being sequestered. The carbon footprint of GFP was estimated over a 100-year time period, a timeframe frequently used in carbon accounting analyses.

Our group referred primarily to the methodologies established by the California Air Resources Board (ARB) for use within the California Emissions Trading Scheme and the Verified Carbon Standard (VCS) to develop a framework for estimating GFP's carbon sequestration impacts[30,31]. The VCS methodology was referenced to due to its status as the most widely-used global voluntary offset program and its inclusion of a methodology for calculating carbon stored through forestry projects. The ARB methodology was referred to due to its status as a growing compliance market within the United States and Canada, as well as its detailed methodology for generating forestry offset credits. We also referred to recent scientific literature to verify certain aspects of these methodologies, as well as to assist in gathering data parameters for tree species that are not explicitly included in either the ARB or VCS.

The following descriptions will provide an overview of our team's methodology for calculating GFP's net carbon footprint. It also informed the development of an Excel-based tool for determining asset-level carbon impacts. The specific functionality of this tool is described in depth in the user manual (Appendix B).

5.1. Carbon Sequestration

In order to estimate the amount of carbon sequestered within each forest asset, we developed a list of key carbon pools present in forest ecosystems and evaluated their appropriateness for inclusion in our GFP-specific carbon model. Ultimately, our model measures the carbon sequestration impact of the total above- and belowground biomass of the trees that GFP cultivates for sale, as well as the carbon embodied in the long-lived wood product pool. Silvicultural emissions necessary for forest management are also estimated in the model. Table 1 below provides a summary of how the ARB and VCS methodologies compare to our methodology used to model GFP's carbon sequestration impacts:

Table 1: Summary comparison of treatment of each carbon pool/source in the ARB, VCS, and the GFP model methodologies

Carbon Pool	***ARB***	***VCS***	***GFP model***
Total Tree Above-Ground Biomass	Included: Total tree biomass is calculated through DBH measurements and appropriate allometric equations.	Included: Total tree biomass is calculated through DBH and height measurements and appropriate allometric equations.	Included: Value is calculated using ARB methodology and output from GFP forest production modeling.
Non-Tree Aboveground Live Biomass	Optional: Largely contains shrubs that would be included only in certain offset projects. Requires onsite measurement.	Optional: Typically excluded with the assumption that this pool will generally remain unchanged.	Excluded: Due to extreme variability and lack of site-specific measurements.
Dead Wood and Detritus	Included: Measurements require qualitative assessments onsite.	Optional: Typically excluded with the assumption that this pool will generally remain unchanged.	Excluded: Due to the lack of site-specific observations
Below Ground Biomass	Included: Assessed as a part of the total tree biomass calculations, based on a percentage of the total biomass.	Optional: Typically excluded with the assumption that this pool will generally remain unchanged.	Included: Value is estimated on the basis of the "Total Tree Above-Ground Biomass" pool described above
Soil Carbon	Included: Only when there is expected to be significant disturbance. Requires onsite measurements and monitoring.	Optional: Typically excluded, as data collection and monitoring is difficult. The general assumption is that soil carbon will not change significantly over the project lifetime.	Excluded: Due to the lack of access to onsite measurements
Wood Products	Included: Involves converting total biomass to merchantable volume and using mill efficiency factors combined with decomposition coefficients over a 100-year time horizon.	Optional: Generally only included when the project results in a decrease in lumber output. VCS Methodology points to ARB methodology as one of two possible frameworks for doing a product pool carbon account.	Included: Values determined using the ARB methodology in conjunction with harvested merchantable volume estimates supplied by GFP
Emissions	Only CO_2 emissions from site preparation and biological decomposition are considered.	CO_2 emissions from fossil fuels assumed to be insignificant. Methane is considered when there's biomass being burned on site. N_2O is considered if there is a significant amount of nitrogen fertilizer or manure used or if there are nitrogen-fixing species planted during the project.	Included: Values are derived from estimated emissions from the literature based on intensive forest management practices. Administrative emissions will also be included, which usually lie outside the scope of forestry projects, in order to fully capture the impact of GFP corporate activity.

5.1.1. Above Ground Carbon

5.1.1. Live Trees: The largest sink of carbon in above ground living biomass is the carbon stored within living trees. This is the primary means of carbon sequestration within all of GFP's assets. In the scientific literature, researchers have been able to develop allometric equations for many different species based on physical tree measurements such as DBH and height via destructive sampling. The ARB methodology uses species-specific values from Woodall *et al.* (2011), to convert DBH measurements into volume, and then from volume to biomass. ARB then uses Jenkins *et al*. (2003) to convert biomass to carbon mass using species-specific values[32,33]. The VCS directs users to select appropriate species-specific allometric equations to convert DBH and height measurements into biomass, and then biomass into carbon mass. Sources typically employed for these purposes in the VCS methodology might include Senelwa & Sims (1997)[34] or Brown *et al.* (1999)[34].

Utilizing these methodologies on the scale necessary to model all of GFP's assets would require extremely large amounts of data, necessitating that large amounts of time be devoted to collecting and verifying the consistency of forest measurement data from each site. It would have also meant projecting growth patterns using software that this group did not have experience with. The scale of the project made this process infeasible. Instead, our group was able to leverage the current and projected merchantable harvest volume data outputs from the forest production modeling that GFP already performs for all of its assets. We then used Woodall *et al.* (2011) and values from the ARB database to convert merchantable volume into biomass and then into stored carbon mass within the trees. As the output data from GFP's forest production models typically extends out only 60 years from the present, our group determined a means of selecting lengths of time for each species in each asset that represented a "typical rotation." The forest inventory and removals data for these typical rotations were then replicated over the full 100-year time horizon over which the analysis was performed. The following section contains a step-by-step overview of the calculations used for estimating the carbon stored in this pool:

Primary Data Input

A. Merchantable volume

Merchantable volume (m^3)

Merchantable volume is the primary data input provided by the Excel tool users. The following calculations provide a step-by-step demonstration of how to use these values to determine forest carbon sequestration under the ARB methodology.

B. Bole Biomass and Bark Biomass

Bole Biomass (tonne) = Volume (m^3) ** Bole Specific Gravity* ($1\ g/cm^3$) *** ($tonne/10^6 g * 10^6 cm^3/m^3$)

Bark Biomass (tonne) = Volume (m^3) ** Bark Percentage * Bark Specific Gravity* ($1\ g/cm^3$) *** ($tonne/10^6 g * 10^6 cm^3/m^3$)

Using the values of bole specific gravity provided by ARB’s database, the biomass of the bole can be calculated. Specific gravity is the ratio of the density of the wood to the density of a reference substance, typically water. Similarly, the bark has its own specific gravity value that may differ from the bole specific gravity. The ARB database also provides values representing the percentage of bark volume in total merchantable volume. Therefore, the volume of bark can be determined by taking a portion of total merchantable volume, and the biomass of the bark can then be calculated by using the bark specific gravity values.

C. Stem Biomass

Stem Biomass (tonne) = Bole Biomass (tonne) + Bark Biomass (tonne)

The stem biomass includes both bole and bark biomass, and makes up the portion of the forest carbon sequestration that will be removed through the harvesting process. The stem biomass will eventually be harvested and sent to mills for product processing.

D. Total Above Ground Biomass

Total Aboveground Biomass (tonne) = Stem Biomass (tonne)/ (Stem Biomass / Above Ground Biomass

Tree stems harvested for production represent only a portion of the total biomass of the whole tree, which also includes foliage, branches, and coarse roots. The ratio of each of these tree components to the total aboveground biomass can be approximated based on Jenkins' methods, which use diameter at breast height (DBH) as the primary data input for determining the ratios of the mass of each compartment to total above ground biomass. However, this method only distinguishes trees into hardwood and softwood categories, and does not specify ratios at the tree species level. DBH inputs for the calculations were set as the estimated DBH for trees at an age representing half of a typical rotation length, with measurements for eucalypts and pines coming from a GFP forest asset and measurements for other species being drawn from the scientific literature[35]. Due to lack of available inventory data at the other GFP assets, the compartment ratios determined using GFP forest asset data were applied to eucalypts and pines in all GFP assets, while the compartment ratios determined using literature-sourced DBH data for other species were used where appropriate. These inputs are meant to represent the average DBH that can be expected for each species across a wide range of site indices for the duration of a typical rotation cycle.

E. Below Ground Biomass

*Total Below Ground Biomass = Total Above Ground Biomass (tonne) * (Below Ground Biomass / Total Above Ground Biomass)*

Similar to the process for obtaining total above ground biomass from stem biomass calculation, the below ground biomass is estimated by multiplying the total above ground biomass by the ratio of below ground biomass to total above ground biomass. As noted above in section "**D. Total Above Ground Biomass"**, the below ground biomass was determined as a ratio of the total above ground biomass for each tree.

This follows Jenkins' component ratio method for calculating the masses for different components of the tree.

F. Total Tree Biomass

Total Tree Biomass (tonne) = Total Above Ground Biomass (tonne) + Total Below Ground Biomass (tonne)

The total tree biomass is determined by adding the total above ground biomass and total below ground biomass.

G. Total Tree Carbon

*Total Tree Carbon (tonne C) = Total Tree Biomass (tonne) * 0.5*

The carbon mass of the total tree biomass is estimated by multiplying the biomass value by one-half, representing the assumed average carbon fraction of wood.

5.1.1.1. Live Undergrowth: All non-tree living above-ground biomass is included within this pool. Undergrowth was not considered in our analysis, largely due to the level of uncertainty that would accompany any estimation of its size. In both the ARB and VCS methodologies, the calculation of undergrowth biomass is only applicable to very specific projects, and calculations would be primarily dependent on onsite measurements. There are studies that have attempted to establish undergrowth biomass estimates for forests, but the resulting values are all site-specific and vary by specific climate as well as specific forest type. Due to the lack of ability to perform measurements on every forest site combined with the large amount of uncertainty that would come with using site estimates, we conservatively decided to exclude this pool from our calculations.

5.1.1.2. Dead Standing or Downed Trees: This pool includes both standing and fallen dead trees and represents a general measure of forest mortality. This is a dynamic pool that will emit carbon as a result of the decomposition of wood while also sequestering additional carbon that is being added through new dead wood. The interplay of these carbon emissions and additions often result in a relatively stable level of carbon in the dead tree pool. This assumed scenario does not hold if a significant disturbance has caused increased forest mortality over baseline conditions. Both the ARB and VCS methodologies call for onsite observations to estimate a correction factor for this pool. The ARB specifically refers to Domke *et al.* (2011) for guidance on how to estimate deadwood values within a forest based on site-specific observations[36]. We conservatively decided to exclude this pool due to our lack of ability to make on-site observations and the large amount of uncertainty that would come with making general estimations.

5.1.1.3. Detritus: This pool accounts for all of the downed foliage, branches, and other biomass that has died and fallen to the forest floor. Like the previous dead wood section, this pool acts as a slow release carbon source while the dead biomass decomposes. However, the continuous addition of dead biomass to this pool will typically lead to a relatively stable level of carbon, depending on the relationship between the turnover rate and decomposition rate for each forest stand. This pool of carbon was conservatively excluded from our analysis due to the assumed extreme variability between turnover rate and decomposition rate across all of GFP's assets.

5.1.2. Below Ground Carbon

5.1.2.1. Below Ground Biomass: This pool is predominantly composed of coarse roots from trees. The ARB methodology used to calculate aboveground live tree biomass also calculates the root biomass based on component ratios, so no additional calculation was necessary to quantify this pool. An alternative method sometimes used to calculate this pool is using pre-established, species-specific root-shoot ratios to estimate below ground biomass. For example, the VCS methodology cites Mokany *et al.* (2006) to calculate below ground biomass based on observed aboveground biomass[37].

5.1.2.2. Soil Carbon: Soil carbon represents the largest terrestrial carbon pool in the global ecosystem, comprising an estimated two-thirds of carbon stored within forest ecosystems[38]. For the purposes of this analysis, however, this pool is excluded. Both the ARB and VCS require onsite measurements to quantify carbon storage, which have been discussed previously as infeasible for this analysis. Using an estimation would include a large level of uncertainty due to the extreme variation in soil carbon content for different climatic regions. Considering the scale of carbon already stored within the soil, typically between 50-60% of the carbon sequestered in the forest environment, the general expectation under the two carbon accounting methodologies is that soil carbon concentrations will not be significantly altered without a drastic change in site land use (figures adapted from IPCC)[39]. As our primary goal for this analysis is to first determine a baseline value of GFP's net carbon footprint, no land use change considerations have been made and the soil carbon pool was therefore excluded. Expectations of changes in soil carbon resulting from land use change will be discussed in Appendix A of this report.

5.1.3. Ex Situ Carbon Storage

Once the carbon stored within a forest is harvested, it remains stored as the harvested wood is converted into end-use products. The general methodology for product carbon calculation is based on quantifying the transition of carbon in forest trees to end-use products and then to landfills, as demonstrated in Figure 1 below[40]:

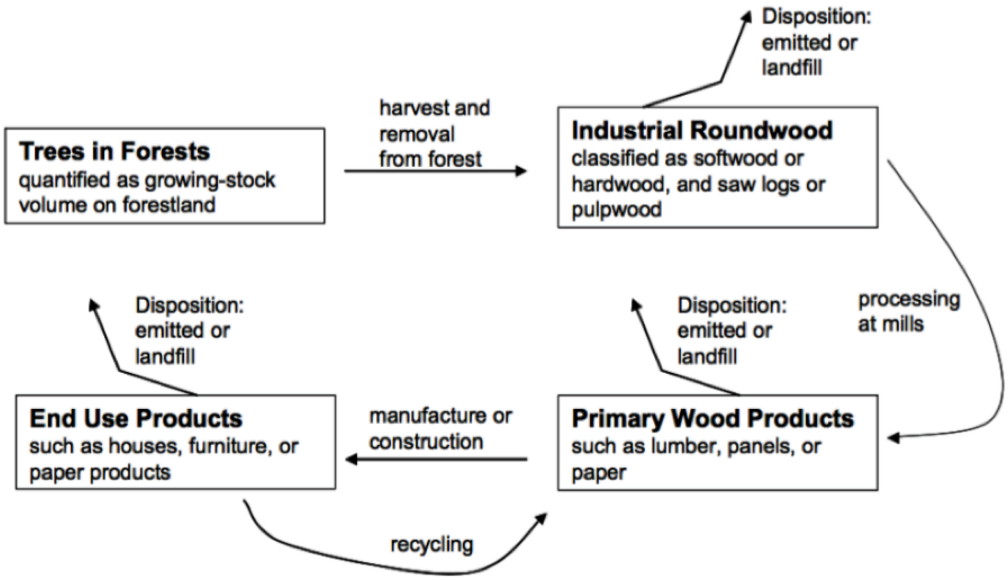


Figure 1: The transition of carbon in forest trees to end-use products is represented by a sequence of distinct pools, separated by the processes that mode carbon between pools.

Our calculation for carbon content in wood products began with the *Industrial Roundwood* pool, which was determined to be the most appropriate fit given the forest removals data available from GFP. The removal inventory obtained from GFP's forest production modeling output is the major input for product carbon calculation; other default values, such as disposition factors, are adopted directly from Smith *et al*. (2006)[40]. The process includes calculating the amount of carbon delivered to the mills, determining the portion of carbon that is converted to wood products, and estimating the share of carbon that is accrued to each end-use product category. In keeping with Smith *et al.* (2006), landfill carbon storage was also included as part of the overall wood product carbon stock.

Both the ARB and VCS refer to Smith *et al*. (2006) to provide a methodology for calculating carbon stored within harvested wood products[40]. This method is designed to calculate the amount of carbon remaining sequestered in wood products on a year-by-year basis over a 100-year time horizon, both for products in the in-use stock and for those that have been landfilled.

5.1.3.1 In-Use Wood Products:

In this project, the following steps were completed to determine product carbon sequestration. The entirety of the methodology was adapted from the *Forest Offset Protocol Appendix C* [30]. Whereas Appendix C provides 100-year average values for product carbon disposition to determine the average yearly sequestration from the wood products pool, our model uses more granular data from Smith *et al.* (2006) to provide a year-by-year estimate of product carbon disposition. This method was felt to be more aligned with the goals and structure of the GFP model, allowing us to examine wood product carbon stock changes on a year-by-year basis.

Primary Data Input

A. Harvest Removal Sum

Merchantable volume (m^3)

Removal sums of harvested wood are the primary data input provided by the Excel tool users. The following calculations provide a step-by-step demonstration of how to use these values to determine wood product carbon sequestration under the ARB methodology.

B. Harvested Carbon

Harvested Carbon (tonne C) = Total Merchantable Volume (m^3) ** Specific Gravity (1 g/*cm^3*) * (tonne/*10^6*g ** $10^6 cm^3/m^3$*) * 0.5*

The quantity of carbon present in the harvested wood is determined by multiplying the merchantable volume of harvested wood by its density and the carbon fraction of wood. The density of harvested wood was assumed to be equivalent to the bole density of the tree species.

C. Wood Product Carbon Stock

*Wood Product Carbon Stock (tonne C) = Harvested Carbon (tonne C) * Annual Disposition Factor*

The quantity of carbon present in the wood product stock is determined by multiplying the carbon mass by the annual disposition factor for that wood product category. These disposition factors are provided on a year-by-year basis over a 100-year time horizon in Table 6 in Smith *et al.* (2006).

D. Cumulative Wood Product Carbon Stock

$$\begin{aligned} &\mathit{total\ carbon\ in}\ \boldsymbol{m}\ \mathit{years} \\ &\quad = \sum_{n=1}^{m} \mathit{removal\ volune\ in\ year}_{\boldsymbol{n}} \times \mathit{tree\ density} \\ &\quad \times \mathit{disposition\ factor\ in\ year}_{\boldsymbol{m\text{-}n+1}} \end{aligned}$$

Due to the longevity of wood products, the carbon stock present in wood products must be summed cumulatively over time to accurately determine the carbon sequestration impacts of wood products. Annual additions to the wood product stock as a result of harvests are considered in this sum, as are the deductions resulting from the gradual decay of the wood products. A calculation example is provided below:

- Year 1, Pines, Softwood Sawlog products

  Total carbon (metric t) = Removal volume in year 1 (m^3*) * density (*t/m^3*) * year 1 disposition factor (%)*
- Year 2, Pines, Softwood Sawlog products

  Total carbon (metric t) = Removal volume in year 1 (m^3*) * density (*t/m^3*) * year 2 disposition factor (%) + Removal volume in year 2 (*m^3*) * density (*t/m^3*) * year 1 disposition factor (%)*
- Year 3, Pines, Softwood Sawlog products

  Total carbon (metric t) = Removal volume in year 1 (m^3*) * density (*t/m^3*) * year 3 disposition factor (%) + Removal volume in year 2 (*m^3*) * density (*t/m^3*) * year 2 disposition factor (%) + Removal volume in year 3 (*m^3*) * density (*t/m^3*) * year 1 disposition factor (%)*

An important factor to note through this process is the impact that the carbon disposition factors will have on different types of products. In this analysis, there is a large difference in the factors associated with pulp logs and saw logs. Pulp logs are assumed to be utilized primarily in the manufacturing of paper products, while saw logs are assumed to be used primarily for manufacturing sturdier products that will be in use over longer periods of time. This difference in expected longevity is reflected in the disposition factors, with the pulp log factors decreasing faster than saw logs as they reach their end of life sooner.

5.1.3.2. Landfills:

As the wood products reach the end of their lifetimes, it was assumed that they are disposed of in landfills. Here, the carbon is stored for an additional period of time while continuing to break down into CO_2. Due to the anoxic environment and typically dry nature of landfills, the decay rate of the landfill carbon stock grows initially but then slows to a stop, leaving a semi-permanent sink of carbon stored in landfills from these wood products[41]. The calculation for carbon stored in landfills is embedded in the above calculations for wood product stock. As the disposition factors shrink for in-use products, the increase in landfill factor is added to the corresponding in-use factor to calculate the total amount of carbon stored in wood products.

5.2. Carbon Emissions

5.2.3. Silvicultural Emissions

This source of carbon includes all the emissions associated with planting, managing, and harvesting the trees cultivated on GFP forest assets. Values for silviculture emissions specific to each management activity were adapted from Markewitz (2006) which quantified the silviculture emissions incurred by a multitude of activities performed under an intensive management regime for loblolly pine stands in the southeastern United States[42]. Additionally, a descriptive timeline of silviculture activities were provided at a species- and region-specific level by GFP's asset managers; this information was used to refine the annual per-hectare silviculture emissions associated with each asset's net forest carbon impacts.

5.2.4. GFP business operations

This source of carbon includes emissions associated with the energy required to operate GFP offices as well as emissions associated with air travel. Annual office emissions resulting from energy use were estimated using data on GFP's office square footage in combination with EPA emission factors for commercial buildings[43]. Air travel emissions were estimated using the total air mileage traveled by GFP associates in 2015 in combination with EPA emission factors associated with air travel[44].

5.3. Development of Asset Carbon Model Tool

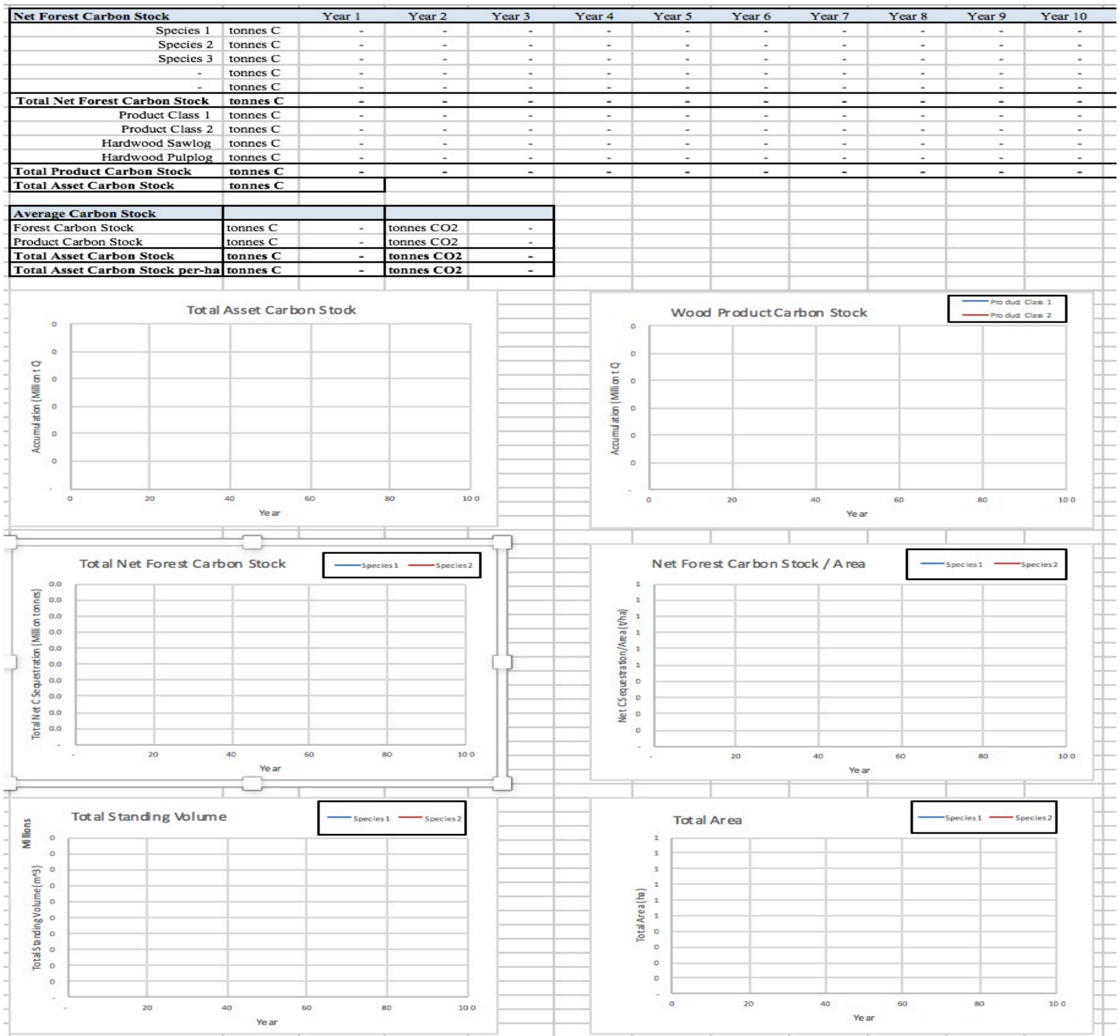
After the methodologies underpinning the calculation of forest carbon, product carbon, and silviculture emissions were defined, we constructed an Excel-based tool to allow users to calculate the total net carbon stock associated with each GFP asset. Based on literature-sourced values for GFP's key tree species, users can input inventory and timber removal data resulting from GFP's forest production model to obtain estimates of the asset's total carbon stock over a 100-year time horizon. Emissions associated with GFP administration activities, including office energy use and business travel, are calculated within a separate Excel file to determine the corporate greenhouse gas footprint. All Excel files developed in this analysis will be provided along with this report.

6. Results and Discussion

Under the terms of our confidentiality agreement with GFP, we have agreed to not disclose any specific values calculated as a result of this analysis. In order to present examples of the data generated in our analysis while protecting this proprietary information, random linear transformations were applied to a selection of data values to simulate the carbon accounting results for a forest asset.

As a result of our analysis of GFP's carbon footprint, we were able to determine that the amount of carbon being sequestered by the forest assets in their portfolio was orders of magnitude greater than the amount of carbon emissions attributable to GFP business operations and silvicultural activities. Under a conventional carbon footprint approach, the values presented below would represent a negative footprint. To more clearly present observable trends in our report, we have transformed our graphs to represent total net carbon sequestration as positive rather than negative values. The following figures demonstrate typical outputs that our model generated for each of the eighteen forest assets modeled.

After the appropriate data fields have been populated by the user, our Excel-based tool generates a summary page in the Excel model that presents projected values for forest carbon stock and wood product carbon stock for that asset over a 100-year time horizon. Figure 2 shows what this summary output page will look like. The carbon stock table at the top of the page shows projected carbon on a year-by-year basis. The blank graphs in the output sheet are populated as line charts with species- or product category-specific series that show how the variable in question varies over time.



Net Forest Carbon Stock		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Species 1	tonnes C	-	-	-	-	-	-	-	-	-	-
Species 2	tonnes C	-	-	-	-	-	-	-	-	-	-
Species 3	tonnes C	-	-	-	-	-	-	-	-	-	-
-	tonnes C	-	-	-	-	-	-	-	-	-	-
-	tonnes C	-	-	-	-	-	-	-	-	-	-
Total Net Forest Carbon Stock	**tonnes C**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Product Class 1	tonnes C	-	-	-	-	-	-	-	-	-	-
Product Class 2	tonnes C	-	-	-	-	-	-	-	-	-	-
Hardwood Sawlog	tonnes C	-	-	-	-	-	-	-	-	-	-
Hardwood Pulplog	tonnes C	-	-	-	-	-	-	-	-	-	-
Total Product Carbon Stock	**tonnes C**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Total Asset Carbon Stock	**tonnes C**										

Average Carbon Stock				
Forest Carbon Stock	tonnes C	-	tonnes CO2	-
Product Carbon Stock	tonnes C	-	tonnes CO2	-
Total Asset Carbon Stock	**tonnes C**	**-**	**tonnes CO2**	**-**
Total Asset Carbon Stock per-ha	**tonnes C**	**-**	**tonnes CO2**	**-**

Figure 2: An example of what the summary output page looks like in our Excel model. The carbon stock table at the top of the page is cut off at year 10, but the model provides annual carbon stock projections out to year 100.

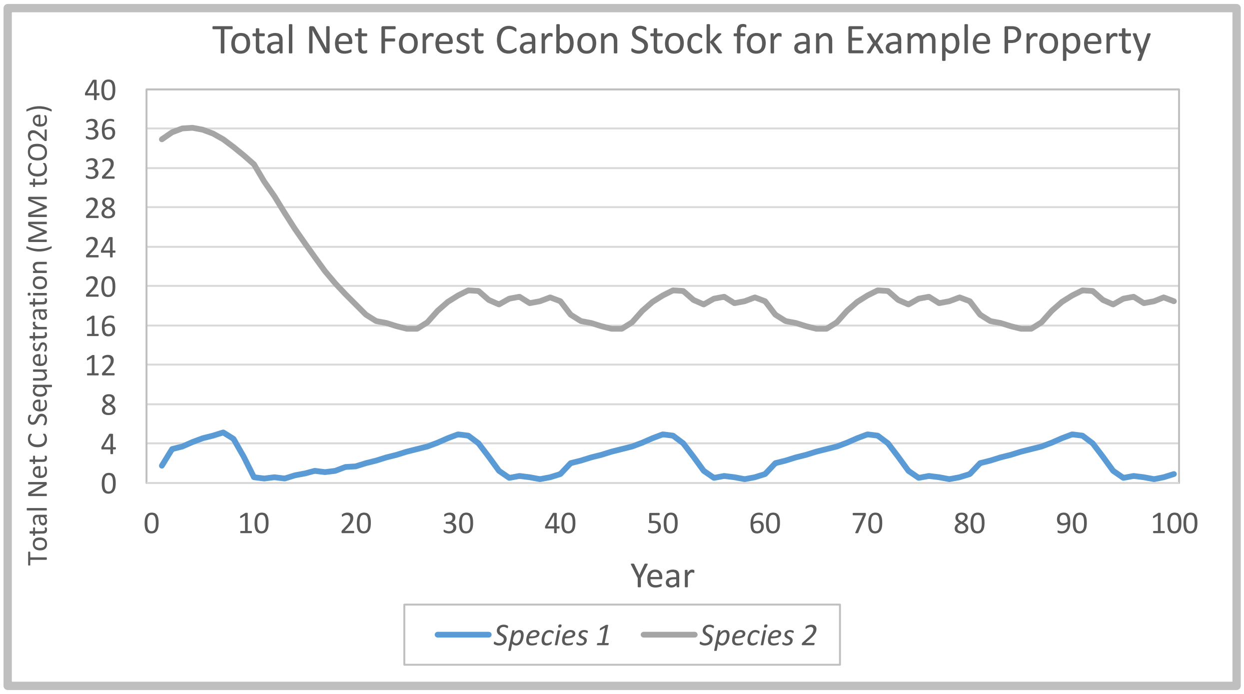


Figure 3: Graphic illustration of how forest carbon sequestration fluctuates over the modeled period for a simulated forest asset. Note the recurring peaks and troughs of sequestered carbon stock resulting from the growth and harvest of forests over time.

Figure 3 is a visual representation of how carbon storage within a forest fluctuates over the course of time. The steep decline for each species represents a harvest where carbon is removed from the forests and shifted towards the product stock.

Figure 3 clearly displays the trends in forest carbon stock that we would expect given our understanding of GFP's silvicultural management process. Across the asset, various stands of trees are planted, accumulate carbon as they grow, and are eventually harvested, returning their carbon stock to zero. While these activities will coincide for stands of the same age class, the range of different age classes and large number of stands present on the asset tend to flatten out the rise and fall of forest carbon stock at an asset level. Due to the uneven distribution of stands within age classes, however, small peaks and troughs emerge in the dataset as above-normal amounts of carbon stock are accumulated and removed as these stands reach harvest age. The average level of carbon stock for each species corresponds to the amount of area devoted to cultivating each species and its average carbon density over a typical rotation.

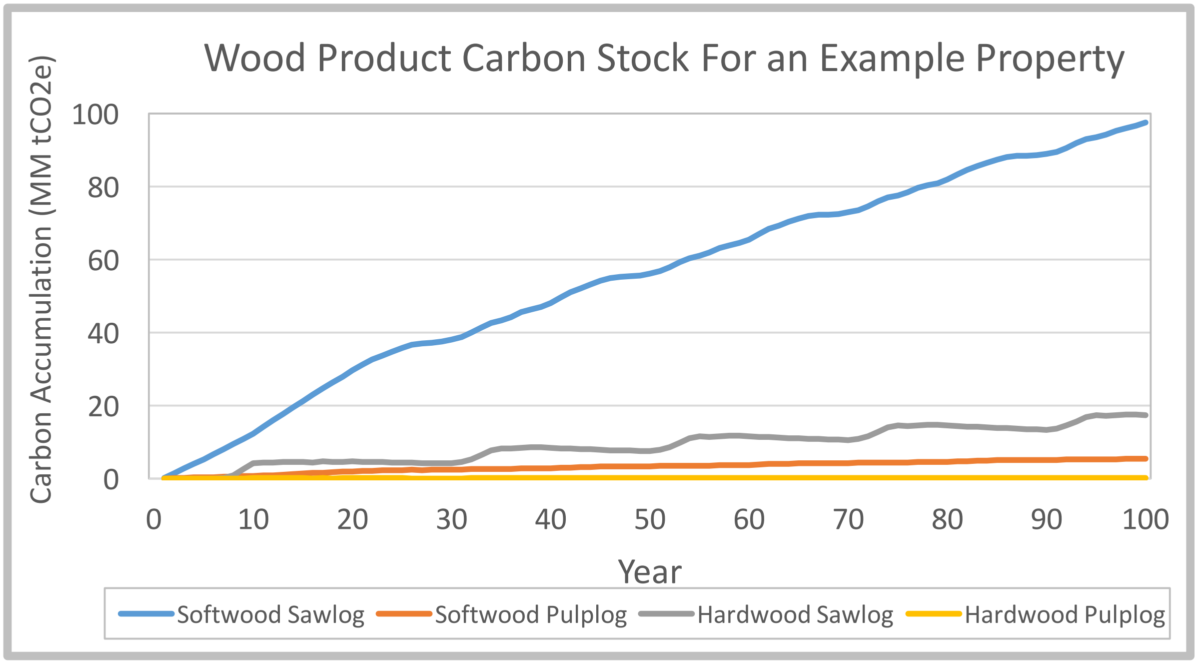


Figure 4: A graphical representation of the trends in the accumulation of sequestered carbon stock that can be observed in a simulated forest asset.

Figure 4 demonstrates how carbon storage within product pools will vary with time beginning from a value of zero in the first year of analysis. When comparing between softwood and hardwood sawlog, one can also notice the step-wise nature of the hardwood sawlog compared to a relatively more consistent rise within the softwood sawlog. As this graph represents product stock resulting from the entire asset, this trend can be attributed to more consistent and extensive harvest activities for softwood in the asset.

Although the values have been randomly adjusted, the starting point was not changed from zero. This is an integral part of our analysis, in which we determined a baseline of carbon sequestration impacts in 2015. Without any past data to consider, the product carbon stock associated with GFP prior to 2015 must be set to zero. A key observation that can be made from this graph is that product carbon stock for sawlogs and pulplogs do not accumulate at the same rate. Both softwood and hardwood sawlog carbon stocks accumulate more quickly than pulplog carbon stocks due to the greater longevity of sawlog products. These different rates of accumulation, as well as different amounts of annual additions to each category from harvesting, result in the different slopes observed for each trend line.

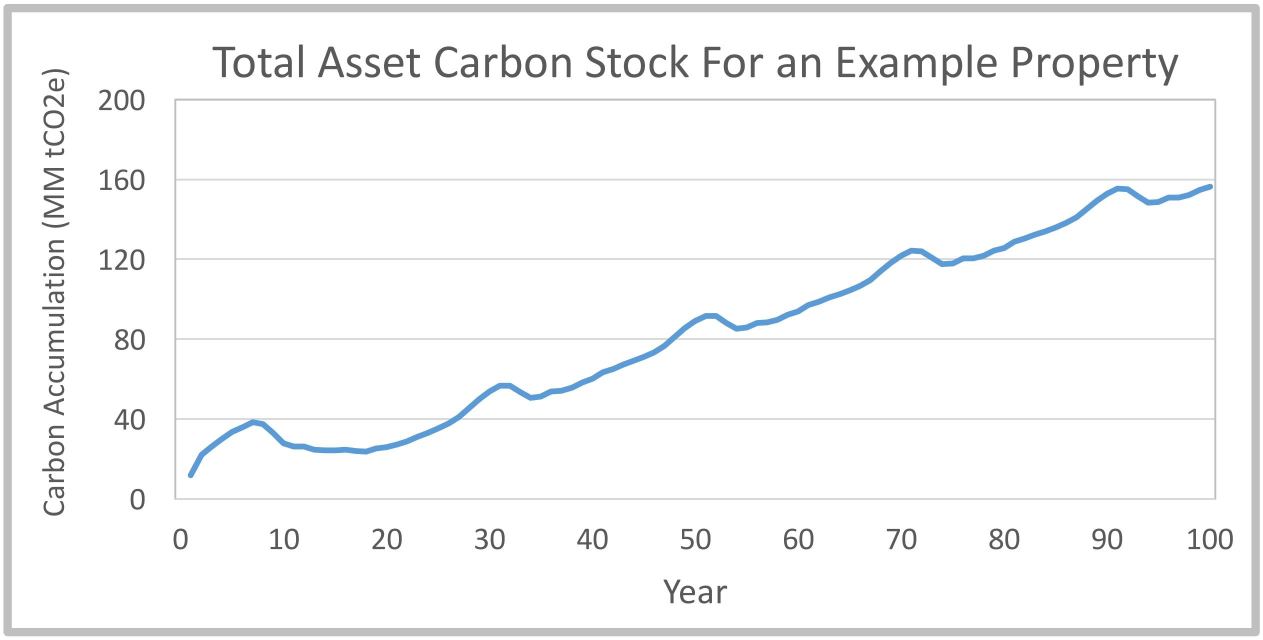


Figure 5: A graphical representation of how the total carbon stock from the forests and wood products of a simulated asset will accumulate through time.

Figure 5 demonstrates how the carbon stock for a simulated asset will increase through time. The recurring small peaks show local maxima in forest carbon stock achieved prior to major harvest events, while the general positive slope of the line demonstrates the accumulation of product carbon stock for the simulated asset over time. The accumulation of carbon stock in the wood product pool drives an overall positive trend in asset-level carbon stock, offsetting negative fluctuations in forest carbon stock following extensive harvest activities

While additions to the product carbon pool largely offset the reduction in forest carbon pool following extensive harvest activities, a small overall decrease in total asset carbon stock can be observed due to losses of carbon during the process of harvesting and processing the timber at mills.

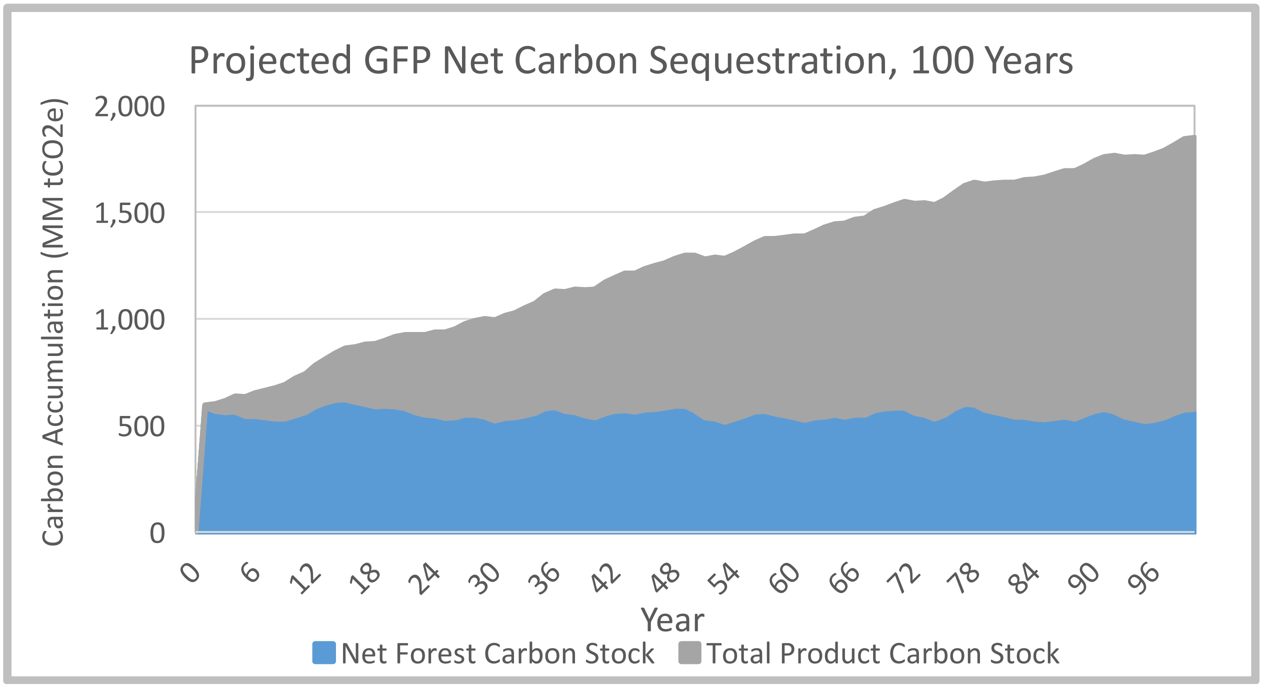


Figure 6: A graphical representation of how both forest carbon stock and product carbon stock accumulate through time across all of GFP assets.

Figure 6 demonstrates the accumulation of both forest carbon stock and product carbon stock across all of Global Forest Partners assets. For an individual asset, the impacts of harvests will have a noticeable impact on total asset carbon stock, but these effects are largely neutralized when observing all assets in aggregate. This figure is also shows the drastic difference between accumulating wood product carbon stock and the relatively stable forest carbon stock.

7. Recommendations

After performing this analysis, it is clear that Global Forest Partners sequesters much greater amounts of carbon emissions than they generate on an annual basis. While this carbon accounting analysis achieved the majority of its goals, recommendations for future uses of this analysis include the following points:

- <u>Integrate carbon sequestration estimation into asset acquisition and management process</u>

  The tool that we have created for GFP within this report will allow the organization to quickly quantify the additional sequestration benefits that an asset acquisition or modification of current management techniques would have. This is particularly useful when evaluating the potential for carbon monetization of an asset. For new acquisitions, GFP can quickly quantify the potential gains that an afforestation project would have and for current assets, GFP can quickly quantify the potential gains that a modification of management would have such as increasing the rotation age of the species at that site.

- Establish a firm institutional understanding of carbon offset projects

  In order to prepare for extensive changes in the global carbon market environment in the coming years, GFP needs to take steps to develop a thorough institutional understanding of the value proposition of carbon offset forestry projects. While this report provides a foundation for this understanding, GFP can take further actions to fully integrate offset projects into their range of strategic options. GFP should continue to keep abreast of global carbon policy developments, track carbon prices and volatility across major existing carbon markets, and estimate the impacts of new carbon markets. Furthermore, GFP should incorporate the Excel-based carbon accounting tool into the valuation process for prospective asset acquisitions in order to assess the regulatory and financial feasibility of pursuing carbon offset programs on the new asset.

- Consider further refinement of the model for region-specific data to meet criteria for carbon offset accreditation

  While the model developed over the course of this analysis allows for a quantification of the carbon sequestration potential different assets possess, it would not be of use when pursuing the certification of carbon offset credits. As we discussed in the methodology of this paper, a widely used methodology for calculating live-tree biomass includes the use of allometric equations and biomass projection programs. There are also a number of pools that rely on on-site measurements which could be estimated with a model that can incorporate more region-specific data.

- Reevaluate carbon monetization potential after 2020

  As is discussed in Appendix A, the simplest and most effective type of carbon offset forestry project to engage in is an afforestation project. The proof of additionality in this instance is much easier than in others, but it relies on the acquisition of a new asset. There are also many geographical restrictions currently placed on forestry projects that greatly decrease the potential GFP may have in accrediting their existing assets. Due to the difficulty of accrediting the carbon being sequestered currently, our group recommends waiting until 2020 before pursuing any projects directly tied to their forestry management. There are several reasons to reevaluate after this date:

- *Chinese ETS*: In line with its goal to peak emissions around 2030, China is planning to implement a national ETS by 2017. There is some doubt surrounding the feasibility of this timeline, but the market is certain to be operational by 2020. The Chinese market is expected to surpass the EU ETS in terms of volume of emissions covered and become the largest ETS body. The use of forest offsets is expected to play an important role in the market, given that China's INDC includes the goal of increasing domestic forest carbon stock by roughly 1 Gigaton[45]. In addition, China has shown intentions of establishing a linkage with South Korea's national ETS, which is currently the world's second-largest carbon market only to the EU ETS in volume of emissions covered[46]. There is already cooperation occurring between Beijing and the South Korean system. Should this connection occur, Asia will become a new global hub for carbon monetization. A complete breakdown of global carbon markets can be found in Appendix C.
- *United States Cap-and-Trade*: Cap-and-trade may reach unprecedented prevalence in the U.S. if the Clean Power Plan takes effect. The Clean Power Plan, developed by the EPA and initially released in 2015, requires states to reduce their emissions by 2030. Under the terms of this legislation, states are allowed to collectively trade emissions reductions in order to meet their goals. It is believed that many states will choose to join an existing emissions trading scheme to meet their goals, such as the California scheme, the Regional Greenhouse Gas Initiative (RGGI) in the Northeast, or else initiate their own schemes. Final state plans for emissions reductions must be submitted by 2018, crafting a new landscape of US carbon markets. Although the legislation has currently been stayed by the Supreme Court, the Clean Power Plan is likely to have a large impact on the future of carbon legislation in the United States.
- *New Emissions Agreements*: The Kyoto Protocol expires in 2020, and discussion has already begun in the international community over how to proceed with reducing emissions in a post-Kyoto policy environment. The UN's REDD+

program received increased attention at the 2015 Conference of Parties in Paris, and seems likely that REDD+ will be further developed and integrated into future international agreements on global emission reductions and forest preservation. The agreement reached in Paris establishes a new reliance on individual contributions from countries, and many are pursuing a market scheme to reach their targets. A thorough breakdown of the impacts that the Paris impacts will have on the role of forests within a carbon trading landscape can be found in Appendix D.

8. Conclusion

With the increasing global focus on reducing greenhouse gas emissions, many companies are attempting to measure their impact footprint. In many instances, electricity use or other typical business activities will result in large quantities of carbon emissions. Due to the expansive portfolio of forest assets that Global Forest Partners (GFP) manages on behalf of its investors, however, GFP finds itself sequestering far greater amounts of carbon than they emit.

As a result of this project, we were able to quantify the large amounts of carbon that GFP sequesters on a yearly basis and provide an Excel-based tool for continued monitoring and evaluation of GFP's carbon impacts. After researching the global stance around carbon trading and the acceptance of forestry-based offset credits, we recommend that GFP begin taking steps to develop competency in planning carbon offset forestry projects in preparation for future changes in the global policy and market environment for carbon. As the future of the global landscape regarding carbon emissions becomes clearer as we progress towards 2020, GFP will be well-placed to evaluate and undertake potential forestry offset projects, maintaining their reputation for investment success, institutional savvy, and environmental consciousness.

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Appendix A: Common Carbon Offset Projects

In order to evaluate the potential for GFP to monetize the carbon being sequestered within their assets, it is important to understand the various types of carbon offset projects that align with GFP's core competencies. While different carbon trading schemes have slight variations and restrictions on accepted projects, we will outline three of the common projects that are most relevant to GFP in the sections below.

Afforestation/Reforestation Projects

Afforestation/reforestation (A/R) projects are endorsed by the Kyoto Protocol and involve the establishment of trees on land that was previously devoid of trees[47]. While the two types of projects are grouped together due to their similar nature, there are small differences between them. While definitions vary on the exact time frame differentiating the two, afforestation projects generally refer to the establishment of forest on land that has historically not contained forest, while reforestation projects refer to the establishment of forests on land that merely has not supported trees over a relatively shorter timeframe[48,49]. Land slated for reforestation projects is generally occupied by forests that have become severely degraded, which can be attributed to disease, damage from pests, extensive fire damage, or other types of disturbances.

While the difference in these projects is small, afforestation projects are easier and more straightforward to engage in due to the relative ease in proving additionality. Reforestation projects have the potential to include more uncertainty surrounding carbon projections in the existing baseline scenario. Depending on the cause of forest degradation in the area that is being slated for a reforestation project, it can be difficult to determine the baseline carbon projection that would occur with natural regeneration of the land. In contrast, afforestation projects occur on land that has not been forested for a considerable amount of time, so there is a body of historical evidence to guide project sponsors in estimating the baseline carbon projection of the previous land use.

The sequestration potential of forested landscapes in comparison to other landscape types was discussed earlier in this report. Given the large amounts of biomass they contain, land conversion to forests holds a significant advantage over many other offset project types in demonstrating clear additionality. The inclusion of A/R projects that involve harvesting is allowed due to the classification by the UNFCCC of forests being "temporarily unstocked" after a harvest[50]. Where forestry projects are allowed, there will usually be a requirement of proof that the forest land is being sustainably harvested, which can be satisfied through certification by a sustainable forestry organization such as the Forest Stewardship Council (FSC). In markets that do not include wood product carbon stock, afforestation projects that result in an un-harvested natural forest will sequester higher amounts of carbon than silvicultural plantations that experience harvest regimes. Soil carbon stocks will likely play a role in estimating the carbon impacts of any A/R project due to the shifting land-use occurring within these projects and will be discussed below.

Soil Carbon

While the model presented in this report does not quantify or project soil carbon stocks, this section seeks to provide a general overview of soil carbon storage potential across several landscapes. Soil carbon calculations are applicable to afforestation projects primarily due to the land use change involved in the project, so research on the matter has been focused on landscapes that are most likely to be involved in afforestation projects. These landscapes include natural forests, silvicultural plantations, grazing lands, and agricultural croplands.

Soil accumulates carbon slowly over time with the addition of both above- and below-ground biomass. As the organic matter decomposes in the soil, some carbon dioxide will be released back to the atmosphere, but a certain level of carbon that is not easily decomposed, such as lignin contained within the plant, will remain stored in the soil[51]. Soil carbon quantities are affected largely by both biomass additions as well as climatic variables. Globally, the highest latitudes have the largest soil carbon stocks due to the low temperatures that discourage decomposition, while soil carbon stocks in the tropics are able to grow despite a climate that encourages rapid decomposition, due to the large amount of biomass additions[52,53].

Forests produce the greatest amounts of biomass in the world and, as a result, contribute the greatest amounts of litter to soil carbon[54]. While forestry operations harvest large portions of the biomass that would otherwise contribute to the soil carbon pool under natural conditions, the long rotation ages allow for a buildup of yearly litter as well as large amounts of root biomass.

Harvesting operations are also responsible for disturbing soil carbon stocks on site, leaving the site susceptible to erosion until a new rotation is planted.

Guo & Gifford (2002) performed a meta-analysis of how land use changes affect soil carbon stocks[55]. The findings of this study indicate the highest amount of soil carbon storage potential in pasture land, followed by natural forest land, silvicultural plantation land, and crop agriculture land. This ranking is not universally agreed upon, with some varying results on soil carbon storage within pasture land. Nilsson & Schopfhauser (1995) found soils within pasture land to have the lowest carbon content out of the four landscapes with the other three ranked in the same order[54]. When GFP certified their 'El Arriero' property as an afforestation project, the scientific literature supported a conclusion that the pasture land in question had lower soil carbon stocks than would occur in the proposed plantation area[56,57].

Paul *et al.* (2002) discusses how many of these soil carbon measurements are taken as secondary measurements and are not the main focus of many experiments[58]. This leads to inconsistent methodologies, classifications, and as a result, potentially inconsistent data. While these studies have found varied results on the soil carbon content of different landscapes, we will review each of the four main types described in the above studies in greater detail.

- Crop Agricultural Land: It is generally acknowledged that these lands are very poor for carbon accumulation. These systems contain much less biomass than forested systems, most of which is harvested and removed on an annual or semiannual basis. The ground is constantly disturbed as land is prepared for planting and then harvested later in the season, which discourages buildup of the soil and encourages erosion. Agricultural lands are often left fallow for large portions of the year, which encourages further erosion of soil carbon stocks. If GFP were to pursue a project that involved establishing a forest on old agricultural land, soil carbon will be an important carbon pool to consider.
- Pasture Land: There are conflicting conclusions about the carbon content of grazed lands and are likely dependent on the health of the pasture being surveyed. Overgrazed lands imply that vegetation has not been allowed to regenerate adequately, leading to several negative consequences including a reduction in soil carbon stocks. Natural grassland, however, has been shown to recycle carbon content at greater rates than forested lands, which can lead to

rapid accumulations of soil carbon[54]. The continuous ground cover allows for minimal erosion and more consistent accumulation of carbon content. It is likely this difference that has caused conflicting comparisons of grazing land to both silvicultural plantations and naturally forested lands. If GFP were to engage in an afforestation project on former pasture lands, it would be important to gain an understanding of the landscape beforehand, such as was demonstrated in the ‘El Arriero’ carbon offset project.

- Silvicultural Plantations: As discussed in the previous section on grazing land, there are is debate surrounding the soil carbon storage potential of silvicultural plantations relative to grazing lands, but silvicultural plantations are consistently considered to store more soil carbon than crop agricultural land and less soil carbon than naturally forested lands. While silviculture is a form of agriculture, it involves far less frequent disturbance of the land and much greater amounts of biomass are allowed to remain on site to decompose and contribute to the soil. There are still large amounts of biomass removed from the site that ensure plantations will consistently contain less soil carbon than natural forests. Different carbon accounting methodologies will have different means for calculating soil carbon content as a part of a silvicultural project and it is important to use these methods to compare potential project gains relative to the baseline conditions.
- Natural Forest Land: In the context of the research done in this area, natural forest land refers to unmanaged forest that is allowed to grow without any sort of biomass harvest. When considering soil carbon in forest ecosystems, the main substantial differences in conditions between natural forest land and a silvicultural plantation occurs as a result of the harvest process and undergrowth clearing that the silvicultural plantation undergoes. Based on these differences, natural forest land will accumulate slightly more soil carbon due to increased biomass accumulation on the forest floor and the avoidance of soil disturbance from harvest machinery. While natural forests may face disturbances such as fire or disease, leading to less carbon accumulation, these types of disturbances are not accounted for in the research done on the issue.

Improved Management Techniques Projects

Improved management technique projects cover projects that are designed to improve the productivity of land already being managed for silvicultural purposes. This report will provide several examples defined within the ARB methodology including[30]:

- Increasing the overall age of the forest by increasing rotation ages
- Increasing the forest productivity by thinning diseased and suppressed trees
- Managing competing brush and short-lived forest species
- Increasing the stocking of trees on understocked areas
- Maintaining stocks at a high level

While this list does not include every type of activity that can improve the management of silvicultural lands, it gives a clear overview of some major means of improving land productivity. Assuming current GFP assets are being managed to maximize productivity, the potential for GFP to develop a project in this category on current assets is limited to a potential increase in rotation age.

While longer rotation ages may achieve higher levels of sustained biomass in the forest, there are conflicting studies discussing the effects on other pools of carbon that may reduce the net gains that can be achieved by the project[59]. The impact on soil carbon, for example, is unclear due to the impacts of fewer harvests. During a harvest, there is a drastic increase in biomass additions to the soil carbon stock, but there are also emissions and land disturbance associated with the use of harvesting machinery. The impact on wood product pools is another area of conflicting impacts associated with longer rotational ages. Longer rotations result in less carbon entering the product pool, which would decrease the carbon sequestration benefits associated with this type of product. Conversely, increased rotation lengths have the potential to increase the proportion of saw logs being produced at the asset, which can be turned into long-lived products with a greater carbon longevity than their pulpwood counterparts. Overall, the benefits associated with improved management techniques will likely be harder to quantify and will likely not have the same magnitude of net sequestration benefit as other types of offset projects.

REDD + Projects

REDD+ projects are the first category of offset projects discussed that is not endorsed by the Kyoto Protocol. Short for 'Reducing Emissions from Deforestation and Forest Degradation', the REDD+ program seeks to provide a financial incentive for developing countries in tropical regions to better manage and supervise the forests within their country[60-62]. Deforestation has been a topic of great concern in the global community, with a particular focus on deforestation activities occurring in tropical regions. Even though tropical forests contain the highest amounts of biomass in the world, the level of deforestation taking place in the tropics has made tropical forests a net source for global carbon emissions [63,64]. The REDD+ program seeks to not only create a mechanism to directly encourage responsible forest stewardship, but also to generate increased funds for sustainable development.

There are five types of projects that are specifically referred to that may qualify for the REDD+ program including[65]:

- Reducing emissions from deforestation
- Reducing emissions from forest degradation
- Conservation of forest carbon stocks
- Sustainable management of forests
- Enhancement of forest carbon stocks

This wide array of allowed project types combines and builds upon those previously described project types endorsed by the Kyoto Protocol. The REDD+ program hopes to build upon the Kyoto Protocol methodologies by not only quantifying forest carbon stocks but also encouraging sustainable development within developing countries. The program has continually developed since its creation and is likely to be a focus of global agreements for combatting climate change after the expiration of the Kyoto Protocol in 2020.

Appendix B: User Manual for the Excel Carbon Model

Forest Asset Carbon Excel Tool
User Guidebook

Produced on behalf of Global Forest Partners LP
Date: 18 April, 2016

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Table of Contents

1. Introduction

This guidebook is intended to provide the user of the Asset Carbon Excel Tool with a detailed description of the framework and data values utilized within the Excel Tool, as well as a step-by-step walkthrough that will train the user to make use of the Excel Tool for the purposes of modeling the carbon footprint of a forest asset.

The Asset Carbon Excel Tool was developed by the graduate student team of the University of Michigan's School of Natural Resources and Environment (SNRE), in conjunction with Ernest "Bo" Dixon, IV and David Lindahl of Global Forest Partners LP (GFP). The intent of the tool is to provide users with a transparent, easy-to-learn vehicle for estimating the carbon footprint of a forest asset on the basis of the carbon sequestered in its trees ("Forest Carbon") and in the wood products that result from the harvesting of those trees ("Product Carbon"). Carbon emissions resulting from the silviculture activities occurring in the forest asset are also estimated in the model.

The tool's default data values and calculation methodologies are based primarily upon the methodology utilized by the California Air Resources Board (ARB) for quantifying carbon sequestration in forests within the California cap and trade program. Supplemental data was also taken from peer-reviewed scientific literature regarding relevant forestry research. These sources will be explicitly attributed to the data and calculation steps of the Excel Tool in the **Overview of Excel Tool Contents** section of this guidebook.

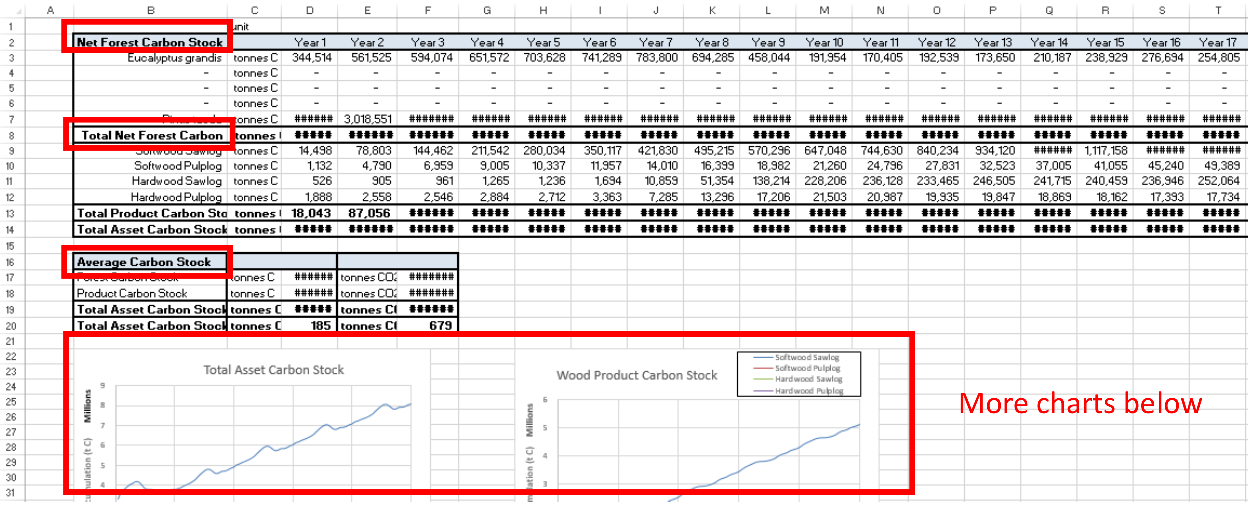
The tool is specifically calibrated to allow the user to leverage asset-level data obtained from GFP's forest production model for forest inventories and harvest yields to quickly determine the average annual Carbon footprint of that asset over a 100-year time horizon. The **Modeling a Forest Asset** section of this guidebook will provide a detailed overview for the proper process of utilizing the Excel tool. This process is primarily limited to overseeing the translation of input data into the Excel tool's format, as well as refining the tool's charts and MAI regression equations that help to accurately fill data holes.

2. Overview of Excel Tool Contents

a. Summary Output

This sheet contains the final outputs of:

- The two main components of the Excel tool (Forest Carbon modeling and Product Carbon modeling)
- The asset's overall average carbon stock resulting from the annual average impact of those same two components
- A number of summary charts to quickly inform the reader about the scale and trends of the asset's carbon impact



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1			unit																	
2		**Net Forest Carbon Stock**		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17
3		Eucalyptus grandis	tonnes C	344,514	561,525	594,074	651,572	703,628	741,289	783,800	694,285	458,044	191,954	170,405	192,539	173,650	210,187	238,929	276,694	254,805
4		-	tonnes C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5		-	tonnes C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6		-	tonnes C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7		[illegible]	tonnes C	######	3,018,551	#######	######	######	######	######	######	######	######	######	######	######	######	######	######	######
8		**Total Net Forest Carbon**	**tonnes**	**#####**	**######**	**######**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**
9		Softwood Sawlog	tonnes C	14,498	78,803	144,462	211,542	280,034	350,117	421,830	495,215	570,296	647,048	744,630	840,234	934,120	######	1,117,158	######	######
10		Softwood Pulplog	tonnes C	1,132	4,790	6,959	9,005	10,337	11,957	14,010	16,399	18,982	21,260	24,796	27,831	32,523	37,005	41,055	45,240	49,389
11		Hardwood Sawlog	tonnes C	526	905	961	1,265	1,236	1,694	10,859	51,354	138,214	228,206	236,128	233,465	246,505	241,715	240,459	236,946	252,064
12		Hardwood Pulplog	tonnes C	1,888	2,558	2,546	2,884	2,712	3,363	7,285	13,296	17,206	21,503	20,987	19,935	19,847	18,869	18,162	17,393	17,734
13		**Total Product Carbon Sto**	**tonnes**	**18,043**	**87,056**	**######**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**
14		**Total Asset Carbon Stock**	**tonnes**	**#####**	**######**	**######**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**
15																				
16		**Average Carbon Stock**																		
17		Forest Carbon Stock	tonnes C	######	tonnes CO2	#######														
18		Product Carbon Stock	tonnes C	######	tonnes CO2	#######														
19		**Total Asset Carbon Stock**	**tonnes C**	**#####**	**tonnes C(**	**######**														
20		**Total Asset Carbon Stock**	**tonnes C**	**185**	**tonnes C(**	**679**														

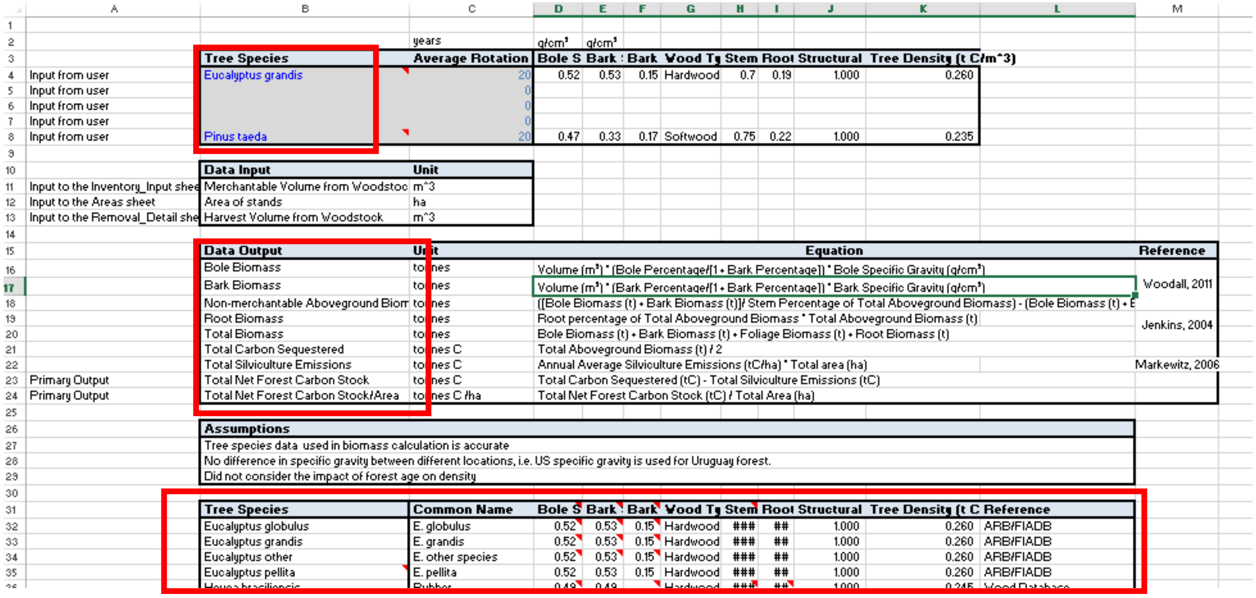
More charts below

b. Info and Assumptions

i. *Description*

This sheet contains:

- An overview of the tree species cultivated in the asset
- The calculations utilized to determine the carbon stock represented by the asset's standing trees
- A table providing default values for various aspects of tree biomass distribution for the main species that GFP manages



	Tree Species	Average Rotation	Bole S	Bark :	Bark	Wood Ty	Stem	Root	Structural	Tree Density (t C/m^3)
		years	g/cm³	g/cm³						
Input from user	Eucalyptus grandis	20	0.52	0.53	0.15	Hardwood	0.7	0.19	1.000	0.260
Input from user		0								
Input from user		0								
Input from user		0								
Input from user	Pinus taeda	20	0.47	0.33	0.17	Softwood	0.75	0.22	1.000	0.235

	Data Input	Unit
Input to the Inventory_Input shee	Merchantable Volume from Woodstoc	m^3
Input to the Areas sheet	Area of stands	ha
Input to the Removal_Detail she	Harvest Volume from Woodstock	m^3

	Data Output	Ur it	Equation	Reference
	Bole Biomass	to nes	Volume (m³) * (Bole Percentage/[1 + Bark Percentage]) * Bole Specific Gravity (g/cm³)	Woodall, 2011
	Bark Biomass	to nes	Volume (m³) * (Bark Percentage/[1 + Bark Percentage]) * Bark Specific Gravity (g/cm³)	
	Non-merchantable Aboveground Biom	to nes	([Bole Biomass (t) + Bark Biomass (t)]/ Stem Percentage of Total Aboveground Biomass) - (Bole Biomass (t) + B	Jenkins, 2004
	Root Biomass	to nes	Root percentage of Total Aboveground Biomass * Total Aboveground Biomass (t)	
	Total Biomass	to nes	Bole Biomass (t) + Bark Biomass (t) + Foliage Biomass (t) + Root Biomass (t)	
	Total Carbon Sequestered	to nes C	Total Aboveground Biomass (t) / 2	
	Total Silviculture Emissions	to nes C	Annual Average Silviculture Emissions (tC/ha) * Total area (ha)	Markewitz, 2006
Primary Output	Total Net Forest Carbon Stock	to nes C	Total Carbon Sequestered (tC) - Total Silviculture Emissions (tC)	
Primary Output	Total Net Forest Carbon Stock/Area	to nes C /ha	Total Net Forest Carbon Stock (tC) / Total Area (ha)	

Assumptions
Tree species data used in biomass calculation is accurate
No difference in specific gravity between different locations, i.e. US specific gravity is used for Uruguay forest.
Did not consider the impact of forest age on density

Tree Species	Common Name	Bole S	Bark :	Bark	Wood Ty	Stem	Root	Structural	Tree Density (t C	Reference
Eucalyptus globulus	E. globulus	0.52	0.53	0.15	Hardwood	###	##	1.000	0.260	ARB/FIADB
Eucalyptus grandis	E. grandis	0.52	0.53	0.15	Hardwood	###	##	1.000	0.260	ARB/FIADB
Eucalyptus other	E. other species	0.52	0.53	0.15	Hardwood	###	##	1.000	0.260	ARB/FIADB
Eucalyptus pellita	E. pellita	0.52	0.53	0.15	Hardwood	###	##	1.000	0.260	ARB/FIADB

On this page, the user must input values representing the name and average rotation length of each species grown in the asset. The cells containing tree biomass distribution data in the first table on the sheet will then populate to provide clarity to the end user, and serve as a source for calculations performed in the *Forest_Carbon* and *Product_Carbon_Calculation* sheets.

ii. Read Me

This sheet is intended to give a short overview of the contents of each sheet in the Excel tool. The *Read_Me* sheet should serve as a brief summary of the contents of this section of the Excel tool guidebook and provide the user with a quick reference point regarding the purpose and content of each sheet.

iii. Silviculture Emissions

This sheet provides a detailed overview of the carbon emissions produced by the silvicultural practices that are assumed to occur on a per-hectare basis over the course of a single rotation for each species in the asset. These values and processes are drawn from Markewitz (2006), which studied loblolly pine stands in the Southeastern United States under intensive management regimes and were assumed to be reasonably similar to GFP’s silvicultural practices[42]. These emissions are summed over the course of one rotation and annualized to develop a single total tonne C emissions/hectare-year figure. Data values that are not relevant due to the silvicultural regime used to manage a specific species on the asset should be removed from the total tonne C emissions/hectare figure employed for that species in the sheet.

iv. Methodology Comparison

This sheet provides a high-level overview of the carbon pools that are included and estimated under two predominant carbon accounting methodologies, the Verified Carbon Standard (VCS) and the methodology employed by the California Air Resources Board (ARB), as well as the GFP proprietary Forest Asset Carbon Excel Tool. This should provide the reader with a quick comparison between the different prevailing methodology, as well as a brief justification for the pools' inclusion or exclusion in the GFP model.

c. Detailed Output

i. Forest Carbon

This sheet summarizes the data values relevant for determining the carbon stock of the standing volume of each species in the forest asset.

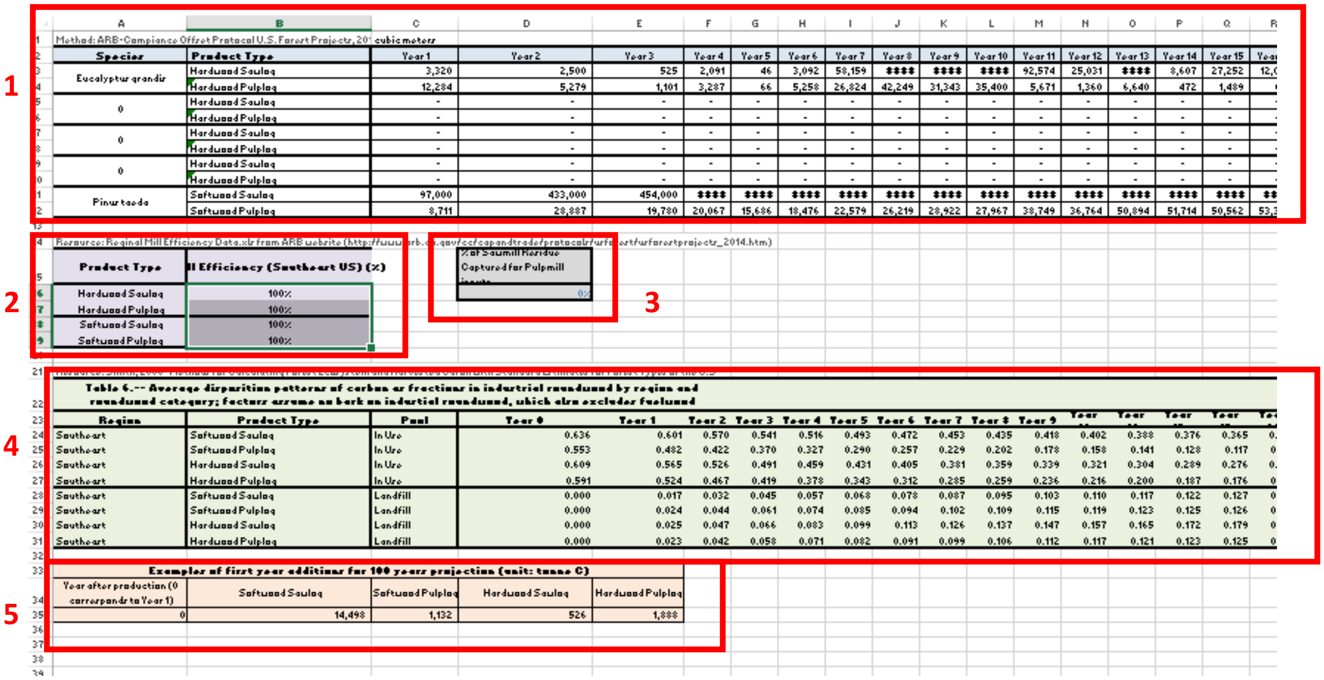
- In the first table, the inventory data provided from the *Inventory_Output* sheet is summarized.
- In the second table, the standing volume data is multiplied by the tree compartment ratio values in the *Description* sheet to obtain estimates of the biomass present in the Bole, Bark, Non-merchantable Aboveground, and Root compartments of the assets' trees.
- In the third table, these biomass values are multiplied by the default carbon fraction of ½ to obtain an estimate of the total carbon sequestered by each species.
- In the fourth table, the per-hectare silvicultural emissions associated with managing each species are multiplied with the area occupied by that species to determine total silvicultural emissions.

- The fifth table shows a summary of the area occupied by each species in the asset on a year-by-year basis.
- In the sixth table, the total silvicultural emissions of each species is subtracted from the total carbon sequestered by each species in order to determine the total net forest carbon stock of each species. This table represents the final output of the *Forest_Carbon* sheet, and as such is referred to by the *Summary_Output* sheet.
- Finally, the total net forest carbon stock is summarized on a per-hectare basis for each species in the seventh table.

ii. Removal Sum

This sheet summarizes the removal data provided in the *Removal_Detail* sheet.

- The first table summarizes the total removal volumes for each species and product types on a year-by-year basis.
- The second table (in purple) contains factors representing lumber or pulp mill efficiency. As the carbon disposition factors provided in the fourth table have this value already included, mill efficiencies were set to a default of 100% under our project methodology.
- The third table (in grey) allows the user the ability to change the percentage of sawmill residue that is captured and reused as pulp mill inputs. In keeping with the assumptions of the ARB methodology, we have set this value to a default of 0%.
- The fourth table (in green) contains the average disposition patterns of carbon as fractions of the initial timber carbon stock less bark. The values in this table are drawn directly from Smith *et al.*, 2006 (Table 6, P30-31)[40]
- The fifth and last table (in orange) provides an example for the product carbon stock calculation process.



Method: ARB-Compliance Offset Protocol U.S. Forest Projects, 20 cubic meters

Species	Product Type	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Yea
Eucalyptus grandis	Hardwood Sawlog	3,320	2,500	525	2,091	46	3,092	58,159	####	####	####	92,574	25,031	####	8,607	27,252	12,
	Hardwood Pulplog	12,284	5,279	1,101	3,287	66	5,258	26,824	42,249	31,343	35,400	5,671	1,360	6,640	472	1,489	
0	Hardwood Sawlog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Hardwood Pulplog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
0	Hardwood Sawlog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Hardwood Pulplog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
0	Hardwood Sawlog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Hardwood Pulplog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Pinus taeda	Softwood Sawlog	97,000	433,000	454,000	####	####	####	####	####	####	####	####	####	####	####	####	##
	Softwood Pulplog	8,711	28,887	19,780	20,067	15,686	18,476	22,579	26,219	28,922	27,967	38,749	36,764	50,894	51,714	50,562	53,

Resource: Reginal Mill Efficiency Data.xls from ARB website (http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/usforestprojects_2014.htm)

Product Type	ll Efficiency (Southeast US) (%)
Hardwood Sawlog	100%
Hardwood Pulplog	100%
Softwood Sawlog	100%
Softwood Pulplog	100%

% of Sawmill Residue Captured for Pulpmill inputs
0%

Table 6.-- Average disposition patterns of carbon as fractions in industrial roundwood by region and roundwood category; factors assume no bark on industial roundwood, which also excludes fuelwood

Region	Product Type	Pool	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year	Year	Year	Year	Yea
Southeast	Softwood Sawlog	In Use	0.636	0.601	0.570	0.541	0.516	0.493	0.472	0.453	0.435	0.418	0.402	0.388	0.376	0.365	0.
Southeast	Softwood Pulplog	In Use	0.553	0.482	0.422	0.370	0.327	0.290	0.257	0.229	0.202	0.178	0.158	0.141	0.128	0.117	0
Southeast	Hardwood Sawlog	In Use	0.609	0.565	0.526	0.491	0.459	0.431	0.405	0.381	0.359	0.339	0.321	0.304	0.289	0.276	0.
Southeast	Hardwood Pulplog	In Use	0.591	0.524	0.467	0.419	0.378	0.343	0.312	0.285	0.259	0.236	0.216	0.200	0.187	0.176	0
Southeast	Softwood Sawlog	Landfill	0.000	0.017	0.032	0.045	0.057	0.068	0.078	0.087	0.095	0.103	0.110	0.117	0.122	0.127	0
Southeast	Softwood Pulplog	Landfill	0.000	0.024	0.044	0.061	0.074	0.085	0.094	0.102	0.109	0.115	0.119	0.123	0.125	0.126	0
Southeast	Hardwood Sawlog	Landfill	0.000	0.025	0.047	0.066	0.083	0.099	0.113	0.126	0.137	0.147	0.157	0.165	0.172	0.179	0
Southeast	Hardwood Pulplog	Landfill	0.000	0.023	0.042	0.058	0.071	0.082	0.091	0.099	0.106	0.112	0.117	0.121	0.123	0.125	0

Examples of first year additions for 100 years projection (unit: tonne C)

Year after production (0 corresponds to Year 1)	Softwood Sawlog	Softwood Pulplog	Hardwood Sawlog	Hardwood Pulplog
0	14,498	1,132	526	1,888

d. <u>Inputs and Calculations</u>

i. Inventory Inputs

In this sheet, the user must input the asset's standing inventory values from GFP's forest production model, which represent the annual merchantable volume within each age class of each tree species cultivated in the asset. The species name in the first left column will be automatically filled according to the first table in the *Forest_Carbon* sheet. The sheet provides space to hold inventory data over a 100-year period for age classes 0 to 60 for each tree species. It is not necessary to populate all the cells, and all blank cells will be carried through as zeroes in the related sheets of the Excel file.

ii. Unit Stocking

In this sheet, the asset inventory values from the previous sheet are tallied and used to determine a weighted average stocking level per-hectare for each species in Column CZ. These values are used as the data values for a linear regression of merchantable volume against age. The table found in cells DC4:DF9 shows the results of that linear regression for a default selection of the stocking level of each species from ages 10-22. Column DA calculates a projected average stocking level per-hectare on the basis of these linear regressions, which are drawn upon in the following *Inventory_Output* sheet in the event of missing data values. The intent of Column DA is to quantify the pre-merchantable volume present on young stands so that the carbon content of these stands can be estimated.

iii. Inventory Output

In this sheet, the final inventory values used to determine the annual merchantable volume values within each class of each tree species cultivated in the asset are shown. This sheet requires no user manipulation, and operates based on a logic that prompts the model to select the original input inventory data from the *Inventory_Input* sheet where possible. If the values in the *Inventory_Input* sheet are missing or zeroes, the model instead selects the projected inventory data based on the *Unit_Stocking* sheet, or otherwise populates the cells with zeroes in the event of both previous data values being zero. The sheet provides space to hold inventory data over a 100-year period for age classes 0 to 60 for each tree species.

iv. Areas

In this sheet, the user must input the asset area values, representing the areas covered by each age class of each tree species cultivated in the asset. The species name in the first left column will be automatically filled according to the first table in the *Forest_Carbon* sheet. The sheet provides space to hold area data over a 100-year period for age classes 0 to 60 for each tree species. It is not necessary to populate all the cells, and all blank cells will be carried through as zeroes in the related sheets of the Excel file.

v. Removal Detail

In this sheet, the user must input the detailed removal data from the GFP forest production model. Column A, representing species name, will be automatically filled according to the first table in the *Forest_Carbon* sheet. The user must further specify the product type (Sawlog or Pulplog) represented by each row of removal data in Column B and provide the product index.

vi. *Product Carbon Calculation*

This sheet calculates the forest product carbon and lists all the intermediate annual data used to obtain the final results for annual wood product carbon stock within each of the four product categories. Each grouping of ten rows in the 100 x 100 data table draws upon total removal data by product category for that year and multiplies it by the corresponding disposition factors and mill efficiency from the *Removal_Sum* sheet and tree densities from the *Description* sheet. The second table at the bottom sums each column to get cumulative annual figures.

3. Guide to Modeling a Forest Asset

a. Translating input data from GFP's forest production model

i. *Selecting tree species and rotation length*

Begin by selecting the *Description* sheet in the Excel tool. Cells B4:C8 (formatted with a gray background and blue text) are designated to receive user inputs regarding the tree species present in the asset and the average rotation length of each of those species. The species name inputs will be utilized to populate the other sheets of the Excel tool to indicate the tree species being modeled. The rotation length will be used to determine the annual per-hectare silvicultural emissions associated with each species, as well as for fine-tuning the mean annual increment (MAI) linear regression model and for selecting rotations for replication over the 100-year time horizon.

In column B, begin by selecting the tree species in the asset from those provided in the dropdown list. This will cause the blank cells of the topmost table to populate cells D4:K8 with values specific to each tree species. It will also populate the species-specific cells in the *Summary_Output*, *Silviculture_Emissions*, *Forest_Carbon*, *Removal_Sum*, and *Product_Carbon_Calculation* sheets with the species names.

In column C, input the average rotation length for each tree species in years. This data should be obtained from the average clearfell age of each tree species as determined in the GFP forest production model's *Average Ages* sheet for that asset. When this data is not available, you may instead choose to discuss the typical rotation length with the asset manager or utilize an assumption based on typical rotation lengths for each species across GFP's other forest assets. A rotation length must be selected for each tree species modeled in the Excel tool.

An additional step in the process is required for assets that have tree species falling under multiple management or ownership regimes. For example, in one of GFP's eucalyptus assets, eucalyptus stands are cultivated under three different ownership regimes. In the case of these scenarios, the user must take additional steps to distinguish the different regimes in the Excel tool. To begin, the user should create a comment for each of the ownership/management regimes in column B of the *Description* sheet, indicating the name of the regime as it appears in the GFP forest production model output and the name that will be used in the other sheets of the Excel tool (for example, using the name "Eucalyptus spp" to represent a specific ownership regime within a eucalyptus asset). Next, the user must go to the *Forest_Carbon* sheet and update the species name labels in cells B4:B8 to align with the newly-designated label convention. This change will update the species names in the *Summary_Output*, *Silviculture_Emissions*, *Inventory_Input*, *Unit_Stocking*, *Inventory_Output*, and *Removal_Detail* sheets, clearly designating the different regimes for the user's next input steps and later interpretation.

ii. Inventory inputs

Begin by selecting the *Inventory_Inputs* sheet in the Excel tool. In this step, the user will copy and paste the inventory data from the *Inventory* sheet of the GFP forest production model into the framework of the Excel tool's *Inventory_Inputs* sheet. This data will be used in the *Unit_Stocking*, *Inventory_Outputs*, *Forest_Carbon*, and *Summary_Output* sheets to determine the carbon impact of the standing trees in the forest asset.

For each tree species, select the inventory data for each age class (row data) to be copy and pasted into the corresponding row in the *Inventory_Inputs* sheet in the Excel tool. Be sure to copy and paste the data as values in order to maintain the formatting of the Excel tool. It is important to be aware of missing age classes in the GFP forest production model output - inventory data should only be copied over from the age classes that are detailed in the GFP forest production model output. Do not address any apparent holes in the data, or make any additional changes to the input data; the Excel tool will handle the issue of missing data in later sheets. The user should also take note of whether the GFP forest production model data begins in year 0 or year 1 (the year values can be found in the column labels in row 2), and ensure that the input data for other sheets in the Excel tool begins in that same year.

iii. Areas

Begin by selecting the *Areas* sheet in the Excel tool. In this step, the user will copy and paste the area data from the *Areas* sheet of the GFP forest production model into the framework of the Excel tool's *Areas* sheet. This data will be used in the *Unit_Stocking*, *Inventory_Outputs*, *Forest_Carbon*, and *Summary_Output* sheets to determine the carbon impact of the standing trees in the forest asset.

For each tree species, select the area data for each age class (row data) to be copied and pasted into the corresponding row in the *Areas* sheet in the Excel tool. Be sure to copy and paste the data as values in order to maintain the formatting of the Excel tool. It is important to be aware of missing age classes in the GFP forest production model output—area data should only be copied over from the age classes that are detailed in the GFP forest production model output. Do not address any apparent holes in the data, or make any additional changes to the input data; the Excel tool will handle the issue of missing data in later sheets. The user should also take note of whether the GFP forest production model data begins in year 0 or year 1 (values can be found in the column labels in row 2), and ensure that the input data for other sheets in the Excel tool begins in that same year.

iv. Removal details

Begin by selecting the *Removal_Detail* sheet in the Excel tool. In this step, the user will copy and paste the removals data from the *Removals* sheet of the GFP forest production model into the framework of the Excel tool's *Removal_Detail* sheet. This data will be used in the *Removal_Sum*, *Carbon_Product_Calculation*, and *Summary_Output* sheets to determine the carbon impact of the wood products sources from the forest asset.

For each tree species, select the removals data from the column showing the product index class (sometimes labeled as "level_0") to be copy and pasted into the corresponding rows in the *Removal_Detail* sheet in the Excel tool. Be sure to copy and paste the data as values in order to maintain the formatting of the Excel tool. Then, determine whether each product index class represents either sawlog or pulplog products, and designate each row by typing either "Sawlog" or "Pulplog" into Column B.

Finally, select the annual removals data corresponding to each row and copy and paste as values into the Excel tool. Do not address any apparent holes in the data, or make any additional changes to the input data.

b. Fine-tuning the MAI linear regression model

In the *Unit_Stocking* sheet, the data from the *Inventory_Inputs* sheet is cross-referenced with the data from the *Areas* sheet to determine a weighted average stocking level on a per-hectare basis for each age for each species. These values can be found in column CZ, corresponding to the species age class designations in column CY. Column DA represents the projected average stocking level on a per-hectare basis for each age for each species. The intent of this column is to display the results of a linear regression on average stocking levels over time, which can be drawn upon by the Excel tool in the *Inventory_Output* tool in the case of:

a) Missing inventory data values for specific years
b) No inventory data values for stands prior to their first-inventory

The data values in column DA can stand in for missing information and also help to estimate the carbon impact of pre-merchantable volume in young tree stands. Lastly, the table in cells DC4:DF9 contains formulas for calculating the estimated mean annual increment (MAI) of each tree species (based on a linear regression of merchantable volume on age class), the intercept value of that linear regression, and the r-squared values that help evaluate the fit of the linear regression model to the real-life data. The estimated MAI and intercept values are used to populate Column DA.

Begin by selecting the formula for the linear regression of MAI for a specific tree species. The user must ensure two key criteria are met to ensure an appropriate linear regression is being performed.

- First, the cell selection representing the Y-values (located in column CZ) must involve the data ranging from the first positive value for that tree species in Column CZ through the data representing the average stocking level at the average age of harvest for that tree species. This is to ensure that the model is being developed specifically to fit the average stocking levels over the typical lifespan of a tree stand.
- Secondly, the cell selection representing the Y-values must not include any blank values, which will result in the linear regression formula returning errors for all age classes. When a blank cell is present in the progression of average stocking values in column CZ, a judgment call must be made to select as many consecutive years of data for that tree species prior to harvest age in order to maximize the fit of the linear regression model.

Once an appropriate range of Y-values has been selected from Column CZ, the user must ensure that a corresponding range of X-Values has been selected from Column B in the same formula in order to allow Excel to perform the linear regression. While tree growth does not follow a linear trend, a few key factors led us to standardize the modeling of a linear relationship between age and standing volume for each species on an asset. While the ease of linear modeling is clear, it was only settled upon after carefully considering the fact that a) the vast number of stands at different age classes within an asset would tend to minimize the influence of individual stands with higher-than-average or lower-than-average standing volume, driving asset-level stand volumes towards the average; and b) as shown in it is possible to plot a linear trend for standing volume that, between age 0 and harvest, results in the same cumulative carbon impact over its lifespan as does the logarithmic growth trend experienced by the stand in actuality (Figure 7).

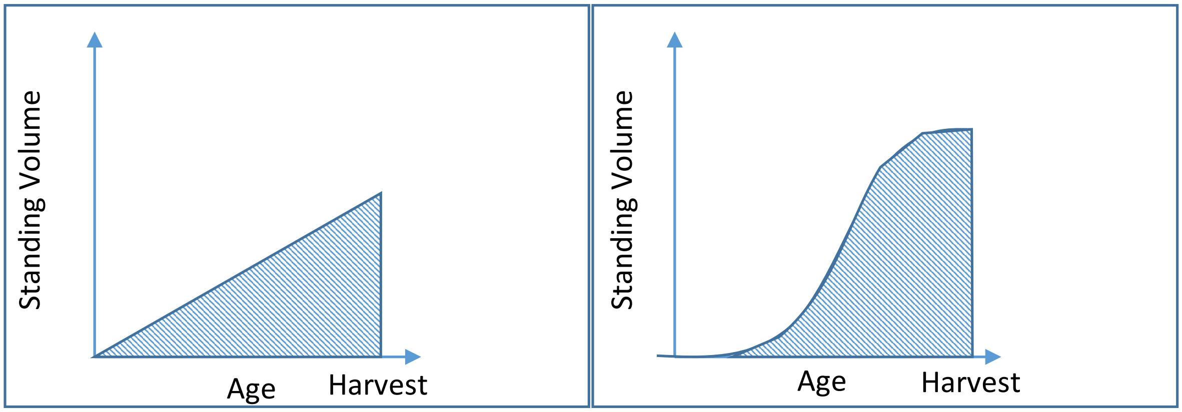


Figure 7. Despite the differences standing volume per hectare values shown for each individual year in the two projections, the cumulative standing volume they contain is roughly equivalent over the rotation.

To finalize the linear regression, the user must also update the cell selections in the corresponding cells representing the linear regression's intercept and r-squared value. Afterwards, the user should evaluate the R-squared value to determine if the linear regression model does indeed appear to be an appropriate fit to the real-world data - typical R-squared values for good fits on the GFP standing volume estimates ranged from 0.90 upwards, but may be somewhat lower for stands with unusually long or non-linear growth patterns. Relatively low R-squared values should encourage the user to consider possible alternative methods for modeling the yearly growth patterns of that tree species.

For some tree species, the average rotation length will be short enough to extremely limit the data values available for a linear regression model. When less than 4-5 values are available in Column CZ, the user is advised to utilize their judgment in selecting an average stocking level per-hectare at or around the average harvest age for that tree species. That stocking level can then be divided by the average harvest age to determine average MAI on a strictly linear basis. This calculation should be performed in the corresponding cell for the Est. MAI in column DD, and the intercept in column DE should be manually set to 0. The formula in the r-squared value can be deleted when utilizing this method.

c. Selecting rotations for replication over the 100-year time horizon

Once the above steps have been completed, the model will function as intended and will populate all values and charts in the *Summary_Output*, *Forest_Carbon*, and *Removal_Sum* sheets. While the typical carbon accounting forecast is performed over a 100-year time horizon, the model values for forest carbon will be calculated only for the number of years presented in the initial GFP forest production model data. The model values for product carbon behave differently, decreasing along a clear decay function after reaching the number of years present in the GFP forest production model data as the existing wood product stock gradually breaks down over time. In order to model the carbon impact of the asset over the 100-year time horizon, the user must make an assumption about what constitutes a typical rotation's worth of inventory data for each tree species and then replicate that typical rotation for the remaining years of the model.

To determine the "typical rotation," begin by revisiting the *Description* sheet and take note of the typical rotation length for each tree species. Then, select the *Summary_Output* sheet and scroll down to the "Total Standing Volume" chart beginning in cell B58. Here, it is possible to follow the patterns of standing volume (merchantable + pre-merchantable volume) for each tree species over time. Due to a slightly-uneven distribution of age classes within a species, small peaks typically appear in the progression of standing volume as the largest cohorts of stands reach harvest age, followed by small troughs once they have been harvested and replanted. Using the typical rotation length as a guide, visually determine a rotation that appears most typical among the years modeled with the GFP forest production model input data. Typically, this will be the second rotation present in the data; the first rotation is often strongly influenced by current market conditions, which may influence the timeline for harvesting, while the last rotation is designed by the GFP forest production model to fully liquidate the asset and will result in above-average removals.

> *For example: Years 20-30 were selected as a typical rotation for a eucalyptus asset under a specific ownership regime, rather than Years 1-11, to account for any changes in volume or estate area that may occur in the early year results of the forest production model.*

Some tree species will achieve a total or near-total drawdown of volume prior to the last years of the GFP forest production model data; it can typically assumed that these species are intended to be replaced by other tree species on the estate and thus do not need to be replicated over the 100-year time horizon.

Once the typical rotation years for each enduring tree species have been selected, the user should insert a comment for that tree species in the B column of the *Description* sheet to record which years were selected for selected for replication over the 100-year time horizon. Then, the user must update the input data in the *Inventory_Input*, *Areas*, and *Removal_Detail* sheets to correspond to this replication.

> *Using the eucalyptus regime mentioned above as an example, the user would select the cell in Inventory_Inputs for the 1-year-old age class of eucalyptus spp in the values matrix for Year 31 and set it equal to the value for Year 20, highlighting the cell to indicate the beginning of the replication period.*

This formula can be extended down the column through the 60-year-old age class of the species, and then the entire column's formulas can be extended out to Year 100 by clicking and dragging the bottom-right corner of the selected column. This process should be performed for each tree species that will be replicated over the 100-year time horizon. Once the formulas have been extended out to Year 100, the user can select the full range of highlighted cells (in this example, from the 1-year-old age class in Year 31 through the 60-year-old age class in Year 100) and then copy and paste those cells into the corresponding cells in the *Areas* sheet. These two sheets are formatted exactly alike, which will ensure that the formulas act in exactly the same manner in the *Areas* sheet.

In the *Removal_Detail* sheet, the same process should be performed for the same selection of years. The user would set the removal value for the species-product index in the first year following the typical rotation years equal to the first year of the typical rotation (setting Year 31 equal to Year 20, in keeping with the above example), extending that formula to all product indexes for that species, and then extending the formula out to Year 100. Following these actions, the user can return to the *Summary_Output* sheet and should observe the exact replication of the typical rotation years out to Year 100 in both the forest carbon and product carbon cells at the top of the sheet and in the charts located further below on the *Summary_Output* sheet.

Appendix C: Current Status and Short Term Projection of Global Emissions Trading Schemes

1. European Union

The emissions trading scheme in the European Union (EU ETS) was established in 2005 and as of February of 2016, remains the largest international carbon trading scheme in the world[18]. It is a mandatory scheme with a voluntary opt-in, covering approximately 2 Gigatons CO_2 e of emissions in 2015[18]. All 28 member countries of the European Union participate in the EU ETS, as do three additional members of the European Free Trade Association. After an initial "trial phase" following the market's establishment, during which the EU could work out some of the issues associated with starting a new program, the number of allowances have decreased throughout the progression of the program[66]. The program has been considered a success. It has overcome initial protests that this system would be a large economic burden and achieved its desired results at a fraction of the projected cost[67]. The price of carbon fell dramatically due to the recession, but has been rising since. The future outlook for carbon prices is positive given current proposed changes for 2019, which will seek to remove some of the excess credits that accumulated as a resulted from the recession[68].

While the European Union is aware of the environmental and social issues surrounding deforestation, forestry credits are not accepted in the EU ETS. Several reasons have been publicly cited to support this position. One of the major reasons is that as of 2008, emissions resulting from deforestation were three times higher than the emissions covered in the trading scheme. Allowing crediting of these emissions would flood the market with an excess supply of offset credits, tanking the credit price[29]. The EU also feels that there are unresolved issues surrounding the monitoring and verification process of ensuring the claimed emission reduction activities are taking place. The last reason cited by the EU as a reason for not including forestry credits is the lack of certainty surrounding the permanence of the project emission reductions. If a company were to go bankrupt, for example, there would need to be an established protocol for liability to ensure any net emission reductions made were not immediately lost. The inclusion of forestry credits in the EU ETS has not been ruled out indefinitely, but will likely not be accepted into the market unless several trading schemes across the globe can be linked to increase demand for carbon credits or if more comprehensive methods for verifying and monitoring forestry offset projects are developed. For the time being, the EU is committing some of the revenue generated from offset credit auctions to efforts at reducing deforestation.

The European Commission has maintained that the EU ETS is an excellent building block for establishing an international emissions trading scheme, which they believe will "reduce the cost of cutting emissions, increase market liquidity, stabilize the carbon price, level the international playing field, and support global cooperation on climate change" as well as minimize carbon leakage [66,69]. The EU has attempted to create international linkages in the past. Notably, it supported a 2012 deal designed to link with the Australian ETS by the beginning of 2015[70], but the deal was scraped in 2013 when the newly-elected Australian Prime Minister Tony Abbott shuttered the Australian ETS[69]. In January 2016, the EU ETS agreed to create a linkage with Switzerland's ETS, which is the second international linkage behind the recent linkage deal between the emissions markets of California and Quebec[69]. We believe that forestry offset projects will not be accepted in the EU ETS until there is a much greater degree of linkage between trading schemes across the globe. As the development of carbon markets was a topic of the Paris talks, and there is an increasing effort in developing national programs, this is a scenario that is well within reason but is very unlikely in the near-term.

2. China

Over the last several years, China has been experimenting with a market-based scheme to curb its carbon emissions. Beginning in 2011, China established intentions to phase in seven subnational pilot schemes over the following years to test how the system would work on the national scale[71]. Combined, the Chinese pilot ETS has become the second-largest trading scheme in the world behind the EU ETS and the largest national scheme in the world, with a cap of 1.3 Gigatons CO_2e[18]. The purpose of the pilot schemes was to experiment with how an ETS would work within China and in that regard, it has been a large success[72,73]. This pilot stage of a national program will prove to be an important stage of many national systems. The speed with which this pilot program was rolled out has led to a lack of liquidity, however, which has been the biggest issue that has plagued the program[74]. Some are attributing the lack of engagement in the market to issues with the overly generous amount of allowances given in some areas, a lack of a futures trading market, and the tendency of companies to hold on to their allowances until it is clear what their compliance obligations will be under the national ETS. Whatever the cause, the lack of liquidity in the trading scheme has led to substantial volatility in in the carbon price in some areas. This issue will need to be addressed when the national ETS is rolled out.

The Chinese market will trade China Certified Emissions Reductions (CCER). These credits will be very similar to the certified emissions reductions established under the CDM, and any CDM project that falls within China's border and has not yet been registered may be registered in the Chinese system to gain CCERs[75,76]. The Chinese government recognizes the carbon sequestration potential and environmental benefits of forests and therefore is extremely supportive of afforestation and reforestation projects. Due to the geographic constraints of CCER eligibility, forestry projects are not expected to pose the risk of significantly impacting credit volumes that would drive down carbon prices. This is one of the reasons that the EU ETS does not allow forestry projects. Just like the EU, there is concern about verification and monitoring processes for forestry offset projects, which place additional constraints on where the government will accept these types of projects.

After the success of the pilot program, China made its commitment to establishing a national ETS by 2017 in its 2015 agreement with the United States to curb carbon emissions[77]. This start date has been criticized as too ambitious due to unresolved regulatory uncertainties, such as how many companies will be initially included, and it is possible that the scheme will not be implemented until after 2017[71,78]. While there can be no certainty about whether China will ultimately join an international scheme or link with any other country until the national program is established, the likelihood of this seems strong given the cooperation already occurring between Beijing and Seoul. It is likely that, as with the EU, it would take an international linkage between different schemes in order for international forestry projects to be accepted within the Chinese scheme. If the national program becomes established and links with the South Korean market, this region will become a very important hub for carbon trading.

3. USA

Chicago Climate Exchange

Launched in 2003, the Chicago Climate Exchange (CCX) was North America's first emissions trading scheme[79]. The program increased its trading volume until it peaked in May of 2008, when there were approximately 10 million tons of carbon offset credits being traded with a peak price of $7.40 per ton of carbon[80]. During its operation, the program recognized the benefits offered by forests and accepted afforestation/reforestation offset projects located within either the United States or non-Annex 1 countries[81]. During this time, the new Democratically-controlled Congress and presidency were attempting to pass legislation that would create a partnership with the CCX[82]. As President Barack Obama was a member of the Joyce Foundation board of directors that gave the grant that allowed the CCX to begin trading, many felt that this measure would quickly be passed[80]. The legislation eventually failed to pass the Senate, however, marking the effective end of emissions trading for that time and prompting the CCX to close its doors on December 31, 2010[83].

Regional Greenhouse Gas Initiative

On December 20, 2005, seven northeastern states signed a memorandum of understanding to participate in a regional attempt to curb carbon emissions from power plants as a part of the Regional Greenhouse Gas Initiative[84]. While the CCX did not persist following the failed climate legislation in 2010, the RGGI continued to operate. It is possible that this is due to the mandatory nature of the RGGI scheme, while the CCX was a voluntary program. Although the region has seen significant drops in carbon emissions since the establishment of the RGGI, there is some debate as to whether this decrease in power plant emissions is due to the program itself or from other contributing factors, such as reduced electricity demand as a result of the recession and the nationwide shift from coal power plants to natural gas power plants[85]. However, studies that take these factors into account have still concluded that the drop attributable to the RGGI is still significant and the billions in revenue being pumped back into local economies as a result of the program have worked to lower electricity bills and support the addition of renewable energy sources[86,87]. As it stands currently, the RGGI accepts forestry projects in the form of A/R projects, improved forest management projects, and avoided conversion projects but the projects must take place within the United States[88]. Faced with an overabundance of permits causing a very low price for carbon offsets, the program is considering drastically lowering the cap by 2020 to increase demand and raise prices for carbon offsets[89]. Considering the lack of demand for carbon offsets within the current program, it is unlikely that the program will expand its geographic acceptance of forestry projects to projects falling outside of the United States.

California

On September 27, 2006, the state of California passed its own legislation to commit the state to cutting carbon emissions to 1990 levels by 2020[22]. Within this legislation, the California Air Resources Board (CARB) was given the authority to establish a carbon cap-and-trade program within the state. The potential passage of a nationwide scheme, proposed by California Congressman Waxman in 2009, delayed California's implementation as they did not want to establish a conflicting program. After this legislation failed to pass the Senate, however, California went ahead to establish their own program and began trading on January 1, 2013[22].

The program has been considered very successful. In its first year, each auction saw stable, reasonable allowance prices with all allowances being sold[90,91]. This suggested that regulated entities accepted the program and that they were already planning around the emission caps established by the program. The ARB scheme is considered to be more thoroughly protected against collapse due to its inclusion of a price floor, which is scheduled to rise slightly every year and provide a consistent signal that emissions present real costs. The California program has also expanded its range and continued to find success. In 2014, the program established the first international linkage between trading schemes when it linked with Quebec, Canada, and in late 2015, Ontario also agreed to link with this system[92]. Prices have remained stable and the state continues to make substantial amounts of money during auctions, which can then be funneled into state initiatives designed to move towards a society with fewer emissions and a greater proportion of renewable energy[90].

Forestry offset projects are accepted within the program [30]. The ARB methodology has served as a model for much of the analysis presented in this paper and has been discussed in detail in various parts. The forestry offset projects accepted by the ARB are afforestation/reforestation projects, improved forest management projects, and avoided conversion projects. Currently, all projects must occur within the United States to be certified under the ARB methodology. The marriage of California and Quebec allows forestry offsets sourced anywhere in the United States to be traded, but forestry projects in Quebec and across Canada are not yet allowed to participate in the linked market due to California's current regulations[93]. Since 2010, California has also been exploring the potential for including REDD+ offsets from Chiapas, Mexico, and Acre, Brazil[94]. It is unclear whether these plans will move forward after Brazil banned the sale of international REDD+ credits on November 27, 2015[95].

The California cap and trade market has proven successful in the early stages of operation, but the further development of this scheme remains a question. As the CARB's authority to carry out the state's cap and trade program ends in 2020, new legislation needs to be passed in order to allow the program to continue to help meet the state's new ambitious emissions reduction goals through 2050[96].

There is a strong possibility of further expansion of the ARB trading scheme in the coming years. The passage of the Clean Power Plan (CPP), before being placed on hold by the U.S. Supreme Court in February 2016[97], had been seen as the national government encouraging a cap and trade system[98]. Under the CPP, states would be assigned specific emission reduction goals by the EPA and would then be allowed to decide individualized plans for achieving the goals. This plan aligns well with cap-and-trade systems, with the cap serving as a proxy for the emission reduction goal and the trading scheme allowing various states to balance the cost and timing of their planned emission reductions. Following this thread, it was expected that most states would develop a mass-based reduction approach so that emission allowances could be traded[96]. According to White House statistics, in 2015, at least 20 states were considering carbon trading as a method of meeting their targets[99,100]. Joining an existing trading scheme like ARB could be an option for those states. However, the ultimate fate of CPP will remain unknown until the Supreme Court has a final decision on CPP's passage, which may be several years off[101]. States have no obligation to submit emissions reduction plans yet, but many states may opt to develop a plan before the final ruling to avoid any penalties incurred as a result of not being prepared[101].

4. South Korea

Between 1990 and 2014, South Korean emissions doubled and the country became the world's seventh largest greenhouse gas emitter[102]. Unlike the other top global emitters, South Korea was not counted as an Annex I country under the Kyoto Protocol, and therefore has no binding global responsibility to reduce emissions[103]. Regardless of this distinction, South Korea has made a commitment to reduce its emissions by 30% below its projected 2020 levels, or approximately 4% below its 2005 levels[102]. In 2012, South Korea became the second Asian country to fully commit to a carbon cap and trade system, which will be the major component of the country's plan to cut their emissions[104]. The trading scheme is a mandatory scheme targeting the country's top emitters, but will have a voluntary opt-in option as well. Due to the subnational pilot status of China's current ETS, South Korea's trading scheme is officially the second-largest national scheme in the world behind the EU ETS[104]. Domestic forestry projects that prove additional carbon sequestration are allowed in the South Korean market for offsets[103,105].

The program had an eventful first year in the face of significant resistance from the industries being targeted. Over the course of 2015, over 40 lawsuits were filed against the Ministry of Environment for the implementation of the scheme, with most cases demanding a greater number of allowances than were previously allotted[106]. There have been disagreements over the projected 2020 emissions target as well, with the opposition feeling that the desired reductions are too ambitious to realistically be achieved.

The market has faced large supply shortages resulting in sluggish trading[107]. These lackluster conditions are due in part to the belief that companies did not receive enough credits, causing them to hold their surplus and driving a lack of flexibility between offset credit types. Offset credits earn Korean Offset Credits (KOCs), which need to be converted to Korean Carbon Units (KCUs), the currency of the Korean ETS, before they can be traded on the carbon market[108]. The resulting high prices from a market faced with a supply shortage has further angered companies that are already upset with the program.

In the coming years, the South Korean government will attempt to correct some of the issues that have led to the displeasure over the first year of trading. At the beginning of 2016, the South

Korean government shifted responsibility of the program from the Ministry of Environment to the Ministry of Strategy and Planning[106]. Some believe that this indicates the industries' demand for additional allowances will be met to some degree in the coming months. In May 2016, KOCs will be allowed to be traded on the compliance market, which regulators hope will address some of the issues surrounding the supply of offset alternatives for companies lacking sufficient allowances[106]. After 2020, companies will also be allowed to use international credits, instead of being limited solely to domestic credits, to meet a small percentage of their compliance requirements[109]. As far as future linkages are concerned, Beijing has agreed to cooperate with Seoul in developing their respective trading schemes, which would suggest the South Korean scheme will be joined with the Chinese scheme once it is fully established[46]. With the acceptance of international offset credits after 2020 within the South Korean market, there is a potential for South Korea to influence any trading scheme they link with towards accepting international credits either directly or indirectly.

5. New Zealand

New Zealand is currently attempting to meet its commitment to reduce emissions to 30% below 2005 levels by 2030[18]. In 2008, New Zealand followed the model set by the EU ETS by creating its own emissions trading scheme (NZ ETS) as its cornerstone method for achieving its emissions reduction goal[110]. As is the case with other similar schemes, the program faced a rocky beginning. In its first several years, the system has not proven successful and emissions have risen 13% since the program began[111]. This has been attributed to an abundance of allowances and very low carbon prices that have not incentivized companies to reduce their emissions. The situation changed after NZ ETS switched to a domestic-only market. Starting from June 1, 2015, some types of Kyoto Protocol units are restricted within the NZ ETS[112]. As a response, the price of trading units in the compliance market rose quickly and similar results are expected to occur in the voluntary market[113].

Karpas & Kerr (2011) analyzed the effects and impacts of the inclusion of forestry in the NZ ETS[114]. New Zealand is the first country to include forestry within their national compliance scheme, largely due to the large impact that forestry has on New Zealand's economy and the recognition that forestry may accomplish the most cost-effective net emissions reductions in the nation. The projects accepted within the country focus on reduced deforestation as well as increased reforestation and afforestation, which is similar to projects contained within the Kyoto Protocol. Where New Zealand's policy differs is that it makes distinctions between forests established before and after 1990, as well as between natural forests and what are referred to as "exotic forests". At the end of 2013, the NZ ETS opted out of the second phase of the Kyoto Protocol and international carbon offset units, such as Certified Emission Reduction units, were no longer accepted in the market as of May 2015[115]. The forestry component of the scheme has proven to be relatively successful, with deforestation drastically decreasing, and forestry projects are slowly picking up steam within the rest of the market. Uncertainty regarding the future of the program has been the largest detriment that Karpas & Kerr have identified for project developers investing in large scale forest plantings.

Looking to the future, the national government is discussing how to improve the effectiveness and stability of the market in terms of trading as well as prices. Limiting international offsets has helped lift the price, and will potentially incentivize the development of more domestic offsets projects. However, the disconnect from international market may not be lasting. If the need arises for the sake of market liquidity, the use of international units will be reviewed[116].

6. Japan

In 2010, Japan began considering a national emissions trading scheme, but the plan became bogged down due to large industry pushback and was officially abandoned in 2012[117,118]. Instead, the country has three carbon markets operating on a sub-national level. While the national program was being debated, Tokyo launched its own cap-and-trade program that became Japan's first mandatory emissions trading scheme[116]. Saitama followed Tokyo's lead in initiating its own ETS in 2011 and, like Tokyo, both cities saw immediate results and achieved significant emission reductions[119]. Besides these two compliance programs, there is also a voluntary program operating in Kyoto[113]. Both compliance programs require offset projects to be within Japan, and only Saitama accepts forestry projects in the form of Forest Absorption Credits[116]. Forest Absorption offset projects include any project that will increase the amount of storage of carbon within the city limits of Saitama, such as afforestation/reforestation and improved management practices, and is valued at 1.5x the value of regular offset credits[116].

While trading schemes have developed on the sub-national level, Japan has also pursued the development of a carbon tax as an alternative means of pricing carbon emissions. After the proposed national ETS program failed to pass, Japan established a carbon tax that they would phase in over several years with the tax peaking in April 2016[120,121]. There has been predictable backlash over the measure, with an added concern over the strain placed on fossil fuel power plants in the country after the Fukushima disaster took out a large source of nuclear energy. Japan is expected to release an updated plan for meeting carbon reduction commitments through a combination of a carbon tax, an ETS, and wide-scale implementation of carbon capture and storage technology[122-124]. Powerful industry lobbyists have obstructed the establishment of an ETS in the past and are expected to attempt to prevent the ETS once again. The carbon tax and CCS technology implementation have both been recommended as legitimate means for Japan to reach their emission reduction goals while avoiding the expected resistance against a national ETS.

Appendix E: Discussion on COP21 Paris Talks

Introduction to Conference of Parties

The United Nations Framework Convention on Climate Change (UNFCCC) was established at the 1992 UN Conference on the Environment and Development to acknowledge the need to reverse the trends of climate change and limit anthropogenic sources of greenhouse gases[125]. The Convention came into effect shortly after being ratified by its 50th country signee in 1994[126]. The first 'Conference of Parties' (COP1) took place the following year in order to discuss how best to address the goals established by the Kyoto Protocol, as well as to discuss possible implementation strategies for achieving the desired emissions reductions[127,128]. Since then, there has been a yearly conference of parties to continue discussions on global emissions reductions. The most recent Conference of Parties was held in December 2015 in Paris. Leading up to COP 21, there was an unprecedented level of both private and public support[129,130]. An excellent example of the increased private interest was seen in July 2015, when 13 of the biggest companies in the United States, including Google, Walmart, and PepsiCo, agreed to invest $140 billion to fight climate change by adopting and encouraging low-carbon practices and technologies both within their companies and in the general public[131]. Many are viewing the final agreement from the conference as very successful.

Inclusion of Forests in Discussions

In the final agreement reached at COP 21, forests are formally recognized for their role in stabilizing global carbon emissions[132]. This is indirectly a very important milestone for the continuing development and inclusion of the UN REDD+ program in global efforts to preserve forests. The increased recognition of the role of global forests was also evident in the pledge of $5 billion that Norway, Germany, and the UK have made towards the protection of forests in developing countries[133]. There are also approximately 80 countries that have identified land use, including agriculture and forestry, as a key area of focus in their national emissions reduction goals[132]. While many of the world leaders involved with the negotiation are declaring the final agreement reached as a significant milestone, there are complaints from environmental researchers and climate policy advocates such as Bill McKibben and James Hansen that the negotiations were not enough, as much of the agreement is not binding[134]. When considering the commitment of different countries to their forest land, there are some countries that have shied away from significant action. Both the European Union and United States are examples of large countries that have recognized the importance of forests in their emissions reduction plans, but have refrained from including any specific action around forest management in their climate action plans[135,136].

Moving Forward Post-2020

Mansell (2016) reviewed how the agreement reached in Paris differs from the Kyoto Protocol and how it will impact the development of global markets[137]. Since its establishment in 1997, the Kyoto Protocol has served as the foundation for global efforts to reduce emissions. With the expiration of the Kyoto Protocol occurring in 2020, the agreement reached at COP 21 seeks to begin guiding global action surrounding climate change in the years after 2020. Whereas the Kyoto Protocol was based on setting binding emissions reductions, the Paris agreement requires participating countries to submit their own intended nationally determined contributions (INDC) for compliance between 2020 and 2030, with a great degree of flexibility regarding strategies for achieving their goal. With 65 countries committing to using international carbon markets as a means for achieving emissions reductions, as well as another 24 committing to using them in the future, COP 21 is an important agreement for the future of global carbon markets.

As is discussed in Appendix C, many current emissions trading schemes, such as the EU ETS, are actively pursuing international linkages between different markets. Given the large number of countries committed to establishing a market mechanism for reducing emissions, there is an excellent opportunity for the global community to increase these linkages, which would create a strong potential for international credits to be accepted. With the continuing development of the REDD+ program and the formal inclusion of forests as a means for offsetting global carbon emissions, the likelihood of international forestry credits being accepted in more compliance markets has greatly increased. As of February, 2016, it is still unclear whether projects previously certified under the CDM will still be applicable after 2020. It is this potential for a global shift after 2020 that contributed to our recommendation for GFP to revisit the monetization of their sequestered carbon after this date.