Down the Drain

Carbon Offsets Revisited

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Source: (One Good Thing By Jillee, 2014)

Abstract

Climate change discussions have begun to shift from strategies for mitigation to those of adaptation and geoengineering - approaches that carry significant risk and uncertainty. While some adaptation strategies are already being necessarily deployed, the historical approach for mitigation has largely overlooked carbon uptake, which constitutes half of the equation dictating atmospheric carbon concentrations. This omission is clearest in the arena of "carbon offsets," where "carbon credits" are sold in the form of units of CO_2-equivalent to "offset" emissions. Most saliently, credits for "avoided emissions" are essentially treated the same as those for sequestration, which has strongly manifested in REDD and REDD+ schemes. While conservation has many merits, a major premise of this paper is that "offsetting" by avoiding sink destruction should not be viewed the same as returning carbon to a non-atmospheric sink.

When looking at the difference between avoided emissions and sequestration in relation to "tipping points," a model begins to emerge that is almost identical to traditional economic theory. This overlap is not by coincidence, as emissions are symptomatic of an economy that does not properly reflect the cost of goods and services in sales prices. Based on this understanding, this document provides a model for a new type of market that can be established, whereby emissions can truly be "offset," and the externality cost of carbon can be properly priced. Largely building off of the policy framework of the Climate Leadership Council, in which "carbon dividends" are paid to the public from carbon tax revenues, this document elaborates on this notion by more directly applying market principles to create a framework that will align with the functioning of contemporary economies.

The concept of "carbon equity" is introduced for owners of preserved sinks to be compensated for conservation. Additionally, entities facing taxes are given an alternative by agreeing to return emitted carbon to a non-atmospheric sink, rather than pay a tax. To demonstrate the proposed framework of this document, a new financial security is used to show how a distinction between an absolute and time-value of carbon can be applied in a way that allows entities to truly offset emissions in line with market dynamics; in addition to creating a new financial market with significant opportunity. The security uses a traditional REDD+ project to capture time-value and uncertainty, and a coastal mangrove restoration project to demonstrate absolute value. Ecosystem-based solutions have been chosen due to lower carried uncertainties from other externalities, and benefits beyond carbon storage.

Climate change mitigation provides a perfect opportunity to reassess capital markets in a way that allows for both equitable compensation to all actors, and maintains the ability of agent choice to mold economic dynamics. The study has highlighted how markets can be better contextualized in terms of externalities. A bridge that can be formed between two traditional contrasting schools of economic thought is demonstrated through an inverse security that is reflective of cost – in turn, allowing for a new and lucrative market to be formed. While further research and collaboration, as well as an acceptance of uncertainty will be needed for ultimate implementation, the feasibility seems promising in terms of the broad scope of stakeholders that will benefit, and allowing a high level of flexibility for entities that need to compensate for carbon emissions.

Preface

This document is intended for a broad, yet informed audience, including those in the financial sector, economists, policymakers, data analytics specialists, and various members of the broader scientific community, among others. An attempt has been made to fully explain rationale and provide a recommended course of action that is rooted in a well-informed theoretical framework foundation, yet facilitates a broad understanding amongst a diverse group of stakeholders whose support will be necessary for successful implementation. Nonetheless, some may find certain aspects to be oversimplified, while others will find some elements to be overtechnical and difficult to follow. The document should be viewed as a mere starting point, with the intention to be expanded upon with input from a broad range of experts spanning many fields, and suggestions for refinement are welcomed and encouraged. For those not requiring a nuanced explanation of the innermost functions of the framework, it is recommended that Chapters 2 and 3 only be skimmed for relevant information to one's respective area of expertise.

The author would like to make disclosure of his employment by Conservation International Foundation (CI) at the time of writing, as it relates to the use of the Alto Mayo Protected Area as an example for the financial security design. While the project is operated by CI-Peru in conjunction with the Peruvian government, no privately held information has been used in the creation of this document, and the views and opinions expressed throughout "Down the Drain: Carbon Offsets Revisited" are solely those of the author.

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Chapter 1: Introduction

1.1 Topic Selection

1.1.1 Methodological Miscue, and Misdiagnosis

The "bathtub" analogy is often used to teach and communicate the central issue with regards to climate change (NCAR, 2017). The model represents the Earth's climate and ecological systems as a bathtub, with the water from the faucet corresponding to global greenhouse gas (GHG) emissions, and the drain representing the GHG absorption capacity of natural systems. At the current rate, the "faucet" is running much more rapidly than the capacity of the drain can accommodate, and therefore the bathtub is eventually going to overflow. This translates to Earth's climatic systems reaching a "tipping point," whereby annual global average temperature rises to a threshold value, from which irreversible and catastrophic impacts are realized; 1.5^{o} C or 2.0^{o} C are commonly used threshold levels, and have even been chosen as explicit targets of the Paris Climate Accord (UNFCCC, 2017).

The problem is typically presented with the single solution of turning off, or significantly slowing down the flow from the faucet (i.e. cutting emissions). In the nascent stages of conceptualization, followed by the realization and understanding of global carbon stocks and tipping points, this solution held more merit in the past than it does at present (although this does not appear to be the sole reason for having had it presented in this manner for so long). As time has progressed and while efforts to address the issue have not advanced significantly, lowering GHG emissions to levels that would allow for the Earth's absorption capacity [a capacity that has continued to be stymied by anthropogenic causes, such as land-use change – LUC (Canadell, et al., 2007)] to prevent the realization of reaching a tipping point seems to be growing exponentially more difficult with each passing day. Some have even gone so far as to argue that the point whereby climate change could be mitigated through these types of measures has long since passed (Aitkenhead, 2008; Harris, 2009).

Prominent talks have shifted to the needs for adaptation, or finding ways that humans can design infrastructure and change normal activities to continue surviving within a vastly changed climate system from the one in which they evolved. While adaptation to already realized adverse effects has been occurring in cities like Venice and Miami, the efforts and expenses incurred through such measures have been quite large, and are only the beginning of what would potentially be needed (Ministero delle Infrastrutture e dei Trasporti (mit), n.d.; Fountain, 2015). Another possible set of solutions relates to geoengineering techniques, or intervening with geosystems and changing them with the intention of mitigating damage [e.g. spraying aerosols into the atmosphere to mimic the global cooling effect that volcanic eruptions can have (Rotman, 2013) It may seem that trying to adapt to such uncertain and volatile conditions, or trying to intentionally alter climatic systems would preferably be viewed as a last resort, after all options for mitigation have been exhausted (this is not to say that contingencies shouldn't be put in place, but that resources should not be unnecessarily diverted if alternatives can be found).

While humans have historically been able to maintain domain over their environments via their ingenuity and technology, one cannot assume that this can continue forever. In terms of planning and survival, persisting on post-tipping point Earth may be as difficult as colonizing another planet (transport aside). On the other hand, perhaps living under such conditions would be entirely viable, but the level of risk and uncertainty is so enormous, that it appears utterly foolish (verging on insanity) to take such a gamble.

Additionally, one cannot discount the fact that technologies have grown ever more potent at an exponential rate since the latter half of the 20th century, and that advanced technologies carry the risk of creating additional, and potentially greater problems than they were originally intended to solve (Diamond, 2005). For example, fossil fuels have positively revolutionized a plethora of aspects of human life ranging from agriculture to plastics, and the switch from chlorofluorocarbons (CFCs) to hydrofluorocarbons (HFCs) has nearly stopped the diminishment of the ozone layer; however, both of these technologies emit powerful greenhouse gases (GHGs) and therefore are contributors to global climate change (EMPA, 2012). Relying on technology is almost something that could be seen as treating the symptoms but not the underlying disease, and where the side effects from the medicine could end up being worse for the patient than the disease itself originally was; as could very well be the case with several proposed geoengineering strategies (Robock, Marquardt, Kravitz, & Stenchikov, 2009; Extance, 2015).

In this case, the underlying "disease" is not one related to climate, but one of economics. Capitalist markets have historically had an inability to properly capture and price "externalities" despite the concept having been introduced nearly 100 years ago by Arthur Cecil Pigou (Pigou, 1932). Externalities can be described as costs of goods and/or services unreflected in the respective sales price before a corrective measure such as a tax is put in place. Externalities are usually expressed as being adverse in nature, and usually borne by society at-large. Pollution and public health costs associated with alcohol and tobacco consumption are commonly used examples. The urgency, and ubiquitous risk posed to all humans allows for climate change mitigation to provide the perfect opportunity to address this problem, although the manner in which it's approached must be drastically changed.

1.1.2 RCPs, REDD+, …and Reality

Perhaps the train of logic driving the shift in discussions of adaptation and geoengineering follows from the fact that so much time has passed with little action, and that what had historically been presented as the "solution" to the mitigation problem is appearing to be unfeasible. The result appears to have been akin to a knee-jerk reaction, whereby policymakers and climate experts are frantically reacting to what they now view as a looming inevitability. However, what appears to be (at least largely) lacking in the public dialogue is consideration of the other side of the equation (which has always been there). It would seem as if the drain in the bathtub were partially blocked or clogged, unclogging it would seem to go a long way in preventing an overflow. The Earth's "drain" is undoubtedly "clogged" from the extensive anthropogenic destruction of various types of ecological carbon sinks.

This is not to say that this part of the solution has been <u>totally</u> ignored, but broad communications largely have been, and the perspective taken on it has led to a point where the full magnitude of its potential to help may not have been fully realized. This could possibly be due to two reasons: the first being in the (nearly entirely) technological focus of sequestration efforts, which while under development, have historically not been seen as particularly economical or scalable, at least in the near-term (WEF & The Conversation, 2015); the second, although somewhat more speculative, could be due to the manner in which "carbon offsetting" has been implemented and communicated. The voluntary market consists of many types of "carbon credits," all sold as "offsets," but which often have fundamentally different underlying mechanisms. The notion of being "carbon neutral" would imply that one is undoing their emissions, however, in reality "carbon neutral" means *marginally lessening projected emissions in relation to the damage that would be caused by one's individual contribution in the absence of such a reduction* (which applies when the relationship is properly quantified and the offset properly priced; quite often not the case). Some argue that without more rigorous regulations mandating offsets, the market will never fully develop. While this may have some validity, the difficulty in implementing such regulations may not just stem from political frictions (which, overall on a global scale seem to be less than in the past, barring the odd exceptions here and there), but from the obscurity that has arisen from what exactly constitutes a "carbon offset" and being "carbon neutral."

This is most saliently demonstrated by the existence of REDD+ schemes (formerly REDD).[1] When the notion was first adopted by the United Nations Framework Convention on Climate Change (UNFCCC) in Montreal in 2005, the feasibility of fighting climate change by merely cutting emissions was more viable than at present (UNFCCC, 2016). The notion of an "offset" in this context was that as a large part of GHG emissions have been caused by deforestation and forest degradation, by helping to preserve carbon stocks, the global "basket" constituting all GHG emissions would be made smaller, thus falling closer to the natural uptake capacity of the Earth. In addition to various criticisms that have arisen as they relate to topics such as indigenous rights (Brentnall, 2014), it was also realized that a perverse incentive to threaten forests arose in countries that were already implementing robust conservation methods (UNFCCC, 2011). In the context of REDD as it originally was conceived, a forest that was not threatened had little value, and the value of "carbon credits" which could be generated from a forest were based on the threat level it faced. This means that it suddenly became in the interest of countries that were already protecting their forests to threaten them, so that they could in turn protect them, which they were already doing, but instead be paid to do so.

Hence, there was an evolution of the concept, and REDD became REDD+ which aims to account for the inherent forest carbon stock value, and the importance of biologically diverse, healthy forests, (UNFCCC, 2011). Although well intentioned, this concept is even more obscure to the general public and likely, by extension, to any individual who is not a scientific expert (i.e. policy makers); which in turn makes translating this to a well-received policy for implementation to be quite difficult. Furthermore, following the same logic of REDD, offsets are also sold on things such as power generation from wind facilities, or the purchasing of cook stoves for individuals who would otherwise be gathering and burning wood (Cool Effect Inc., 2017). The inherent problem posed with such schemes is that it is virtually impossible to determine what's being avoided as compared to a scenario in which the scheme was not in place; and that damage is being "offset" by less damage occurring elsewhere, rather than repaired.

Attribution (i.e. knowing why an emission was avoided) is impossible to determine in REDD (+) markets as things stand. For example, there are projects with credits issued in accordance with the Verified Carbon Standard (VCS) listed for sale on the Markit Registry that

[1] "REDD" refers to reducing emissions from deforestation and forest degradation by allowing for payments to threatened forests in developing countries from developed countries, originally under the auspice of the U.N's Clean Development Mechanism – CDM (Global Canopy Programme, 2016a). The concept has been somewhat broadened in the introduction of carbon credits from REDD and REDD+ projects into the voluntary market, where the purchaser need not be in a developed country. REDD+ is an enhanced version of REDD that is described in the main text.

carry "vintages" as early as 1996 (Markit Group Ltd., 2017). Credits from forest carbon projects are issued in vintages, based on a thorough audit of the forest carbon stock and the current threat level posed to that particular forest. For example, a project may have 600,000 verified carbon units (VCU's: meant to be equivalent to an avoided emission of a greenhouse gas indexed to one tonne[2] of CO_2 equivalent- tCO_{2E}) issued for the 2017-2019 vintage; meaning that it's expected that by conserving the underlying forest, 600,000 tCO_{2E} will have been avoided from being emitted into the atmosphere which would have otherwise occurred during this time without having the project in place, and thus have been "offset." Subsequently, the project may have 575,000 VCUs issued for its 2020-2022 vintage. If the entire vintage 2017 – 2019 is not sold by the time that the 2020 – 2022 vintage is issued, there's no implication in terms of credit reconciliation; the 2017 – 2019 vintage credits can still be traded and retired, even though the emissions were avoided in the absence of their sales. This creates a wrinkle in the market, and only the most well-informed buyers appear to be aware of the inherently different value of different vintages; and such buyers are a minute portion of a market that is already quite small.

The logical gap represented by the uncertainty of what "would have happened" in the alternative manifests itself strongest in the availability of credits on the exchanges from historical vintages. How can one justify "offsetting" an emission today by paying for what didn't happen 20 years ago? Furthermore, as the credits are still available, the underlying project which generated the credits is still running, and thus the emissions were avoided without the credits having been sold, meaning that the credits were inherently greatly overestimated in value (barring external support from project financing not tied to the sale of credits, which often happens with some of these projects). Does this mean that there is no value-added in buying historical vintage credits? The answer is no, simply because the funds (if properly channeled) will still go to pay for ongoing project implementation costs, which means that there is some level of continued emissions avoidance. What this tells us however, is that it's impossible to verify the exact value of any given VCU from an avoided emission as it compares to any given unit of CO_2 equivalent emission (in relation to both time and instance of occurrence or non-occurrence), and therefore it is not really a valid way to offset emissions in the purest sense of what an offset would imply.

Following the desire to undo what has been done, the only valid way to offset an emission is to remove an equivalent amount of the emission from the atmosphere. Therefore, offsets must be distinguished into two categories: one related to the avoidance of emissions, which carries an immense amount of uncertainty both *ex-ante* and *ex-post*; the other being the returning of a unit of GHG from the atmosphere to a carbon sink which still carries *ex-ante* uncertainty (and some

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[2] The spelling of "tonne" is used to denote one metric ton.

ex-post when the concept of "permanence" is considered – a topic that will be touched upon later in this document). When framed in this manner, the understanding of the persistence of GHGs in the atmosphere looks much like the function of money in an economy (with a few distinctions), and therefore can be easily (and nearly directly) translated to the workings of common models for capital markets, largely based on basic economic theory.

Following common vernacular, "carbon" can be used as a general descriptive term encompassing all greenhouse gases, both as they exist in the atmosphere or in sinks, with the potential to move from one to the other at a given point in time. In this context, "carbon" could be seen to carry the same meaning as "money" in that it is a standard measure of value. While money is primarily a measure of value (following as the measure of value, it can derivatively serve to express cost), whereas in economic terms "carbon" has historically served as an expression of cost, for which the inverse derivative of value has not yet fully manifested in modern economies. However, expressing carbon in terms of value is entirely possible. If carbon held in the atmospheric sink bears a cost on society at large, its absence holds a value. Logically, atmospheric sink absence means a presence in a non-atmospheric sink[3], and therefore a value is created in such a presence. Such a value would be elastic to changes in atmospheric versus non-atmospheric sink concentrations (the inherent issue of diminishing value via conservation and sequestration is addressed in Chapter 4).

Much like money can be measured in various currencies, carrying different values in the present and changing in value over time (e.g. through inflation), carbon can be measured in terms of different greenhouse gases which persist in the atmosphere for different lengths of time (causing different intensities of damage over varying time intervals). Just as the U.S. dollar has been used as a reserve currency, acting as a central measure against which other currencies can be compared, CO_2 has been the standard established by which to measure GHG emissions against. This is due to its centrality (until this point[4]) in terms of its contribution to climate change; exemplified by the fact that all gases are measured in terms of their global warming potential (GWP) which has been standardized against the global warming potential of CO_2 (IPCC, 2007). A full presentation of the translation of basic economic theory to carbon and climate change can be found in Appendix A below; however, the key concepts to take away are that, a) carbon has both an absolute value and a time-value; b) while money is expressed in

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[3] For simplicity, problems that may arise from excess carbon concentrations in other sink types (e.g. oceans and acidification) have been excluded, although should be factored into comprehensive valuation models.

[4] The van Vuuren model for RCP 2.6 projects that by the end of the century CO_2 will not be the primary global GHG contributor (van Vuuren, et al., 2011).

relation to zero, carbon must be presented in relation to the tipping point – Ť;[5] and c) carbon held in a sink can be expressed as value in terms of "equity," while carbon in the atmosphere can be expressed as a cost in terms of "debt." These concepts are central to re-approaching climate change mitigation in a way that can properly place value on emissions and finally facilitate carbon offsets in the purest sense.

Following from these concepts, and with an aim to "purely" offset carbon emissions, this document largely treats sequestration as capital (e.g. the amount borrowed on a mortgage to pay for a house, commonly referred to as the principal), due to its primary function of affecting the magnitude of atmospheric GHG concentrations. Avoided emissions are primarily treated as a cost of capital (e.g. the interest paid on a mortgage), due to their primary function in delaying the realization of Ť. Both sequestration and avoidance affect both the time and magnitude dimension as well, respectively, but the primary function of each serves to differentiate their values. (See Appendix A for further background on this concept.)

The presented solution for climate change typically doesn't aim to approach mitigation from the angle of increasing carbon uptake capacity. This is especially reflective of the most prominent literature on climate change; namely, in the Representative Concentration Pathways (RCPs) and their use in formal policy discussions, such as those of the Intergovernmental Panel on Climate Change - IPCC (IPCC, 2014). An RCP can include any combination of factors that would be projected to lead to specified levels of atmospheric radiative forcing – RF (i.e. increased warming from solar radiation); however, four pathways are typically examined for RF levels of 2.6 w/m^2, 4.5 w/m^2, 6 w/m^2, and 8.5 w/m^2 (IPCC, 2014; Moss, et al., 2010). With regards to the pathways themselves, most of the literature seems to indicate that of these four pathways, only RCP 2.6 (which includes a brief peak RF of 3.0 w/m^2) is projected to likely limit average global warming below 2.0^o C above pre-industrial levels with a reasonable level of assurance (IPCC, 2014; van Vuuren, et al., 2011). While many models have been drawn for RCP 2.6, the ongoing work of van Vuuren *et. al.* is by far the most widely used (IPCC, 2014; Moss, et al., 2010; van Vuuren, et al., 2011). While this model does include some consideration for carbon sequestration through reforestation (although largely offset by land-use change – LUC - for bioenergy production), and carbon capture and storage – CCS (mostly from coal), little consideration has been given to the potential for sequestration through broader types of ecosystem restoration, conservation, and other activities that would enhance carbon uptake (van Vuuren, et al., 2011).

[5] Ť is used as a general term to express a point whereby the damage caused by climate change can be viewed as "unacceptable" (i.e. catastrophic and irreversible). While various tipping points with varying severity have been conjured, such as the five drawn out by Cai, Lenton, and Lontzek; this document consolidates the concept to a single point for simplicity and clarity (Cai, Lenton, & Lontzek, 2016).

While this exclusion is partially due to significant uncertainty and a poor understanding of global carbon cycles (Moss, et al., 2010), it would appear somewhat negligent to continue to exclude these on such a large scale. If GHG emissions are ultimately even just slightly higher than those presented by the optimistic assumptions of the five-year old RCP 2.6, then even a 5% or 10% increase in uptake capacity could be the difference between realizing and not realizing Ť.

This exclusion has not been limited to the work of van Vuuren *et. al.* (Moss, et al., 2010), and is saliently reflected in communications of the global "carbon budget," which is commonly and narrowly expressed in terms of cumulative anthropogenic emissions since the Industrial Revolution, rather than the total atmospheric carbon stock at any given point in time [which is only alluded to through the communications of atmospheric CO_2 concentrations in terms of parts per million – ppm (IPCC, 2014)]. Given that the natural carbon uptake capacity of the Earth constitutes half of the climate change equation, it is quite surprising how little attention has been given to this, and a need for understanding global carbon uptake and implementing measures for enhancement becomes apparent.[6]

Aside from such an exclusion from the definition of the problem itself warranting attention, the need for incorporating these measures in discussions of, and action towards solutions becomes paramount in urgency for two reasons. The first is that the RCP 2.6 model provided by van Vuuren *et. al.* includes extremely optimistic emissions reductions (explicitly disclosed by the authors), arising from global collaboration and immediate action to reduce emissions (which haven't followed in the six years since the paper was published), and providing almost no room for error; this is made even more difficult by the fact that the model assumes that new technologies can be implemented globally, and in a timely manner (van Vuuren, et al., 2011). Furthermore, the recent withdrawal from the Paris Climate Accord by the United States (while not yet fully implemented) demonstrates how precarious success through this manner of effort would be, and perhaps speaks to the increasing prominence of adaptation and geoengineering as viable plans of action (Galston, et al., 2017; Scherffius, et al., 2013; Brasseur & Granier, 2013).

The second reason comes from an increasing understanding of climatic tipping points, their inter-relationships, and the trigger levels of RF for the realization of Ť. The recent work of Cai, Lenton, and Lontzek, 2016 presents five possible tipping points [melt of Greenland ice sheet (GIS); shift to a (more) persistent El Niño regime (ENSO); dieback of the Amazon rainforest

[6] It should be noted that there have been some efforts to better understand the carbon uptake cycles for inclusion in the RCP framework, although these efforts do not appear to be resonating in global climate discussions (Canadell & Raupach, 2008).

(AMAZ); disintegration of the West Antarctic ice sheet (WAIS); and collapse of the Atlantic thermohaline circulation (AMOC)], with AMOC being of the most severe consequence (Cai, Lenton, & Lontzek, 2016). While these tipping points vary in severity, with associated costs that may be viewed as "acceptable" by the general public and policymakers, the study also outlines a potential "domino-effect," whereby one tipping point may trigger another, leading to unprecedented, devastating, and potentially irreversible effects (Cai, Lenton, & Lontzek, 2016). For this reason, and while incorporating risk preference considerations for "social planners," the authors recommend a target warming level of 1.5^{o} C (Cai, Lenton, & Lontzek, 2016); a level that is further supported by other studies (Hansen, et al., 2016). While an increase of 1.5^{o} C falls mostly within the projected temperature increase ranges of RCP 2.6 by the years 2065 and 2100, it does not fall entirely within these likely ranges (0.4^{o} – 1.6^{o} C for 2065, and 0.3^{o} – 1.7^{o} C for 2100), and demonstrates a potential need to target RF levels below 2.6 w/m^2 (IPCC, 2014).

1.2 Goals and Scope

1.2.1 Choosing a Direction

This document aims to present a new framework for approaching the issue of climate change by building off an existing proposal which has been introduced in the past year (that of the Climate Leadership Council - CLC), and demonstrating how financial instruments can be created and brought to market that will properly capture the price of carbon and the notion of a "carbon offset" (Baker, et al., 2017). It is hoped that this framework will effectively help to lower atmospheric GHG concentrations in a way that allows for a dynamic integration and refinement of the underlying factors that contribute to higher levels of "radiative forcing" (RF; essentially global warming). The framework will allow for an understanding as to how a multitude of factors affect changes in the "social cost of carbon," and expand upon this notion to help to inform the price of a unit of carbon *at a given point in time*, as well as the value of restoring that unit at a specified later point in time (i.e. separating a value of carbon from a time-value of carbon from an emissions perspective). Combining these factors allows for an examination of a new way to look at offsetting, one by which the ultimate goal will be to reduce one's respective contribution to ensure that global atmospheric concentrations of carbon do not exceed chosen threshold values as they relate to the chosen Ť. To do so will take time, and therefore uncertainty, and efforts to reduce emissions and shift out the time by which a threshold concentration level will likely be reached can be seen as a way to compensate for the time-value dimension.

The study is rooted in five broad goals to enable a new framework for mitigating climate change. A bottom-up, specific example is hypothesized to be one of the most cost-effective, highest-impact sub-strategies that could be incorporated into a broader, all-encompassing strategy. Specifically, this document is intended to:

1. *Reformulate the approach to mitigating climate change in a manner that (a) fully exploits sequestration potential to the extent feasible, preferably through ecosystem restoration; and (b) determine how emissions reductions can dynamically, marginally affect the times at which climatic tipping points are realized.*[7]
2. *Translate the basic economic principles of absolute value and time-value to that of carbon and re-examine the broad concept of "offsetting carbon" in order to standardize it by separating current offset schemes into two distinct groups; those that sequester carbon (primarily, although not entirely, addressing the magnitude dimension), and those that avoid emissions (primarily, although not entirely addressing the time-value dimension).*
3. *Demonstrate how the separation of the two dimensions of magnitude and time-value can be concretely applied through the creation of a new financial market. This goal has sub-components, and will formulate the foundation for this document's desired output. The sub-components include:*
    a. *Creating a financial security that is rooted in underlying ecosystem-based projects: a coastal mangrove restoration project and a traditional REDD+ project.*
    b. *Examining the potential cost-effectiveness of this security by understanding the required components for implementation and comparing their aggregate to models for the "social cost of carbon" and prominent proposals for a "carbon tax."*
4. *Formulate a basic framework within which this new type of security and similar securities can be marketed and regulated, and determine where collaboration will be needed for technical inputs and implementation.*
5. *Outline areas for future growth and expansion in terms of other types of financial securities; as well as the potential for capturing other types of externalities, whether they be environmental or otherwise.*

1.2.2 Mapping the Boundaries

The specific purpose of this document is to create a new type of financial security that is reflective of the concepts described above and can be demonstrative of a second era of carbon

[7] It should be noted that it is unlikely that the full needs for reductions in atmospheric carbon concentrations will be met through ecosystem sequestration, however, approaching the problem from this angle first allows for the calculation of an increased emissions budget and may make emissions reductions discussions more appealing to policymakers and the general public (McLeod, et al., 2011).

markets that truly capture the concept of an "offset." However, this desired output necessitates a basic framing of various concepts and theories which would underlie it. This will require further research and consolidation beyond the scope of this document. For this reason, various foundational parameters are explained in terms of principal and function, as opposed to specific inner-workings. Ultimately, it is desired that the development of a framework-tailored financial instrument example will demonstrate how other similar instruments can be created, as well as the underlying institutional and regulatory frameworks within which this market must operate.

It is hoped that a collection of assets similar to the one mentioned above can form a global marketplace for the sequestration and storage of carbon, whereby the "time-value" of carbon is appropriately differentiated from an absolute value (essentially distinguishing between carbon in terms of "debt" via emissions and "equity" via storage). A key component to this effort is going to be a standardized index series that can quantify the cost of one unit of greenhouse gas (GHG) emission at a given time, as it relates to the estimated threshold time projection for a tipping point and the projected magnitude of impacts from anthropogenic GHG emissions. While such a marketplace with the ability to properly ascertain and attribute the costs of carbon to an activity at a given point in time may have seemed to be a far-fetched fantasy in the past, the role of "big data" and the ability to interpret such data through complex predictive algorithms and advanced statistical analysis will allow for a level of precision that only a small group of people would have thought possible ten years prior.

Ideally, there would be a single entity that would be in charge of regulation, oversight, and the indices of the marginal cost of carbon. It would initially seem that the United Nations would be the ideal body for this given its global reach and extensive institutional knowledge accumulated via the IPCC and within the United Nations Framework Convention on Climate Change (UNFCCC); however, several issues immediately arise. The first of which is that the U.N. may not have the capacity to implement financial securities, and a collaboration with an organization such as the International Finance Corporation (IFC) may be needed to bring such a security to market; or that a quasi-independent body be established to facilitate the market. Secondly, UNFCCC has taken a much more "hands off" approach in recent years and the IPCC has shifted the onus of integrated assessment modeling (IAM), which would be viewed as perhaps the best starting point for carbon indexing, to the broader scientific community at large (Moss, et al., 2010). Finally, and perhaps most salient in terms of feasibility, would be the difficulty in implementing a global standard that all nations (or at least the vast majority) would abide by, especially in a world where populist nationalist movements are on the rise. For these reasons, the discussion in Chapter 4 will begin to look at some of the ways in which an indexing and regulatory scheme could be most efficiently implemented.

1.2.3 The Destination, and What Comes After

The main output from this study is the outlining and framing of a basic model for a new type of financial security that allows an economic agent to meet an obligation to offset emissions, and incorporates a time-value dimension for the expected length of time that it is expected take to meet the obligation, and is defined in advance, upon entering the agreement. Specifically, the security will be based on a collateralization of a coastal mangrove restoration project and a REDD+ project into a single instrument. While a single-dimension asset could be created that requires an obligation to be met for a higher level of ultimate sequestration than the original emission to compensate for time-value, the division into two separate assets/liabilities helps to better illustrate how current offset schemes should be divided into two types of category, addressing the different elements of atmospheric carbon concentrations as they relate to global warming and tipping points.

Secondly, the incorporation of a REDD+ project serves to demonstrate that there remains value in "avoided emissions" schemes. Finally, with regards to REDD+, since these types of schemes have been in place for over a decade now, verified credits are used to serve as a proxy to indexed-avoided emissions credits[8] in the absence of an index schedule, derived from the index function described in Chapter 2. Coastal mangrove restoration has been chosen as the vehicle for sequestration due to initial findings that indicate a high value for the "blue carbon" of these systems, and relative ease in terms of survival and cost in implementing coastal mangrove restoration projects (Bayraktarov, et al., 2016; McLeod, et al., 2011; Pendleton, et al., 2012). Mangroves also provide an added, although unquantified benefit of protection from coastal flooding[9], an adaptation scheme in itself, which serves as a further benefit and would hopefully increase the appeal in terms of restoration (Spalding, McIvor, Tonneijck, Tol, & van Eijk, 2014) .

The market will have the inherent problem that its essential goal (eliminate the threat of realizing the tipping point) is going to be highly correlated with reducing the value of these securities to the point of being almost nothing (i.e. if there's no longer a threat of realizing the tipping point, then there is no need to offset emissions), which is part of the reason that the

[8] While the REDD+ credits generated from a project are likely overestimated in relation to what indexed credits would look like, initial testing and subsequent testing found the avoided emissions credits to have an inconsequential impact on the pricing of the security, which indicated these credits to be an acceptable proxy for the purposes of this document.

[9] In terms of the scope of this document.

specific examples of a REDD+ project and a coastal restoration project (i.e. ecosystem-based) have been chosen. If climate change is averted, other environmental issues such as water security are still likely to persist and, in turn, similar types of obligation schemes could be created, whereby natural systems will likely carry additional value. This is a benefit that is not as likely to be realized by technological means[10]. Secondly, ecosystem restoration and conservation entail a lower externality risk than relying on technology. For instance, while biofuels are often seen as cleaner alternatives to fossil fuels, biofuel production has been criticized on several fronts, of which the most relevant to this argument (when speaking of externalities) would be the consignment of agricultural lands for fuel production, rather than to feed an ever-growing planetary population (Tenenbaum, 2008). However, with ecosystem restoration and conservation, externality costs would be more expected to manifest solely in terms of opportunity costs from foregoing activities that yield short(er)-term economic gains (although not necessarily entirely).

Furthermore, similar types of securities could be used to secure funding for various types of restoration projects that may not prove to be economically feasible in a context that is solely restricted to carbon. This notion dovetails with the concept of payment for ecosystem services (PES) schemes that are now in their nascent stages of development (UNDP, 2017). For example, studies have placed the value of ecosystem services from mangrove forests as high as $194,000/ha./yr. (Duncan, et al., 2016). As carbon would only constitute a very small portion of this value, opportunity exists to value and compensate for the preservation of other important ecological functions (e.g. watershed protection).

However, this approach only begins to scratch the surface of an issue that has plagued free-market economies since their inception: the issue of externalities. Some externalities are widely accounted for in the context of “sin” taxes on services like gambling or products such as alcohol; and through regulations such as those requiring various types of insurance (e.g. automobile insurance), or buy in to insurance-like programs (e.g. U.S. EPA Superfund program). Although the degrees of success through such provisions has varied, and equitability can often be brought into question. In contrast, the approach outlined in this document facilitates the establishment of a foundation from which to build an ability to fairly price goods and services in an economy, both in terms of the primary cost associated with production, operations, and sales, as well as the externality cost incurred by parties not involved in the transaction.

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[10] This relates to the likelihood of a single technology being able to simultaneously mimic the benefits of a natural ecosystem.

Chapter 2: Methods

2.1 Basic Terms and Methods

The term "carbon" will be used extensively throughout this document to refer to the "basket" of greenhouse gases (either the unit or the stock depending on context, but usually specified), standardized to CO2 in terms of global warming potential (GWP). The unit of measure for carbon is expressed as one tonne of CO2 equivalent (tCO2E), and the terms "carbon credit" or "carbon offset" will generally refer to the respective function of a single unit, whereby the term "credit" may refer to an avoided emission credit or a sequestration credit, which typically do not carry the same value in the models (a foundational premise of this document).

Although mentioned in a footnote in Chapter 1, it is worth clarifying, that while not part of the common nomenclature, due to the U.S.-centered approach of this document, the spelling of "tonne" is used to delineate one metric ton, and prevent confusion in the event that the word "ton" were to be interpreted as an imperial ton.

With regards to inflation, U.S. Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) data was used to express all historical values in January 2017 in U.S. dollars (USD$), while future inflation is modeled at 1.5% per annum (U.S. Department of Labor, 2017). Intra-year conversions were calculated based on the month of January (due to the availability for 2017 data at the beginning of this study).

2.2 Re-Approaching Climate Change: The Carbon Budget

The broadest framing of this study begins by defining the existence of a baseline scenario whereby a "tipping point" would be reached and must be avoided. The pursuit of this goal should begin with the examination of baseline scenarios for climatic tipping points, and current projections for global atmospheric carbon stocks in order to gain an understanding of the potential gross sequestration that can be realized within a reasonable timeframe. What exactly constitutes a "tipping point" isn't typically well communicated outside of the scientific community. Initially, the tipping point was thought to merely be a warming level of 1.5^{o} C or 2.0^{o} C above pre-industrial levels, but the dynamic underlying these thresholds had not been considered.

To assess the potential impact that the new security could leverage, it was initially desired to understand what level of global atmospheric carbon stock would correspond to an average warming of 1.5^{o} C above pre-industrial levels (what was taken to be the "tipping point"). However, finding an atmospheric carbon stock level that is likely to trigger a given level of warming and therefore respective environmental damage has proven to be a more difficult task than one might imagine. While the 2014 IPCC Synthesis Report notes that total cumulative anthropogenic emissions since 1870 should not exceed 2,250 $GtCO_{2E}$ (66% probability), no mention is made as to what level of concentration at any given point in time, would correspond to this level of warming (IPCC, 2014). Given this difficulty, a more intensive literature examination was undertaken, with the goal of using subsequent calculations inferred from what information could be derivatively informed from other estimates if needed; or examinations of ranges for the remaining carbon "quota," which were known to possibly be quite large and thus difficult to infer (Peters G. P., 2016). As attempts to estimate such a figure proved to be immensely more complex than initially anticipated, the definition of a tipping point has been defined in a broader sense, and is mostly limited to this chapter.

The term "tipping point" ($\check{T}_{\emptyset}$) in this context is rather subjective, as it relies heavily on the notion of what an "unacceptable" level of damage incurred from climate change would be. However, to also say that this point does not exist would be a foolish premise from which to base policy decisions. Amounts of sea level rise that would flood all major coastal cities globally, in line with current worst-case scenario projects, would almost certainly be deemed to be to a degree that is "unacceptable," and past the "tipping point" (Hansen, et al., 2016). Yet, defining how many climate refugees are "acceptable," or how many "sunny day floods" Miami can cope with is far more difficult to quantify, and are taken to be beyond the scope of this document (Corum, 2016).

Although a single tipping point is typically mentioned in public communications, the work of Cai, Lenton, and Lontzek, 2016 defines and analyzes the five distinct tipping points identified above and encoded here as: melt of the Greenland ice sheet - GIS, drying over Amazonia - AMAZ, disintegration of West Antarctic Ice Sheet- WAIS, shift to a (more) persistent El Niño regime - ENSO, and collapse of Atlantic thermohaline circulation – AMOC. Additionally, various potential interactions among these processes can affect the probability that another will occur. These covariate effects are dependent on the order in which tipping points are reached (Cai, Lenton, & Lontzek, 2016). Of these tipping points, AMOC would be the most severe consequence (Cai, Lenton, & Lontzek, 2016).

However, a consolidated single threshold value is of much more use in terms of catalyzing action. Following closely off the examination of tipping points by Cai, Lenton, and Lontzek, a single tipping point ($\check{T}_{\emptyset}$) can be described as follows (Cai, Lenton, & Lontzek, 2016):

$$\check{T}_{\emptyset} = \Big(\max_{RF \to RF_{\check{T}}} C\,\big(\kappa(C_n) \pm \Delta\acute{\eta}RF_n \pm \rho\big) > RF_{\check{T}}\Big)$$

$$\begin{aligned} RF_{\check{T}} = F(RA) * F\Bigg(& \Bigg(\sum\bigg(\bigg(\Big(\lim_{n\to AMAZ}\Omega - S \pm \Delta\acute{\eta}RF \pm \rho\Big) + \sum M\kappa(\check{T}_n) * \Big(\lim_{n\to AMAZ}\Omega - S \pm \Delta RFn \pm \rho\Big)\bigg) \\ & + \bigg(\Big(\lim_{n\to AMOC}\Omega - S \pm \Delta\acute{\eta}RF \pm \rho\Big) + \sum M\kappa(\check{T}_n) * \Big(\lim_{n\to AMOC}\Omega - S \pm \Delta RFn \pm \rho\Big)\bigg) \\ & + \bigg(\Big(\lim_{n\to ENSO}\Omega - S \pm \Delta\acute{\eta}RF \pm \rho\Big) + \sum M\kappa(\check{T}_n) * \Big(\lim_{n\to ENSO}\Omega - S \pm \Delta RFn \pm \rho\Big)\bigg) + \bigg(\Big(\lim_{n\to GIS}\Omega - S \pm \Delta\acute{\eta}RF \pm \rho\Big) + \sum M\kappa(\check{T}_n) * \Big(\lim_{n\to GIS}\Omega - S \pm \Delta RFn \pm \rho\Big)\bigg) \\ & + \bigg(\Big(\lim_{n\to WAIS}\Omega - S \pm \Delta\acute{\eta}RF \pm \rho\Big) + \sum M\kappa(\check{T}_n) * \Big(\lim_{n\to WAIS}\Omega - S \pm \Delta RFn \pm \rho\Big)\bigg)\bigg)\Bigg) \pm \rho\Bigg) \end{aligned}$$

From this angle, $\check{T}_{\emptyset}$ is defined by the maximum contribution $- \kappa(x) -$ of the global atmospheric carbon stock (C), plus or minus non-GHG fluctuations in radiative forcing ($\Delta ή RF$), plus or minus uncertainty (ρ), that will lead to a level of radiative forcing which will trigger $\check{T}_{\emptyset}$ ($RF_{\check{T}}$). In turn, $RF_{\check{T}}$ is defined as the product of a function of risk aversion preference – F(RA) - (either of society at large or of representative policymakers) and a function of the realizations of the five distinct tipping points and their interactions with one another. The tipping points are expressed in terms of limits that the atmospheric carbon stock (C = Ω - S : i.e. total GHG emissions - Ω - minus total carbon uptake – S) plus $\Delta ή RF$ can reach before the individual tipping point $\check{T}_{\boldsymbol{n}}$ occurs, plus the marginal contribution to the realization of $\check{T}_{\boldsymbol{n}}$ from each of the other individual tipping points being realized - $M\kappa(\check{T}_n)$.

For defining RA, Cai, Lenton, and Lontzek recommend using the Epstein-Zin risk aversion framework, which mostly relates to inter-temporal consumption preferences in economic systems; however, a derivative of the Kahneman Loss Aversion Ratio may be more appropriate in this context if the "loss" can be adequately communicated and quantified (Epstein & Zin, 1989; Kahneman, 2011; Cai, Lenton, & Lontzek, 2016). Solving this equation and attempting to assign values for the risk-aversion preference were seen to be beyond the scope of this document, but must be mentioned due to their fundamental importance of "indexing" to be further elaborated on below. Therefore, based on the analyses of Cai, Lenton, and Lontzek 2016 and Hansen *et. al.*, 2016, $\check{T}_{\emptyset}$ will still be assumed to be realized at the point where average global warming increases by 1.5° C above pre-industrial levels (Cai, Lenton, & Lontzek, 2016; Hansen, et al., 2016).

Through more refined analysis, the threshold value may end up being quite different than that which has been chosen for the purposes of this document. However, this conceptualization provides foundation for the logic behind the concept of a global "carbon budget;" whereby, *ceteris paribus,* there is an acceptable level of carbon emissions that will not cause damages of any significance (e.g. the emissions from the first automobile did not likely have a noticeable effect on a global scale). Whether the value was reached in 1970, or is projected to be reached in 2050, would be a matter of debate beyond the scope of this document. What was relevant was to establish the existence of a maximum, and to have an informed estimate as to what this maximum may be.

An examination of the four prominent "Representative Concentration Pathways," or RCPs (2.6, 4.5, 6, 8.5), has been conducted to understand what levels of sequestration are already factored into these pathways, and what factors contribute to these levels of sequestration (van Vuuren, et al., 2011; Thomson, et al., 2011; Masui, et al., 2011; Riahi, et al., 2011). An attempt was made to understand the Gross Sequestration Potential (GSP) and compare it to the sequestration already built into the RCP's to understand the magnitude by which sequestration through sink restoration can potentially be used to avoid reaching the threshold level of atmospheric GHG concentration. Various areas of significant uncertainty have been found to exist and are outlined, and descriptive methods for refinement, such as improved data consolidation, statistical analysis, and uncertainty diminishment through rigorous data analytics are suggested. Due to the difficulty encountered, most of this analysis is kept to a descriptive, high-level discussion and can be found in Chapter 4.

Finally, a baseline assumption must be made regarding the requisite value of an offset. In a scenario where the carbon stock is safely within even the lowest bounds for a threshold value, an offset need not be at a 1:1 ratio; as the carbon stock approaches the threshold value, the ratio rises closer to 1:1 (if the threshold value was not seen to be a "point of no return," then the ratio could grow to a rate greater than 1:1). While the threshold value is not currently realized (as far as can reasonably be inferred), but adverse effects of climate are already being realized, it is assumed that all emissions need to be offset at a 1:1 ratio. In this situation, the time delay in realizing the sequestration is going to be the sole determinant of the cost of such a delay.

A more in-depth discussion of tipping points and the global carbon budget; specifically, as they relate to the differentiation of the "time-value of carbon" principle can be found in Appendix A.

2.3 Redefining Carbon Markets

2.3.1 Ecosystem Carbon Capture Option (ECCO)

To express the role of how a differentiation between the absolute value and time-value of carbon can be translated to the market, a new type of financial security has been modeled; the "Ecosystem Carbon Capture Option" (ECCO). The ECCO is based on the premise of an individual or firm having an "obligation to offset" an amount of carbon, with a price premium for the time-value of doing so. To allow for flexibility and comparison in implementing such a strategy on a national versus international basis, two securities have been created, one which is entirely U.S. based, the other which is based internationally.

Due to the large sequestration potential for coastal mangrove forests, relatively high survival rates and low restoration costs in comparison to other types of restoration, as well as added benefits with regards to ecosystem services such as, but not limited water filtration and nutrient regulation, as well as the climate adaptation benefit of coastal protection (Bayraktarov, et al., 2016; Pendleton, et al., 2012; Fancy, 2004; NOAA, n.d.); a coastal mangrove restoration project has been chosen to act as the underlying asset for the "principal" of the security (i.e. the ultimate amount of carbon which is to be restored in the form of an "offset"). As the "interest" on the security is more closely tied to the "indexing" function – F(Ï), a traditional REDD+/forest carbon project has been chosen to act as the underlying "asset" for this component of the security. This "interest" serves as compensation for the time-value of carbon, and uncertainty (as it relates to the ultimate survival rate of the site, and carbon stock growth) relative to the projected per unit contribution in relation to a climatic tipping point being realized (further explained below). While there is potential to create a similar scheme as REDD+ for mangrove projects, such a mechanism has not yet been implemented and it would appear more feasible to implement a traditional REDD+/forest carbon project in the short term, due to the high level of overlap between the existing verification process, and the basis for F(Ï).

The security's (expected) yield is expressed in terms of indexed sequestration credits at t=n, expressed as $\ddot{I}(\Theta)_n$, a reflection of the ratio of carbon sequestration credits (Θ_n) to avoided emissions credits (θ_n). The avoided emissions credits express the marginal contribution of avoided emissions (in this case, from avoided forest deforestation and degradation) in relation to the expected time at which the chosen tipping point Ť will be realized, and are fully reflective of the expected probability (threat level) of those emissions occurring.

The inherent value of a carbon stock is captured within the implementation framework in terms of "carbon equity." The indexing function used to price credits can broadly be described as follows:

$$F(\ddot{I}) = M\kappa C_{tCO_{2E}\text{n}} = F\left(\frac{\lim_{n \to \check{T}_{\emptyset}} f(\Omega - S \pm \Delta\acute{\eta}RF \pm \rho) + (\xi_n \pm \rho)}{C_n}\right)$$

Whereby $F(\ddot{I})$ is an expression of the marginal contribution of one tonne of CO_2-equivalent GHG emission at a given point in time ($M\kappa C_{tCO_{2E}\text{n}}$) to the expected realization of $\check{T}_{\emptyset}$. $M\kappa C_{tCO_{2E}\text{n}}$ is expressed as a function of the relationship of the total atmospheric carbon stock at a given point in time (C_n) to the realization of $\check{T}_{\emptyset}$ in terms of total carbon emissions (Ω) minus total uptake (S), plus/minus natural (and non-GHG) fluctuations in radiative forcing ($\Delta\acute{\eta}$RF), plus/minus the associated uncertainty (ρ); plus, already realized economic costs associated with climate change (ξ_n), plus/minus the associated ρ.

The ECCO will operate under the notion that an obligation to offset can be indexed at a fixed ratio at a given point in time in terms of θ_n:$\Theta_{n:}$. For example, assuming that one tonne of CO_2 persists in the atmosphere for 1,000 years, without a time-value consideration and assuming a global carbon budget of zero (no implication of realizing a $\check{T}_{\emptyset}$), the indexing ratio would be 0.001 (i.e. one avoided emission per year for 1,000 years to allow for natural uptake to occur). In reality, the relationship is more complex as there is (most likely) a permissible atmospheric carbon budget and there is a time implication of realizing $\check{T}_{\emptyset}$. However, this example serves to define the paramount function of the index ratio, which is to define the "exchange rate" between

θ_n and Θ_n for any given year and timeframe for sequestration. This allows for the retrospective value attribution of avoided emissions credits in the past; the indexing function of the current year is intended to capture any historical errors in indexing (viewed as a necessary tradeoff).

It should be noted that any verified Θ will have a value equal to Ï(Θ), meaning that on the open market, entities may choose to buy excess Θ directly (i.e. unsold sequestrations that have occurred since framework adoption). Furthermore, verified θ can also be sold for the equivalent Θ based on the index ratio that they carry; retroactive emissions avoidance works in this case (as opposed to current market schemes), as projects are funded up-front and credits for avoided emissions are verified for the past (rather than buying an arbitrary "offset" for an historical vintage that was not used for funding the generation of the credit).

Within the implementation framework, an economic agent will be issued a liability for a number of carbon-equivalent emissions (P_t) on an annual basis based on (GHG-releasing) economic activity, which will carry an indexed value representative of current global climate understanding, such that:

$$\mathrm{P}_t = -\ddot{\mathrm{I}}(\Theta)_t$$

The agent will either agree to offset the obligation for the year at the defined ratio or pay a carbon tax. The ECCO will function much like a call option in that an agent agrees to fund a portion of project implementation, reflective of expected sequestration over a given period of time (defined as 20 years for the models presented in this document) plus compensation for the time-value to realize sequestration, in the form of avoided emissions. Over the course of this period of time project verification will occur at regular intervals (defined as five-year intervals in the models below), with a subsequent option to execute based on upside and downside scenarios. In both scenarios, the verified credits will reduce P_t up to the expectation for that verification period. For upside scenarios (i.e. realized sequestration or avoided emissions such that the realized indexed credits are greater than the expected credits), the agent may choose to either reduce their initial obligation by the amount gained above the expected amount, and re-index the remainder of the security at the current index ratio, or they may sell excess credits on the open market to agents with a shortfall. For downside scenarios, agents can buy excess credits on the open market to make up the shortfall, or pay the CPI-adjusted carbon tax from the obligation year.

After verification and reconciliation, P_t will be reduced by the expected level for t=n at t=0 regardless of the realized $\ddot{\mathrm{I}}(\Theta)_t$; by design this serves to ensure that the amortization schedule cannot be changed and that obligations are not fully met. Furthermore, to better ensure that the market is properly serving the ultimate goal of offsetting emissions, a layer of control is added on both the upside and the downside by requiring a re-indexing of the remaining obligation on gains (essentially an early payback fee), but not allowing for an increased obligation at a re-indexed rate on the downside (i.e. indefinitely pushing the obligation to offset outwards). At the end of life for the ECCO, agents with gains can choose to sell excess credits generated or place a call for excess credits to be converted to a carbon equity stake in the project(s) and thus be entitled to carbon dividend payments (explained below within the implementation framework); agents with losses must make up shortfalls by buying credits, or pay the CPI-adjusted carbon tax from the obligation year. An entity that exercises the call option will be entitled to the proportion of equity called at the end of the restoration project, plus (or minus) and gains (or losses) in the carbon stock after t=20, proportional to the respective share at this time.

The basic principle is that the ECCO will be publicly listed and offered at a cheaper price than that of a carbon tax, likely set between \$40 and \$50 per tonne of CO_2 equivalent (tCO_{2e}). The security will have a coastal mangrove restoration project tied to it as ultimate means to achieving the gross sequestration of the necessary units, while an "interest" will be paid based on an indexing figure, in conjunction with a REDD+ project. It should be noted that an amount of avoided emissions for a given index period would exist that is sufficient to be equivalent to one sequestration credit.

A review of available literature has been conducted to estimate how much this type of project would cost to implement and regulate; and modeling based on success factors has been conducted to estimate both the upside and downside risks associated with the project. After accounting for the project costs, estimates have been added for aspects such as project monitoring and regulatory enforcement. Before modeling was conducted, it was hoped that the price for this mechanism would be significantly less than that of a carbon tax, even with the downside risk accounted for.

2.3.2 ECCO with Underlying International Projects ($ECCO_I$)

The international form of an ECCO ($ECCO_I$) is modeled based on a hypothetical mangrove restoration project in Colombia, and an existing REDD+ project in Peru. Separate countries have been chosen to demonstrate how a regional, or international framework could be implemented (to be touched upon below).

The Ciéga Grande de Santa Marta restoration project, as described by Rivera-Monroy *et. al.*, 2006, has been used as the basis from which to draw most of the restoration model (Rivera-Monroy, et al., 2006). This project has been chosen for several reasons. The first was a high expectation for levels of sequestration[11] in Colombian mangrove forests, supported by the work of Chmura, Anisfeld, Cahoon, & Lynch, 2003, which demonstrated average soil carbon densities among the highest for mangroves in Colombia, second only to South Africa (Chmura, Anisfeld, Cahoon, & Lynch, 2003). The second reason for selecting this project as the basis was the longer timeframe in data collection (ten years) in comparison to other projects that were found in the dataset provided by Bayraktarov *et. al*.,2016 (Bayraktarov, et al., 2016). This was presumed to allow for more confidence in survival rates and cost estimates. While the area ultimately degraded in 2001 after restoration had begun in 1993, the authors attribute the degradation to a rapidly increased salinity level that was caused by a lack of maintenance (due to a loss of funding) of diversion structures which had been set up for project implementation (Rivera-Monroy, et al., 2006). As considerations of long-term project sustainability (in terms of costs, anthropogenic destruction, and natural destruction) are incorporated into the implementation framework underlying the ECCO, this shortcoming of the project was seen to be surmountable in the modeled project with altered underlying financial assumptions.

The sequestration rate which was modeled (net ecosystem productivity – NEP – of ~9.3 tC $ha.^{-1}/yr^{-1}$) was cross-referenced with the allometric data of samples from the Gulf of Mexico (no Colombia specific data were readily accessible) of Komiyama, Ong, and Poungparn (Komiyama, Ong, & Poungparn, 2007). While a net ecosystem productivity (NEP) of ~9.13 tC $ha.^{-1}/yr^{-1}$ is somewhat higher than that of the 5.61 tC $ha.^{-1}/yr^{-1}$ of Puerto Rico (the only case which was explicitly calculated), based on the net primary productivity (NPP) rates for *Rhizophora* (unspecified species) for various samples in Mexico and Dominica in comparison with those of the Puerto Rico sample, an NEP of ~9.13 tC $ha.^{-1}/yr^{-1}$ appeared to be reasonable for this model; this was assumed to be the sequestration rate at full maturity, which was assumed to be ten years.[12]

Due to a lack of readily available data, further assumptions had to be made regarding the growth rate expressed through a change in NEP. Cross referencing the NEP of the Colombia

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[11] The sequestration rate was modeled to be 2.5 g C $/m^2$ / day which was directly converted to 9.125 t $C/ha.^{-1}/yr.^{-1}$ which was used for the NEP value. The sequestration rate was modeled based on what had been taken to be implied for the sequestration rate of local forests from the study (Rivera-Monroy, et al., 2006). However, subsequent examination revealed that the authors were simply referring to a global average provided by a separate study (Jennerjahn & Ittekkot, 2001). For this document, the rate has been left unchanged as it still appears to be a reasonable assumption for the purposes of early modeling; it is intended that further research will be conducted and refinements made as necessary.

[12] Extensive efforts were taken to locate literature detailing the life-cycle, and thus time to maturation of mangrove species, however, no supporting data was located and a ten-year assumption was taken. This highlights part of the broader need for research in this area mentioned later in the document. If such information becomes available, the model will be updated accordingly in future iterations.

model at maturity with that of the Florida model (see below), a ratio of ~1/0.61479 $NEP_{t=10}$ was derived for the NEP of the Colombia mangrove to that of the one in Florida. Applying this rate to the $NEP_{t=1}$ of 3.62 tC $ha.^{-1}/yr^{-1}$ for the Florida model, an $NEP_{t=1}$ for Colombia was estimated to be ~5.88 tC $ha.^{-1}/yr^{-1}$. To demonstrate a diminishing growth rate in line with expectations, ΔNEP was estimated by using the following formula, which was applied to the NEP values for the years t=2 to t=9, beginning with the derivation from $NEP_{t=10}$:

$$NEP_{t-1} = \ln\left(\frac{NEP_t}{11.67}\right) + NEP_t$$

Total sequestration credits for the Colombia project ($\Theta_{I\text{-}2017}$) were estimated by multiplying the NEP by the project area, modeled to be 35,000 ha., and presumed stand survival rates (which would be informed by the validation). As a proxy for calculating Ï(Θ)t, a discount rate of 25% was applied to the expected $\Theta_{I\text{-}2017}$, which was translated directly to the number of θ required. Due to the low implication of θ under various scenarios that were initially tested in terms of the security price, this was seen to be an acceptable and conservative assumption. It should be noted that applying a traditional net present value (NPV) calculation has a significant impact in terms of the intended static nature of the index ratio, however, as all of the modeled securities in this document are across 20-year horizons, a static index ratio can be maintained when comparing various potential scenarios from the models.

For costs, the authors note that the exact total restoration costs were unknown but were estimated to be approximately USD $40 million from 1993-2003. Assuming a high level of capital investment for the first five years; the "goal seek" function in Excel was used to target a total of $40 million in investments over the period 1993-2003; for initial investments at (CPI-adjusted) equal rates for five years, with a drop to a level of 25% of (CPI-adjusted) investment costs in 1998 for ongoing maintenance. This in turn, informed an initial investment amount of $5,648,924 (1993), adjusted to $9,619,767 (2017) for Year 1; and amount of $1,600,397 (1998), first adjusted to $2,404,942 (2017), and increased by 1.5% per annum to yield an initial maintenance rate for the project of $2,590,805 beginning in 2022, and continuing at a +1.5% anticipated CPI-adjusted rate for the remaining life of the security. Land acquisition costs were excluded, as land ownership would be representative of the "carbon equity" concept outlined in the framework sections.[13] An initial validation cost of $20,000 was estimated, with verifications occurring every

[13] Under the framework, land holdings would generate dividend revenues for sink conservation, and therefore are seen to be separate from the costs involved in a sequestration project with revenues coming from credit sales, rather than taxes.

five years, adjusted by projected CPI with a 2017 base rate of $50,000. An indexing fee of $5/ha. was applied in Year 1 (2017) and charged entirely upfront, as with other costs. The baseline $ECCO_I$ model for Θ presented in Appendix B.1 below.

The model for θ_I generation follows closely from observations of the Alto Mayo Protected Area REDD+ project in Peru. Implemented in 2008, the project allows for an iterative comparison of estimated reductions at time of validation to subsequently verified reductions. The project has undergone two rounds of verification; (Markit Group Limited, 2017). The actual schedule of expected θ beginning in 2008 has been transposed onto the $ECCO_I$ model, which begins in 2017; as the validation was only done for a ten-year period, the net expected θ from 2027 onwards was modeled to be 506,586 per year (the simple average of the expected reductions from years one to ten). Furthermore, as the verification periods are not uniform in the underlying project, the first two vintages have been evenly spread across the years, so that θ is modeled on a yearly basis. Expected success rates were not incorporated due to the inclusion of "buffer credits," which essentially act as an insurance pool for ensuring the permanence of verified emissions reductions (VERs) under the current voluntary system (Global Canopy Programme, 2016b); these were modeled to be 10% of gross expected VERs for the second half of the security's life.

Conservation costs (i.e. project implementation costs) were estimated to be USD $7/ha (2008 dollars), which was adjusted by CPI to yield an initial cost of USD $1,465,686, increased by 1.5% per year for the life of the security (Olsen & Bishop, 2009). As with the restoration project, land acquisition costs have been excluded from this analysis.[14] Validation and verification costs have been incorporated in the same manner as with the Colombia restoration project. The baseline model for θ_I is shown in Appendix B.2.

The baseline model for $\ddot{I}(\Theta_I)$ can be found in Appendix B.3, and demonstrates the basic functioning of the $ECCO_I$ over time on a security-wide basis, rather than on an individual agent basis (an agent will have the rights to the respective share of indexed credits purchased at t=0). The reconciliation process of realized credits to expected credits (every five years) at the locked-in rates and ratios is the key feature to model. The expected θ generated from the REDD+ project inform locked-in percentages at a given point in time that $ECCO_I$ holders are entitled to for each

[14] The exclusion of land acquisition is actually more pertinent in this case than in the others as this project is operated by Conservation International Foundation on publicly-owned land, demonstrating the potential for similar collaborations to be worked into the framework for carbon equity (Conservation International - Peru, 2016).

round of verification.[15] θ which are actually generated are compared to the baseline model, and subsequently converted to their $\ddot{I}(\Theta_I)$ value, dictated by the index ratio, and used for aggregation of total $\ddot{I}(\Theta_I)$ against the amortization schedule. Differences in the expected generated Θ versus the actual Θ that are generated do not carry a discount factor due to the separation inherent in this model. With a common basis for comparison established by multiplying the realized θ by the index ratio, a number of $\ddot{I}(\Theta_I)$ for reconciliation is established; the last two lines of the model show how this will be translated to a number of either Θ or θ from which the option can be executed.

2.3.3 ECCO with Underlying U.S.-Based Projects ($ECCO_{US}$)

The $ECCO_{US}$ is modeled to be based on two projects in the United States; one being a mangrove restoration project in Florida (basis for Θ_{US}), the other being a forest carbon project in Tennessee (for modeling θ). Florida was chosen as it is the part of the mainland U.S. where mangrove forests primarily grow (Mitsch & Gosselink, 1993). Although the Bayraktarov *et. al.*, 2016 study had (what appeared to be) a relatively comprehensive dataset for Puerto Rico, it was not considered in this analysis, in order to draw a greater distinction between the underlying data of the $ECCO_{US}$ and the $ECCO_I$ (Bayraktarov, et al., 2016). Implementing the model's selection criteria begins with the data from Bayraktarov et. al., 2016, and examining the different projects located in Florida. Based on the available information in terms of project size and observation duration (ten years)[16], the West Lake (Broward County) mangrove restoration project was chosen as the basis for the cost modeling (Bayraktarov, et al., 2016). As project costs were estimated to be $5,000,000 from the period 1986 to 1995, the same methodology was applied for calculating project implementation costs as was done for the $ECCO_I$. Validation and verification were also assumed to cost $20,000 and $50,000 (2017 dollars), respectively, and verifications were adjusted to +1.5% CPI per annum accordingly.

There was much more uncertainty in calculating the carbon uptake in the Florida model than there was for the Colombia model. Chmura *et. al.*, the 2003 report shows carbon accumulation rates in soil ranging from 39 g/m^2/yr. to 381 g/m^2/yr. for sites around Rookery Bay (Florida), while sites around the Florida Keys are reported to have accumulation rates between 100 g/m^2/yr and 143 g/m^2/yr. Sites around the Shark River Estuary did not have reported

[15] In the event that a reconciliation year falls before a verification, only verified credits will be counted through that point, with the understanding that unverified credits will generate a surplus in future years; or that verified credits through an earlier point in time will be sufficient to cover an obligation through the life of the security.

[16] The West Lake project was the only project above 125 ha. in size except for the Indian River Lagoon project which appeared to be a major outlier in terms of restoration costs per hectare (significantly lower than the other projects at $225/ha.) and size (significantly higher than the other projects at 8,000 ha.).

accumulation rates, but did have similar soil densities to (Chmura, Anisfeld, Cahoon, & Lynch, 2003). The net primary productivity (NPP) of the sites in Florida (*Rhizophora,* unspecified subspecies location within Florida, and age) reported by Komiyama, Ong, & Poungparn, 2007 was 8.10 and 12.10 t/ha./yr., however NEP values were not given (Komiyama, Ong, & Poungparn, 2007). Comparing the NPP values to the NEP value of the site in Puerto Rico (the only site for which NEP was reported), and assuming similar respiration and exposure rates, it could be extrapolated that the NEP for sites in Florida may be between 64.49% and 96.3% of those in Puerto Rico, or between and 3.62 t/ha/yr and 5.40 t/ha/yr. Based on this information, it would seem reasonable to expect an NEP somewhat higher than that reported by Chmura *et. al.*, 2003 (maximum of 3.81 t/ha/yr) which was only for carbon accumulation in soil, although not greater than the NEP values extrapolated from the Komiyama, Ong, and Poungparn paper. A simple average of the 3.62 t/ha/yr and 5.40 t/ha/yr NEP values was therefore used to estimate an NEP of 4.51 t/ha/yr at full maturation in the model (assumed to begin in Year 10). The NEP for Years 1 to 9 was extrapolated by using the formula below as a proxy for growth, yielding an NEP in Year 1 of 0.46, slightly higher than the minimum soil accumulation reported by Chmura *et. al.*, 2003.

$$NEP_{t-1} = \ln\left(\frac{NEP_t}{5.42}\right) + NEP_t$$

The project size was assumed to be 1,000 ha. Since applying an NPV calculation to the model for expected credits is only used as a rough proxy for F(Ï), a discount rate of 20% was applied in this instance to maintain the index ratio of 0.061. In terms of the outcome that was realized (i.e. final price of the security), this was seen to be an acceptable change as the impact was inconsequential. Survival rate for the Florida project was set higher than Colombia's, at 95% per year for the entire life of the project. The model for Θ_{US} can be found in Appendix C.1.

Although REDD+ projects have historically been in developing countries, the California Cap-and-Trade Regulation provides a good starting point for modeling θ_{US}, as forest carbon projects are established in a similar fashion to REDD+ projects with standardized frameworks for validation and verification (ARB Compliance Offset Program, 2013). While a fairly large number of U.S.-based forest carbon projects were found to already be in various stages of implementation in the United States and listed through the American Carbon Registry (American Carbon Registry, n.d.) and the Climate Action Reserve (Climate Action Reserve, n.d.), the pool of potential projects for use in designing the $ECCO_{US}$ was limited to those that have been listed in accordance with the Verified Carbon Standard (VCS) methodology and listed in the VCS project database (Verified Carbon Standard, 2015). The main reason for limiting the projects to VCS projects was to ensure a more standardized, uniform approach in how VERs were calculated for both the $ECCO_{US}$ and $ECCO_I$ as a proxy for modeling θ_{us} (to the extent possible). A list of these projects can be found in Appendix C.2.

As the California Cap-And-Trade Regulation is in a relatively nascent stage, project management data was not relatively available. Therefore, the assumption was taken that project implementation costs would be similar to those of traditional conservation projects which was used as a proxy for estimation. Land acquisition was excluded from the calculations, as these are considered to be captured within the carbon equity framework, separate from the ECCO.

This process began by examining data provided by a 2008 Defenders of Wildlife report, which suggested a national average annual maintenance cost of USD $22.10/acre (2006 dollars), which was converted to $ 66.88/ha. – 2017 dollars (Casey, Michalak, & Manalo, 2008). Next, the report was cross-referenced with the 17 states listed in the report against the VCS project list in Appendix C.2, of which three states overlapped. Of the VCS projects located in those states, the "Blue Source- Coal Creek Improved Forest Management Project" (Coal Creek Project) in Tennessee was chosen due to its significantly larger size in terms of land area (24,739 ha.), and for having a higher carbon concentration than the other two projects in Tennessee (286.83 tCO_{2E}/ha.), although not substantially larger or far from the maximum of 512.56 tCO_{2E}/ha. (The Coal Creek Company, 2016). It should be noted that soil carbon was excluded from the stock assessment in the validation document (unknown reasons), and therefore may be an underestimation for θ, depending on the potential effect that the alternative (destructive) project would have on the soil (The Coal Creek Company, 2016).

As no credits had been issued for the Coal Creek Project at the time of writing, the baseline carbon stock from the Coal Creek Project (7,095,893 tCO_{2E}) was compared to that of the Tennessee River Gorge Trust IFM project in terms of percentage yield of credits per two-year vintage (American Carbon Registry, n.d.; The Coal Creek Company, 2016). The Tennessee River Gorge had a baseline common practice carbon stock of 448,011 tCO_{2E}, and yielded 338,024 verified GHG reductions for the 2015-2016 vintage (Turner, Hirst, & Silon, 2016; Tennessee River Gorge Trust, 2016). Therefore, about 75% of the common carbon stock was issued in the 2015-2015 vintage for the Tennessee River Gorge Trust, which translated to a net θ value for the first vintage in the model (2017-2018) of 5,353,847. A further assumption was taken that 10% of the issued credits would be held in a buffer account, and that each vintage would decline in expected yield by 15% due to a decreased incentive for activities that would degrade the forest carbon stock.

2.3.4 ECCO Testing

The baseline $ECCO_I$ and $ECCO_{US}$ models have in turn been used for the comparative analyses found in Chapter 3. Due to time constraints and the necessitation of advanced modeling techniques for pricing the ECCO[17], sensitivity analysis has been limited to examining the ECCO from an illustrative perspective in order to show how the security can behave under possible types of scenarios. The basis for the carbon tax (ϒ) has been limited to one scenario (described below). The behavior of the ECCO has been modeled to show five scenarios: (1) increased mangrove survival and avoided emissions generation after verification at each increment, (2) both decreased mangrove survival and avoided emissions generated after verification, (3) decreased mangrove survival and increased avoided emissions at each stage of verification, (4) increased credit generation for verifications at t=5 and t=10, followed by decreased generation at t=15 and t=20, and (5) decreased credit generation for verifications at t=5 and t=10, followed by increased generation at t=15 and t=20.

Investor behavior has been modeled to show both expected payoff from selling credits or re-indexing in upside scenarios, and paying a tax versus buying indexed credits on the open market in downside scenarios. End of life carbon equity conversions are only outlined in terms of equity share gains, as tax-dependent and gross sink-dependent dividends have not been calculated.

Gains or losses in credits under each of the tested scenarios were incorporated into the consolidated ECCO baseline models outlined in Appendix B.3 and Appendix C.4; from which credits for reconciliation were generated at t=5, t=10, t=15, and t=20, and expressed both in terms of θ and Θ. A baseline obligation is expressed on a per-credit basis, showing an amortization schedule for the proportional offset obligation that must be reconciled to after each verification. At t=0 the obligation is 1, dropping to 0.83 at t=5, 0.57 at t=10, 0.28 at t=15, and 0 at t=20. Holders of the ECCO who show losses can choose to pay the indexed tax price for the shortfall, or buy credits on the open market to reconcile to the respective amortization for the period. ECCO holders with gains can sell any credits above the amortization amount (shown on a per credit basis below at $4.82 during the first reconciliation), or can apply the gains to lower their obligation, which necessitates re-indexing. Re-indexing is calculated by subtracting the reduction amount from the obligation and multiplying by original tax rate divided by the current

[17] A starting point for pricing the ECCO would be to adopt and expand upon the Black-Scholes-Merton formula in a way that would allow for the consideration of execution under both upside and downside scenarios, as well as volatility associated with project success, re-indexing, and market variations associated with current carbon taxes and indexing. Monte Carlo simulations could be run subsequently to obtain a stochastic distribution for informing the risk distribution and reasonable expectations for ECCO payoff scenarios (Atzberger).

tax rate, whereby the de-obligation is discounted and a new index ratio is generated; the holder is subsequently liable for the indexed tax rate (CPI-adjusted) at the time at which the option is called. Cumulative credits are tracked at the bottom, and used for instances when a holder fully meets their obligation with a surplus in credits, whereby they may either sell on the open market or convert to an equity portion equivalent to the number of credits by which they are over the obligation. If this happens before t=20, the holder can continue to hold the ECCO, or sell the ECCO with the rights to subsequent periods, while still holding the equity conversion from the prior period(s). Equity is calculated at t=20, and all equity holders will be entitled to equity changes (e.g. through soil enrichment) in proportion to their ownership of carbon equity (expressed in shares corresponding to 1 tCO_{2E} stored carbon) for future years.

Figure 2.1: ECCO Reconciliation & Option Execution Process:

Verification Years

ECCOI - Scenario 1	2017	2021	2026	2031	2036	Note
Reconciliation Ï(Θ)		(390,986)	(825,554)	(665,770)	(652,003)	Credits to reconcile against expected generation for amortization
θ to Meet Obligation		(1,550,412)	(3,273,642)	(2,640,037)	(2,585,447)	
Θ to Meet Obligation		(390,986)	(825,554)	(665,770)	(652,003)	
Obligation [Baseline/ per Ï(Θ)]	1.00	0.83	0.57	0.28	-	Baseline amortization schedule
ϒ (2017 Ï / tCO2e) - CLC Basis	$ 47.56	$ 50.48	$ 54.38	$ 58.59	$ 63.11	Tax cost per tCO_{2E} (locked-in indexed rate t=0) / current tax rate at t=n / market price of credits at t=n
ϒ (Ï + n) - CLC Basis	$ 47.56	$ 54.00	$ 65.00	$ 73.20	$ 78.85	
Market Price for Ï(Θ)	$ 47.56	$ 52.24	$ 59.69	$ 65.89	$ 70.98	
Potential Revenue per Ï(Θ - 2017) Sales	$ 25.80	4.82	11.63	10.36	10.92	Potential revenue from sales of credits on open market, per indexed credit
NPV (8%) - Ï(Θ - 2017) Sales Only	$ (10.38)					
Potential Revenue from Ï(Θ) Sales (Re-Indexed)			*10.87*	*9.13*	*10.30*	
Reduction Option / Ï(Θ)		0.09	0.23	0.28	0.15	Option to reduce obligation (to be discounted via current index ratio)
Re-Indexed Obligation		0.79	0.33	(0.10)	(0.15)	New amortization schedule to 0 / negative value means eligibility for equity conversion
Index Ratio	-	0.057	0.050	0.047	0.047	
Cumulative Θ		*811,115*	*2,086,532*	*3,443,876*	*4,801,219*	
*ECCO Equity Basis (Entire Security)**	-	-	-	*64,256*	*163,120*	Carbon equity "shares" converted from exceeding obligation
ECCO Equity Conversion Stake (%) @ t=20				*1.34%*	*3.40%*	

Scenario 1 incorporated very optimistic performance assumptions, and the $ECCO_{US}$ was seen to have been created based on optimistic model assumptions as well. Since the $ECCO_{US}$ was deemed to be unfeasible under Scenario 1, $ECCO_{US}$ testing was limited to Scenario 1 which would have provided for the best performance. However, the discussion in Chapter 4 touches on some of the ways in which the $ECCO_{US}$ may be made feasible.

2.4 Implementation Framework

The regulatory framework for national implementation follows closely from the policy proposal of the Climate Leadership Council (CLC), which proposes a scheme of taxation and "dividends" to the public from all revenues received from carbon taxes (Baker, et al., 2017). This framework has been chosen for several reasons, paramount among them is its potential feasibility in terms of the current political landscape (the CLC heavily promotes its solution as a "Republican" solution), as well as the opportunity for synthesis presented in terms of an ultimate desire to capture externality cost within an economy. The current framework calls for a direct tax on fossil fuels at the source of production with revenues from these taxes to be distributed amongst all taxpayers; households are paid twice as much for adults as for children (Halstead, 2017). However, the policy presented has several aspects which could be enhanced to better capture the concept of a "dividend." Typically, in financial markets a dividend is paid on an equity share that implies ownership, however, a direct redistribution of taxes does not imply any ownership to the recipient (from what could be discerned from the available CLC literature).

Halstead specifically mentions the concept of "loss aversion," as famously outlined by Amos Tversky and Daniel Kahneman in 1991, as one of the key hindrances to addressing the issue of climate change (Halstead, 2017). The concept is based on a general observable psychological preference of individuals to prefer minimizing losses over realizing gains, and that because the "gains" from addressing climate change are long-term and translate to only gaining against maintaining the norm, that individuals are not willing to make the short-term financial sacrifices to see future "gains" that only serve to maintain normalcy (Halstead, 2017; Tversky & Kahneman, 1991; Kahneman, 2011).

However, a logical gap exists in that as it is currently laid out, the policy proposal does not appear to directly imply any immediate loss to the general public, while promising to provide incremental gains in the form of "dividends." What is missing is an objective measure from which to measure loss, whereby the notion of ownership must be introduced, and hence follows the concept of "carbon equity." Rather than pay dividends in a simple, redistributive manner, dividends should be paid based on the proportion of ownership an individual holds in a given carbon sink (based on a rather simple calculation despite its appearance). The following formula could be used to express how an individual dividend would be calculated:

$$D = (\alpha_h + 0.5\beta_h) * (\frac{C_F}{\alpha_F + 0.5\beta_F} + \frac{C_S}{\alpha_S + 0.5\beta_S} + \frac{C_M}{\alpha_M + 0.5\beta_M}) * \frac{Y_{Pu}}{Y_G} + \alpha_i * \frac{C_{Pr}}{\alpha_{iP} r} * \frac{Y_{Pr}}{Y_G}$$

Whereby a dividend (D) is paid to a household (h) based on the number of tax filers (α) plus half of the filed dependents (β), in terms of the household's respective share of all tax revenues attributable to publicly-owned sinks ($\frac{Y_{Pu}}{Y_G}$), *i.e.* those owned on federal (C_F), state (C_S), and municipal (C_M) bases; as well as an individual's (i) share of dividends attributable to their respective ownership in a privately-held sink (C_{Pr}).

By dividing the dividends payment in this manner, the value of sink conservation is presented to the general public in clear financial terms, and conservation is promoted at all levels of terrestrial ownership. While an initial temptation arose to change the coefficient for children from 0.5 to 1.0, as future generations will face greater consequences from climate change opposed to generations present, the number was left unchanged, as increasing the dividend share for children may incentivize larger households, thus promoting greater population growth and subsequent resource strain[18] (voters at any level may wish to change the respective coefficient). While the coefficient was left the same, the concept of "child" was slightly altered to be that of a filer's dependent.

Secondly, the tax base has been somewhat expanded from the CLC proposal to tax fossil fuels at the source of production (as well as some types of industrial emissions) to include land-use change (LUC) and livestock, which can also be seen as major primary-source contributors that would not be adequately captured if the tax was limited to fossil fuel production (EPA, 2017; Horowitz, Cronin, Hawkins, Konda, & Yuskavage, 2017). This is especially important to consider as the current RCP 2.6 model presented by *van Vuuren et. al.* shows much greater shares of non-CO_2 emissions in the years approaching 2100 (van Vuuren, et al., 2011). Non-livestock agricultural activities have been excluded (as have other, less consequential primary sources) as these are seen to be "essential" emissions that may not have an easy technological solution[19] for reductions readily available, and therefore should be accommodated within the carbon budget without cost ("less consequential emissions" are intended to be captured within the indexing process).

To make the ECCO and other financial securities financially appealing, the models rely on the underlying assumption that a polluter is given a choice between paying a carbon tax (ϒ) or offsetting the pollution by agreeing to return it to a sink, and paying compensation for the time it takes to do so, as well as associated uncertainty. ϒ has been set in accordance with the CLC proposal submitted to the U.S. Treasury for analysis, which begins in 2019 at a rate of \$49/tCO_{2E} (Horowitz, Cronin, Hawkins, Konda, & Yuskavage, 2017); the projected CPI rate was backed out of this to obtain a Υ_{2017} of \$47.56. The tax was compared to several estimates for the social cost of carbon (the marginal economic cost of one tCO_{2E}) and deemed to be reasonable and feasible.

The 2015 White House analysis of the social cost of carbon – SCC – provided for an excellent starting point in examining SCC levels, as several values were proposed at different confidence intervals and at different points in time (Interagency Working Group on the Social Cost of Carbon, 2015). The rate proposed by the CLC closely mirrored the midpoints that were

[18] This notion was not further explored and seen as beyond the scope of this document, and it is possible that such a perverse incentive would not arise in the event that the coefficient was changed.
[19] This notion/assumption was not explored in depth, and seen to be outside the scope of this document.

proposed by the Obama Administration (e.g. the CLC proposal recommends $52 in 2020, while the White House provides an average of $42 – 3.0% discount rate, or $62 - 2.5% discount rate (Interagency Working Group on the Social Cost of Carbon, 2015; Horowitz, Cronin, Hawkins, Konda, & Yuskavage, 2017). With regards to the scientific literature, this rate is close to some that were reviewed, such as those provided by Nordhaus of $31 for 2010 – or $34.74 in 2017 (Nordhaus, 2016). However, the rates provided in the policy documents were significantly lower than some presented in other studies, such as that of Cai, Lenton, and Lontzek of $116 for 2010, or the $220 for 2020 presented by Moore & Diaz, 2015 (Cai, Lenton, & Lontzek, 2016; Moore & Diaz, 2015). However, while CLC literature does note that the price of carbon should eventually reach $200, these higher rates were seen as less feasible for implementation, while lower rates would also allow for more prudence in modeling the ECCO. Based on these considerations, the CLC rates were ultimately seen to be feasible for use in the ECCO models (Halstead, 2017).

Υ_{2017} was modeled to increase by 1.5% per annum in line with the expected CPI value, and Υ_n was set in accordance with the CLC proposal presented to the Treasury (as hoped for the rates diverge over time, showing an advantage to "locking-in" an obligation at the 2017 tax rate and potentially being able to profit from sales of excess credits); for the years 2028 (the last year for which a rate was presented) onwards, only a CPI of 1.5% per annum was added (Horowitz, Cronin, Hawkins, Konda, & Yuskavage, 2017). The "market price" per indexed credit - $\ddot{I}(\Theta)$ – was modeled to be a simple average of Υ_{2017} and Υ_n; the logic being that entities with obligations at Υ_n will be willing to pay for credits at a higher rate than Υ_{2017}, but less than $\Upsilon_{n.}$

The security will likely require being listed on a new type of exchange with an oversight body that will ensure that there can be no perverse incentives whereby parties may profit from project failure. While the concept of carbon equity helps to address this issue in that sink owners will be incentivized to preserve their sinks, certain explicit regulations should be put in place; namely, short-selling of the ECCO and other similar securities should be strictly forbidden under any circumstance. The role of "indexing" will be key, and an overall strategy for design and collaboration with parties (e.g. with expertise in modeling uncertainty and manipulating large amounts of data) will be laid forth so that a framework can be built from which further work can be done to bring this type of security to market. The examination will look at implementation on both a global scale, as well as within the context of the United States.

The listing framework for collating the projects and bringing the ECCO to market follows closely off of the recently issued $152 million forest bond from the IFC (Klopfer, 2016). Based on the IFC framework, an organization will issue the security which is to be underwritten by a commercial bank and publicly listed; the issuer will hold finances from the initial listing in an escrow account and disburse funds to projects over the life of the security (IFC, 2016). As the IFC forest bond is listed in accordance with the current voluntary market for REDD+, the listing framework has been enhanced upon to include additional stakeholders (e.g. tax authorities and the indexing body). Ways in which this listing framework can be implemented both nationally and internationally will be discussed below.

Chapter 3: Results

3.1 ECCO Performance

3.1.1 ECCO Baseline

The baseline scenarios detailing project costs, expected indexed credit generation, and price per indexed credit - Ï(Θ) - are shown below for both the $ECCO_{I}$ and the $ECCO_{US}$:

ECCO-I Baseline Costs		
Θ Costs		
Mangrove Restoration	$	49,563,606
Conservation Maintenance	$	44,376,353
Validation/Verification	$	258,173
Indexing Fee ($5/ha)	$	175,000
Sequestration Project Cost	**$**	**94,373,132**
Total Expected Θ		4,236,370
Cost Per Θ	$	22.28
θ Costs		
Conservation Costs		33,892,035
Validation/ Verification		258,173
Indexing Fee		910,000
Total REDD+ Costs		**35,060,208**
Expected θ		9,488,119
Cost Per θ	$	3.70
Required θ		3,464,444
Cost for θ from Peru REDD+	**$**	**12,801,708**
Underwriter Fee (2%)	$	2,143,497
Total ECCO-I Cost	$	109,318,336
Ï(Θ) Available		4,236,370
Cost Per Ï(Θ)	**$**	**25.80**
Index Ratio		**0.061**

ECCO-US Baseline Costs		
Θ Costs		
Mangrove Restoration	$	8,199,563
Conservation Maintenance	$	4,941,821
Validation/Verification	$	258,173
Monitoring & Indexing ($5/ha)	$	5,000
Sequestration Project Cost	**$**	**13,404,556**
Total Expected Θ		79,716
Cost Per Θ	$	168.15
θ Costs		
Conservation Costs		94,541,302
Validation/Verification		254,653
Indexing Fee		305,660
Total Project Costs		**95,101,615**
Expected θ		25,798,869
Cost Per θ	$	3.69
Required θ		65,788
Cost for θ from Tennessee	**$**	**242,513**
Underwriter Fee (2%)	$	272,941
Total ECCOus Cost	$	13,920,011
Ï(Θ) Available		79,716
Price Per Ï(Θ)	**$**	**174.62**
Index Ratio		**0.061**

Based on the assumptions outlined in Chapter 2, the $ECCO_{I}$ could be brought to market for $25.80 per Ï(Θ), and the $ECCO_{US}$ would cost $174.62 per Ï(Θ). It should be noted that this price difference is entirely caused by the differences in mangrove restoration estimates provided between the Colombia and Florida projects. Of particular interest may be that the Tennessee forest carbon project produces avoided emissions credits (θ) at nearly the exact same price as does the Peru REDD+ project. However, this difference may be due to a change in validation technique, as the basis for the Peru project (Alto Mayo Protected Forest) had its validation done in 2008, and verifications done since have shown a significant underestimation in the original validation (Markit Group Ltd., 2017). A new validation technique may reveal higher estimates for θ, and therefore a lower cost per θ; however, this does help to highlight the "early movers advantage" described in Chapter 4. In comparison to a carbon tax (ϒ) of $47.56/tCO_{2E}$, *ceteris paribus,* the $ECCO_I$ baseline looks quite appealing, while the $ECCO_{US}$ does not appear to be financially feasible. If ϒ were to be increased to $200, as is suggested to be eventually necessary by the Carbon Leadership Council (CLC), then the $ECCO_{US}$ may end up being a viable choice for economic agents with offset liabilities (Halstead, 2017).

3.1.2 Illustrative ECCO Performance Scenarios

Scenario 1

Scenario 1 for the ECCO would be a scenario in which the projects realize gains both in terms of θ and ϴ. For the $ECCO_I$ (Appendix D.1.1), based on increases in θ in accordance with those already realized for the Alto Mayo Protected Area (estimated reductions – VER's - versus verified VERs, and an average of these gains for the years in which verification has still not occurred), and an increased survival rate to 85%, close to 2.6m excess Ï(ϴ) would be generated (Markit Group Ltd., 2017). Holders of the $ECCO_I$ could choose to sell all excess credits at each verification, raising the net present value – NPV - (8% discount rate[20]) of the obligation to $10.38 per credit, which translates to gains of $15.42 per credit on the initial listing price of $25.80, or $37.18 in relation to a $ϒ_{Ï\text{-}2017}$ of $47.56/tCO_{2E}$. However, if a holder chooses to apply the gains to their outstanding obligation and re-index, they may meet their obligation by t=15 (as opposed to t=20); the excess realized against the obligation may in turn be converted to an equity stake equivalent to 64,256 "shares" (each share equal to one tCO_{2E}, and across the entire $ECCO_I$ this translates to 1.34% of the total carbon stock at t=20 under this scenario), or can be sold on the open market as Ï(ϴ) (land owner retains equity stake).

In either case the buyer may wish to sell the ECCO for the remainder of life on the open market (entitling a buyer to future proceeds), or continue to hold the ECCO and convert future gains into equity (re-indexing occurs under this scenario as well), or sell credits on the open market. Whomever holds equity generated from the ECCO at the end of life shall be entitled to carbon

[20] The reason that 8% has been chosen as opposed to 25% is because this represents the discount rate on a financial investment, whereas the 25% discount rate used for calculating the necessary θ was a proxy chosen in place of the index function for discounting credits in terms of avoided emissions versus sequestered emissions.

equity gains attributable to stock enrichment (or losses from degradation) in proportion to their ownership stake at t=20; if the conversion was exercised across the entire ECCO, holders would be entitled to a total of 163,120 shares, or about 3.40% of the project's total carbon equity. It should be noted that the buyer may choose to sell credits and/or re-index at any of the four verifications in any proportion of combination that they deem to be desirable, and which the framework would allow.

In terms of carbon sequestered, the $ECCO_I$ would capture 4,801,219 tCO_{2E}, and support avoided emissions of 5,433,907 tCO_{2E} under Scenario 1 over the life of the security; net of purchase or sales from reconciliations.

The $ECCO_{US}$ does not perform well, even under the most optimistic parameters offered by Scenario 1 (97% mangrove survival, gains in θ directly proportional in terms of magnitude to those of the $ECCO_I$). If an entity were to sell all excess Ï(Θ), the net present value of the obligation increases to $159.84 from $174.62; a level still well above the $ϒ_{Ï\text{-}2017}$ of $47.56. Even when changing the net ecosystem productivity (NEP) to that of the Colombia project, the cost to bring the security to market would still be $134.11. While it may be possible that net economic gain could be realized if the future index rate were to fluctuate substantially, or if the dividends were sufficiently high from a potential equity take (for the whole security, 3,228 shares at t=20; about 2.11% of the carbon equity stock for the site), these scenarios are seen to be extremely unlikely, therefore no further scenario testing was done for the $ECCO_{US}$ as it was deemed to be unfeasible as things stand.

In terms of carbon sequestered, the $ECCO_{US}$ would capture 81,394 tCO_{2E}, and support avoided emissions of 109,860 tCO_{2E} under Scenario 1 over the life of the security; net of purchase or sales from reconciliations.

<u>Scenario 2</u>

Scenario 2 (Appendix D.2) represents a pessimistic projection, whereby losses on θ are projected at the same magnitude as the gains under Scenario 1, and mangrove survival is lowered from 75% (baseline) to 50%. However, under Scenario 2, the project still shows an NPV (8%) of the obligation to be $43.97, assuming the holder opts to pay $ϒ_{Ï\text{-}2017}$ instead of buying credits on the market at the modeled value. It is of interest to note in this instance that the security still holds an NPV (8%) for the obligation of $47.33 against the projected market price, and $45.65 against the $ϒ_{Ïn}$ rate at t=n for each verification; both of these values are lower than the $ϒ_{Ï\text{-}2017}$ of $47.56,

indicating that even at a loss of this magnitude, the simple locking-in of the ECCO's value at the 2017 index would be sufficient to yield returns against the initial tax obligation.

In terms of carbon sequestered, the $ECCO_I$ would capture 2,824,247 tCO_{2E}, and support avoided emissions of 1,591,822 tCO_{2E} under Scenario 2 over the life of the security; net of purchase or sales from reconciliations.

<u>Scenario 3</u>

Scenario 3 (Appendix D.3) is one whereby the project shows gains in $\ddot{I}(\Theta)$ for the first two verifications and losses in $\ddot{I}(\Theta)$ for the second two; these were calculated to be in direct proportion to Scenario 1 for verifications at t=5 and t=10, and in direct proportion to Scenario 2 for the verifications at t=15 and t=20. The holder of the security is assumed to lower their obligation and re-index at t=10, however not at t=5 due to the re-indexing increasing the obligation (albeit by a very small amount). By lowering one's outstanding obligation at t=10, the effective price per purchased credit in t=10 versus t=15 on the initial obligation is lowered substantially.

Under Scenario 3 an NPV (8%) against the obligation for the security holder of $25.40 is realized, which, while only slightly lower than the $25.80 cost of the security, remains substantially lower than the $\Upsilon_{\ddot{I}-2017}$ of $47.56, demonstrating financial viability under these conditions.

In terms of carbon sequestered, the $ECCO_I$ would capture 3,683,407 tCO_{2E}, and support avoided emissions of 3,454,990 tCO_{2E} under Scenario 3 over the life of the security; net of purchase or sales from reconciliations.

<u>Scenario 4</u>

Scenario 4 (Appendix D.4) represents an inverse to Scenario 3, whereby losses are realized during the first two verification periods, with gains coming at t=15 and t=20. The dynamics have been modeled in terms of the same magnitude as those in Scenarios 1-3.

Scenario 4 demonstrates a lower NPV (8%) of $32.83 against the obligation than that of Scenario 3 if the buyer were to pay $\Upsilon_{\ddot{I}-2017}$ at t=5 and t=10, and sell credits at market price in later years. If the holder were to instead choose to re-index at t=15 and convert gains into equity at t=20, the NPV (8%) against the obligation would still be $36.36, significantly lower than price of $\Upsilon_{\ddot{I}-2017}$ of $47.56. Equity gains under this scenario amount to 98,864 shares at t=20 (2.51% of carbon stock added if exercised across the entire ECCO).

In terms of carbon sequestered, the $ECCO_I$ would capture 3,942,059 tCO_{2E}, and support avoided emissions of about 3,325,068 tCO_{2E} under Scenario 4 over the life of the security; net of purchase or sales from reconciliations.

Scenario 5

Scenario 5 (Appendix D.5) illustrates what may happen under a scenario whereby one project experiences significant losses, while the other experiences substantial gains. Scenario 5 includes two sub-scenarios: one where the REDD+ project shows losses in accordance with Scenario 2, while the mangrove project shows gains in proportion to Scenario 1; and one where the inverse occurs.

Under Scenario 5.1, losses are realized from the REDD+ project, while gains are shown in mangrove restoration. Financially, the reconciliation process will necessitate compensation for losses which have been realized for all four verification periods. However, the NPV (8%) under this scenario still yields a present value of \$34.44 (paying $\Upsilon_{\ddot{I}\text{-}2017}$ at the periods when shortfall payments are required) against the obligation, well below $\Upsilon_{\ddot{I}\text{-}2017}$. In terms of carbon sequestered, the $ECCO_I$ would capture 4,801,219 tCO_{2E}, and support avoided emissions of 1,556,564 tCO_{2E} under Scenario 5.1 over the life of the security.

Scenario 5.2 was shown to be more lucrative than 5.1. If the holder chooses to pay $\Upsilon_{\ddot{I}\text{-}2017}$ at t=5, and subsequently sell all credits onwards at market price, NPV (8%) against the obligation is \$25.02; the buyer may convert an entire gain to equity at t=20 and still have an NPV (8%) of \$26.71 per credit. The ECCO would have a total convertible amount of 55,803 carbon equity shares, or 1.98% of the carbon sequestered.

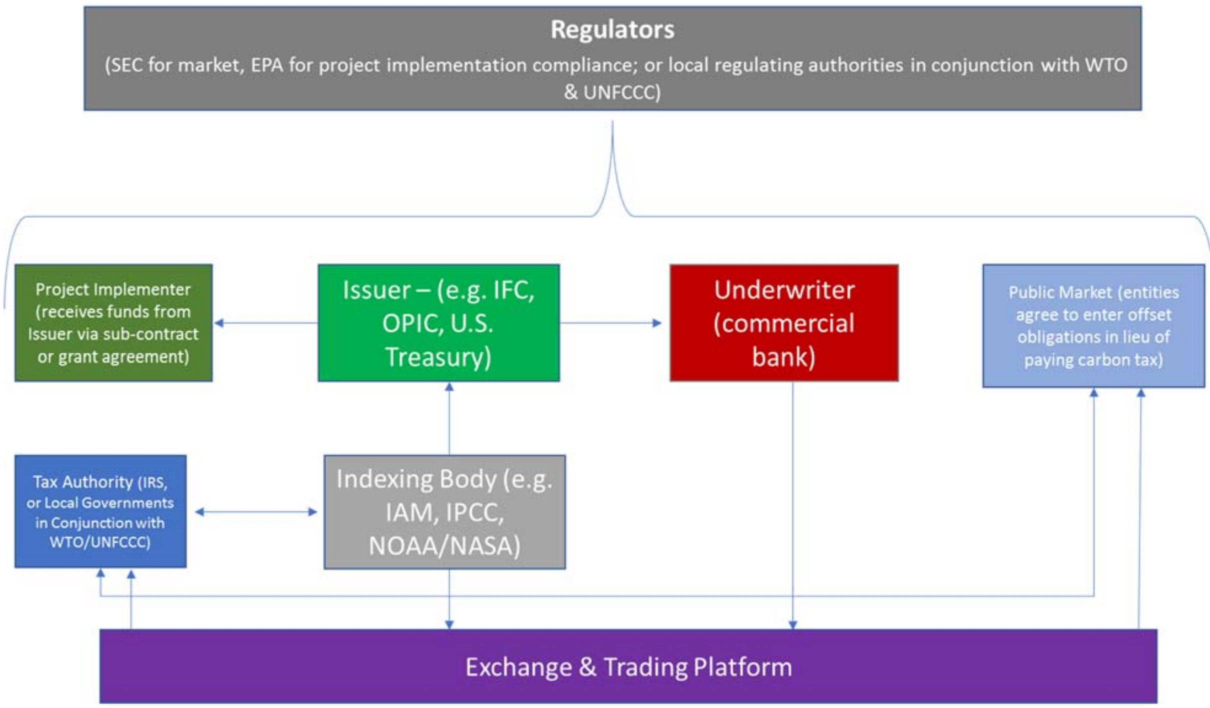
In terms of carbon sequestered, the $ECCO_I$ would capture 2,824,247 tCO_{2E}, and support 5,472,678 tCO_{2E} of avoided emissions under Scenario 5.2 over the life of the security; net of purchase or sales from reconciliations.

Scenario 5.2.2 was created as a final, alternative scenario in order to obtain a better understanding as to how strongly the high returns on the REDD+ project were outweighing the magnitude of those of the restoration project. Therefore, 5.2.2 leaves all parameters unchanged from 5.2, except for the gains in θ, which are cut in half. Under this scenario, while the project necessitates the holder to make up a shortfall in each reconciliation period, the NPV (8%) of doing so is \$28.37 against the current obligation; a level that is still substantially lower than $\Upsilon_{\ddot{I}\text{-}2017}$.

In terms of carbon sequestered, the $ECCO_I$ would capture 2,824,247 tCO_{2E}, and support avoided emissions of about 4,398,319 tCO_{2E} under Scenario 4 over the life of the security; net of purchase or sales from reconciliations.

3.2 Bringing the ECCO to Market

The graphic below outlines the interactions amongst various stakeholders that will be needed in order to bring the ECCO to market:



Primary to the ECCO's functioning is the issuer, or the organization that will coalesce the various project components into a single financial security, to be underwritten by a commercial bank and listed publicly on an exchange. The issuer will likely play a role in project oversight as it will collect the funds raised from the initial sale of the ECCO and effectively hold them in an escrow account, disbursing funds over a period of time to the project implementers. The ECCO prospectus would need to specify what would happen in the event of project failure due to mismanagement. One possibility would be for the issuer to have the right to purchase the respective portion of a similar ECCO at their discretion (differences in index ratios to be reconciled through the exchange), another would be for funds to be returned to security holders, whereby they are liable to pay the carbon tax at the CPI-adjusted rate for the index year on any unsettled obligation against the amortization schedule ($\Upsilon_{t=0}$). Depending on the issuer, a swap agreement could also be used to hedge the underwriting risk of the commercial bank.

Project implementers could be any organization with the capacity to engage in sequestration or avoided emissions projects (not necessarily limited to ecosystem based projects). The validation process would account for organizational risks, prior experience, and success, as well as a feasibility assessment of the proposed implementation budget.

The exchange and trading platform would likely need to be created, and capable of tracking all obligations and generated credits. The platform would need to be capable of reconciling index ratios for different obligation periods and index years.; as well as providing for a marketplace where direct indexed credit purchases, new obligation agreements, and reconciliations could occur. The operator of this exchange is unspecified for the moment, but a nominal fee of $0.10/ Ï(Θ) could be added to every non-tax transaction, similar to other online brokerage platforms. Due to the high level of collaboration required, it is possible that the exchange and trading platform would be maintained by either the tax authority or the indexing body.

The tax authority will issue obligations to taxpaying organizations in accordance with the inventory of emissions for the year.[21] The indexing body will work closely with the tax authority to inform current tax prices, and to inform current index ratios on the exchange. Regulators will be needed to ensure transactional integrity, integrity in project management, and that proper accountability be communicated in a transparent manner to all stakeholders (especially the taxpayers).

[21] Currently an unspecified process to be suggested beyond the scope of this document.

Chapter 4: Discussion

4.1 From Gekko to ECCO

4.1.1 ECCO Performance, Feasibility, and Economic Benefits for Stakeholders

The $ECCO_I$ performed well under all tested scenarios when compared to the proposed carbon tax of $47.56, indicating that, *ceteris paribus*, this type of security could feasibly be listed and publicly sold. While the gains on the REDD+ credits were quite high (possibly due to a change in validation techniques since the Alto Mayo project was first verified), as the losses were calculated to be of the same order of magnitude, the results remain encouraging. Additionally, the frontloading of volatility risk from the avoided emissions projects (θ) helps to convey a lower level of uncertainty across the security's life, hopefully to the effect of making the $ECCO_I$ more appealing to investors. If a carbon tax were to be implemented in accordance with the Climate Leadership Council (CLC) proposal, the $ECCO_I$ would show a positive return (8% NPV) across all tested scenarios. Even under the low-end suggestion of Nordhaus (adjusted to $34.74 in 2017 dollars), the $ECCO_I$ would still show a positive return under most scenarios (Nordhaus, 2016).

Under the most optimistic scenario which was examined, the $ECCO_I$ would allow for an entity to change what had been a 20-year obligation into a 15-year obligation, and still show a small gain over that obligation in year 15. Under the most pessimistic scenario (Scenario 2), the $ECCO_I$ was still found to be cheaper than the carbon tax, indicating that the investment risk from this security, *ceteris paribus*, is quite low. Even when considering the very high returns shown by the REDD+ project (based on the actual validation/verification reconciliation from the Alto Mayo Protected Area), the security remains appealing because losses of an equally high magnitude were accounted for in the downside scenarios. Further examination of different potential scenarios with regards to financial performance may yield different results, however, full price modeling of the security would involve highly advanced derivative pricing techniques that were not feasible to complete within the timeframe needed for finishing this document.

While the $ECCO_{US}$ did not show as impressive returns as that of the $ECCO_I$, it should be noted that the $ECCO_I$ had been modeled based on better informed ecological and cost information with regards to the mangrove projects. It should also be noted that economies of scale did not play much of a role in comparisons between the two securities (the $ECCO_{US}$ was based on much smaller restoration project) in terms of the effects from validation and verification costs. While the uncertainty in things such as costs were high for the $ECCO_{US}$, and what were seen to be conservative estimates were used for mangrove restoration costs, it may be possible that restoration projects could be undertaken at a much lower price in the U.S.

Furthermore, if the carbon tax were to approach some of the higher-end levels proposed in much of the literature, such as the eventual $200 level mentioned as necessary in some of the CLC literature, the $ECCO_{US}$ may begin to look more appealing (Halstead, 2017). Additionally, mangrove restoration may be feasible in Puerto Rico, where (likely) lower costs could be used to create a different $ECCO_{US}$ (Bayraktarov, et al., 2016; Mitsch & Gosselink, 1993). Finally, if other "payment for ecosystem services" (PES) schemes were implemented, or if a business (e.g. a sustainable shrimp farm) wanted to restore mangroves in order to enhance the ecological functioning around its operations area, then perhaps partially raising funds by providing Θ at a subsidized price could be a way for a U.S. based project to be economically viable.

Following on the notion of project implementers using carbon capture schemes to help subsidize business costs associated with restoration activities, it is useful to broaden the concept and consider the benefits that may arise beyond carbon payments and carbon equity. While aquaculture has historically been seen as a key driver of mangrove destruction, mangroves can promote healthier shrimp ponds via effluent filtration (Doyle, 2012; Robertson & Phillips, 1995).

A recent study from South Sulawesi, Indonesia has shown that sustainable aquaculture was not found to be economically preferable to traditional aquaculture due to the associated restoration and rehabilitation costs (Malik, Fensholt, & Mertz, 2015). However, if these costs were to be financed through the issuing of a security such as an ECCO, then it may suddenly prove to be lucrative for shrimp operators to rehabilitate lands and benefit from both carbon equity dividends as well as cleaner, more sustainable operations.

These types of schemes could be particularly appealing in places like Brazil, where *Rhizophora mangle L.* is abundant in the state of Pará, and where some impact investment strategies are already being deployed to support crab farms located in mangrove forests (Encourage Capital, 2016; Machado de Menezes, Berger, & Mehlig, 2008). With plans to have 300,000 hectares sustainably managed through a USD $15m investment, the "Mangue Strategy" proposed by Encourage Capital could already leverage a significant amount of sequestration (Encourage Capital, 2016). Assuming a net ecosystem productivity (NEP) of 2.1, in line with the uptake rates presented by Chmura, *et. al.*, 2003, this area could sequester 630,000 tonnes of CO_2 per year; a single year's unit of sequestration would cost $23.81, well below the $47.56 tax used for the models in Chapter 3. Considering that the $15m investment would reap annual benefits across many years, this sort of venture could provide astronomical returns (Chmura, Anisfeld, Cahoon, & Lynch, 2003). While rice and oil palm expansion appear to be the primary drivers of mangrove destruction in Asia, there still exists some opportunity for sustainable aquaculture, and it could be hoped that the significant higher levels of NEP reported in Asian countries in comparison to those of the Western Hemisphere could be enough to discourage the destruction of mangrove forests for rice production (Richard & Friess, 2016; Komiyama, Ong, & Poungparn, 2007).

In some ways, the ECCO was more complicated than need be through the separation of sequestration credits (Θ) and avoided emissions credits (θ), which may cause confusion in terms of how an indexed credit - Ï(Θ) - is valued. Any Θ which will have been verified after the framework's adoption would be equivalent to one Ï(Θ). The dynamic in terms of discounted sequestration credits manifests from the holder's obligation. The purpose of indexing is to define an "exchange rate" between Θ and θ, which could also be described as a discount rate for Θ, at a given point in time. This is to say that based on the best available projections (from the indexing body) of the marginal contribution of an emission to the realization of the tipping point ($Ť_{ø}$) at a certain point in time, and based on the time that it is estimated to be needed to realize this tipping point, an entity must compensate for the time by which it will take to ensure that a sequestration has been realized. The time horizon dictates the index ratio, or the inverse of the discounted sequestration credit. The index ratio in turn manifests in the amortization schedule at each reconciliation period, and is independent of any other factors, lest the individual choose to lower an obligation and re-index.

One other minor point to quickly touch on would be that under the ECCO scenarios, landowners of sequestration sites carry a risk that gains from the avoided emissions projects will translate to equity conversions on the sequestration project. While the designs presented above were premised from the prospective of the project implementers on their desire to raise enough funding to restore and conserve ecologically valuable areas, and therefore perhaps are somewhat indifferent to this type of risk, security issuer could restructure the option in a manner that would be agreeable to the implementers (e.g. conversion to carbon equity in the avoided emissions project, or equity conversions limited to gross gains on sequestration).

The market dynamics for these securities could prove to be quite interesting due to the opportunities that indexing and speculation would provide. Specifically for mangroves, while increased temperature and water levels can negatively affect survival, high precipitation caused by El Niño-La-Niña cycles can also lead to rapid growth; both of which are phenomena with increased occurrence attributable to climate change (Cai, Lenton, & Lontzek, 2016; Rivera-Monroy, et al., 2006; Cho, 2016; National Wildlife Federation, 2017; Ward, Friess, Day, & MacKenzie, 2016; Chmura, Anisfeld, Cahoon, & Lynch, 2003). Investors may find great opportunity in being able to properly understand how these dynamics may come into play in the localities underlying their securities.

In particular and by design, the ECCO provides for a significant "early movers' advantage" in entering an eventual and more formalized and standardized carbon market. With uncertainty levels highest in the beginning, and low tax rates being proposed to spur investment, buying the ECCO in its early stages will likely allow for the purchasing of credits at a much more favorable index ratio than would be to follow as tax prices and time-value increase. This early movers' advantage would let holders of ECCOs and other similar instruments be able to generate a high level of indexed credits, that in turn would carry a much higher value in the future. As the possibility for significant losses is low, due to having the exit option of paying the CPI-adjusted tax rate instead of having to buy credits to make up for the losses,[22] securities that can be listed at low prices on the market could likely catch on quickly and spur a high level in restorative initiatives.

Yes, there could be criticism in erring on the side of undervaluing credits early on, however, by implementing such attractive investments at an early stage one could pragmatically hope for a "springboard" effect whereby a robust carbon equity and offset market can be catalyzed. As future indexing is intended correct for historical errors, the dynamic market will be self-correcting and reflective of the best available information at a given time, something that markets have often struggled with.

4.1.2 ECCO Environmental Impacts

While the $ECCO_{US}$ was only modeled under the optimistic conditions of Scenario 1, the low-end assumptions of Scenario 2 could be applied to obtain a representative range for sequestration and avoided emissions from the $ECCO_{US}$; 41,956 tCO_{2E} would be sequestered and 32,715 tCO_{2E} of avoided emissions would be supported over a 20-year period under these conditions. Applying the index ratio to the avoided emissions credits, this could be translated to 44,498 tCO_{2E}; as survival was estimated to be 50% under this scenario, a simplified assumption could be that 500 hectares was restored. For sequestration, this would translate to removing about 9,500 cars off the road for one year, except spread over a 20-year period (U.S. EPA, 2016); which is a surprisingly low-level impact, especially with a $13.9m price tag. The effective price per sequestered credit under this scenario would be $312.82, higher than any of the potential social cost of carbon (SCC) figures which were encountered. Under the Scenario 1 assumptions, the $ECCO_{US}$ would sequester 81,394 tCO_{2E} and support avoided emissions of 109,860 tCO_{2E}; total hectares fully restored would be 970 under the same assumptions. The indexed sequestered

[22] In theory, if the policy were to be successful tax rates would eventually start to drop to a point at which point it may make sense to buy credits on the open market as opposed to paying the indexed tax rate.

credits would be 88,111 tCO_{2E} (about the annual emissions of 18,750 cars) with an effective price of $157.11 per tCO_{2E}, which is definitely to the higher-end of estimates found in the literature (U.S. EPA, 2016). While the $ECCO_{US}$ seems grim in terms of costs and impact, the potential ecosystem value and future payment for ecosystem services (PES) schemes could make the $ECCO_{US}$ more appealing. For instance, assuming the ecosystem carries half of the value estimated by Duncan, *et. al.*, 2016, an area of 500 hectares would generate an added value of about $48.5m per year. While quantifying and receiving compensation for this entire value would be extremely difficult, an investment cost of $13.9m might mean that the project could be financial feasible with just a fraction of the ecosystem services generating revenues. Furthermore, the avoided emissions costs were quite low for the Tennessee project, indicating that perhaps an $ECCO_{US}$ with a mangrove restoration project in Puerto Rico, or a mixed ECCO with an internationally-based mangrove project may be feasible for implementation in the short-term. However, as the estimated credits were extrapolated from the verified credits of a separate Tennessee project, it may be possible that this project would be verified for significantly less credits.

The $ECCO_I$ models generated between 2,824,247 and 4,518,795 tCO_{2E} in sequestrations and from 1,591,822 to 5,472,678 tCO_{2E} in avoided emissions (2,921,572 to 4,853,398 sequestration credits when adding the avoided emissions multiplied by the index ratio to the sequestration credits). This translates to removing roughly 580,000 to 1m cars from the road for a year (U.S. EPA, 2016). Simplifying the survival assumptions as done above, it could be estimated that between 14,875 and 29,750 ha. of mangrove forest would be restored through these efforts. This translates to a cost of between $22.52 and $37.42 per indexed tCO_{2E}; a price that is competitive with nearly any of the SCC figures that were examined. Furthermore, assuming that the same value-added by ecosystem services, those from the Florida example above, the $109.3m investment of the $ECCO_I$ could leverage an annual value-added from ecosystem services of about $1.4bn to $2.9bn.

4.2 Carrying the ECCO

4.2.1 Building a Robust, Cost Effective Indexing System

A large tradeoff will be needed in terms of accuracy in the nascent indexing stages, which will be corrected with better informed analyses as time proceeds. However, the indexing function is paramount in its importance as it assigns a value of an emission in a given year based on the best scientific analysis available at the time, in terms of that emission's contribution and required marginal abatement in relation to the realization of the tipping point Ťø. The indexing function will inherently be dynamic and meant to capture the best available understanding of climate change in a given year and appropriate a value. In the earlier stages, the indexing function should err on the side of caution (i.e. implemented with the notion that it will be better to under value, rather than over value assets), to stimulate early investment in perceptively riskier sequestration-based assets, and catalyze regenerative actions that aim to combat global warming. The graphics below help to illustrate how the indexing function should evolve over time:

Figure 4.1: Indexing Function in Year "0" (Initial Execution)

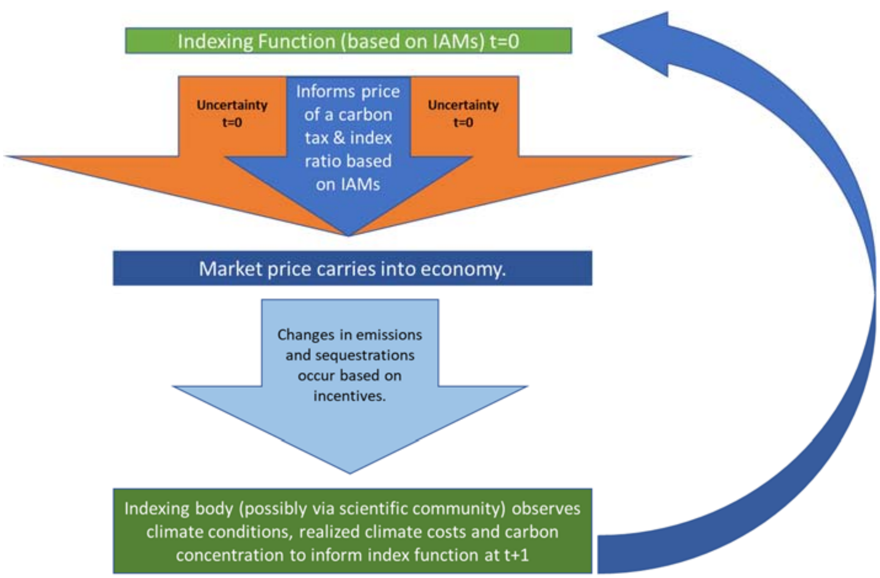
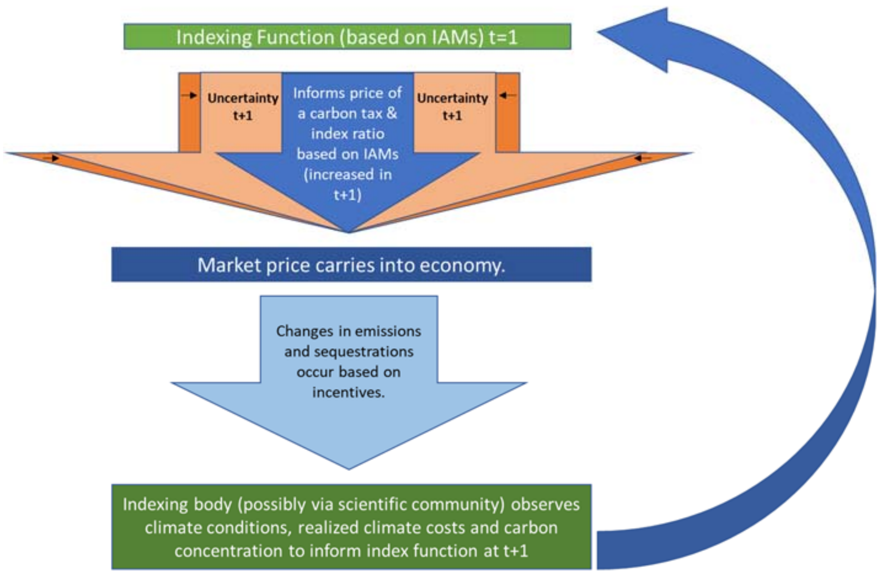


Figure 4.2: Indexing Function in Year 1



The indexing body will determine a schedule of index ratios and will inform a suggested carbon tax price based on current estimations of risk aversion, observed climate impacts, anthropogenic emissions, and size and uptake capacity of carbon sinks; in addition to estimated projections for time-lags and projected emissions scenarios based on technological developments (as well as the feasibility and probability of implementation) and long-term macroeconomic trends. Rather than attempt to model potential "representative concentration pathways," efforts should be redirected towards the development of a single, dynamic concentration probability pathway (DCPP). The DCPP would arise from an algorithm-based predictive model that aggregates large amounts of data and produces mean estimates and variances for future levels of warming across different points in time. The schedule of index ratios would be representative of the avoided emissions needed to marginally delay the realization of the tipping point as it relates to the time required for a sequestration to occur (for example a schedule of index ratios could be released annually for sequestrations that will take place over one to 50-year time horizons). The carbon tax could be suggested in line with the best estimate of the current social cost of carbon, or alternatively re-done in a manner that reflects the average "compensation" that citizens would require polluters to provide, perhaps based on a derivative of Kahneman's loss aversion ratio or another measure (Kahneman, 2011).

The main premise of the DCPP model will be that it is a dynamic, all-encompassing model that will be implemented with a high level of uncertainty at the beginning, but will become more precise as time progresses and more data becomes available and better understood. Furthermore, the DCPP needs not start from scratch, as years of data have already been collected by the scientific community at large, with integrated assessment models (IAMs) having become much more precise than in the past (Moss, et al., 2010). The IAMs themselves likely provide the best starting points for informing the socio-economic aspects of the DCPP, while existing climate models should be aggregated, compared, and combined into the DCPP.

None of this is to discount the difficulty in quantifying and modeling climate systems, specifically with regards to natural uptake cycles and ecological carbon stocks, although some (limited) efforts are being undertaken to better model this aspect of the carbon cycle for RCP models (Moss, et al., 2010; Canadell, et al., 2007). However, the power of "big data" cannot be underestimated either, and allows for a level of modeling precision that was mostly never thought possible. Predictive algorithms and analytics are already being incorporated into various types of technology ranging from object recognition to self-driving cars (Ternovyi, n.d.). The results being produced in these areas provide a level of precision that few would have thought imaginable a couple of decades ago. For example, impressive results have been shown with self-driving cars in terms of collision avoidance in fast-changing multi-million variable environments; often exhibiting better performance than human drivers (Ternovyi, n.d.; Walkowiak, 2016; Blanco, et al., 2016).

Another particularly encouraging example comes from the world of finance, with a comparison of two different hedge funds which had similar inception dates. Global financial markets are immensely complicated, and notoriously have "fat tails," meaning that statistically "impossible" events happen relatively frequently (Valencia, 2010); and to be able to consistently beat markets is a feat that few accomplish. Long-Term Capital Management L.P. (LTCM) was founded in 1994 and dazzled the financial community with its unbelievable success in consistently yielding high returns for investors during its early years. Largely based on the Nobel Prize winning modeling of Myron S. Scholes and Robert C. Merton, the firm ran a global arbitrage operation based on average expected gains from a relatively static model. However, due to just two deals that were perfectly positioned at precisely the wrong time turning sour, the fund nearly tore a $1trilliondollar hole in the global economy and the large commercial banks of Wall Street had to collectively bail out LTCM (the first time a collaboration like this occurred), which was fully disbanded by 1998 (Lowenstein, 2002).

While LTCM almost created a global recession from two bad deals, Renaissance Technology's illusive Medallion Fund has stood the test of time. Renaissance Technology was founded by several IBM programmers in 1988 who applied the data analytics techniques being used in IBM in the 1970's and 1980's to financial markets, with unprecedented success. From 1988 to 2016, the fund only showed one year of net losses on investments after fees, which was 1989; only two other years have yielded returns of less than 25% after fees (returns before fees average nearly 80%). Little is known about the innerworkings of the fund and the variables that are used for modeling, however, the computer code backing their models has been built to include several million lines of code over nearly 30 years. While the firm shares very little about what information it uses in its modeling, a couple of things that have been made public speak to the incredible precision upon which the modeling is built. For instance, a small correlation has been found between sunny days and positive returns in local markets; the correlation is so small that no investor could hope to make any significant gain off of this knowledge, however, in Renaissance's case, it's just one variable of a multi-million variable algorithm that can collectively show immense levels of predictive accuracy. Secondly, the fund caps its size at around $9-10bn as their analytics have revealed that running a fund of a larger size will adversely affect its returns (Burton, 2016). The notion of a fund knowingly capping its size may baffle many financiers.

Further examples of the precision of predictive analytics beyond the world of finance can be found all over, ranging from the ever-increasing accuracy of Google's search suggestions to the precision in electorate targeting of Cambridge Analytica (Bright, 2017). While global atmospheric climate conditions are perhaps orders of magnitude more complicated than self-driving cars, electorates, or financial markets; a slower observed reaction time and an existing foundation allow for corrections to be constantly incorporated before any modeling errors may have too adverse of an effect. Given that much about climate change is already known, as are the types of actions that need to be taken, the carbon equity framework can be used to quickly spur activity in the right direction that gets corrected on nearly a constant basis as time proceeds. Uncertainty can never be removed entirely, however, the precedent for pricing uncertainty has long ago manifested in financial markets, and therefore should not be a limiting factor in attempting to curb the likelihood of reaching a level of atmospheric carbon concentration that would pass a tipping point.

4.2.2 Carbon Dividends in Practice

As mentioned in Chapter 2, taxes would be collected on primary-source emissions and divided amongst registered taxpayers in accordance with their share of the publicly-owned carbon stock, as well as for whatever conservation areas (or other sinks) that they individually own. The indexing body would be able to assign dividend values based on land and ecosystem types in two ways: one being through "validated" shares, and the other being through "verified" shares (similar to current REDD+ methodologies for quantifying credits to be financially feasible). New technologies are making this possible in a way in which many may not have foreseen before. Validated equity shares could be assigned based on low-end estimates of local carbon stocks, calculated through approximations based on the best available data by land type, climate, and ecosystem composition using Landsat imagery, which has even shown some indications of being more accurate than other traditional estimation methods (Savage, Lawrence, & Squires, 2015).

It would be hoped that revenues from indexing fees of financial securities similar to the ECCO could be used to pay for validation and indexing, allowing for the entire carbon tax to be translated to a carbon dividend (perhaps if not, an indexing surcharge could be added to the tax price); another option would be to collaborate with a firm such as Google to seek in-kind or subsidized support as part of its corporate social responsibility (CRS) initiatives (one can only imagine the marketing value in being the "company that saved us from climate change"). Carbon stocks could be estimated through a verification process, whereby a landowner or conservation area manager may hire a certified third-party to more precisely estimate the carbon stock of an area (carbon stock enrichment after verification would be subject to validation estimates unless further verification be undertaken).

An interesting discussion has arisen in the scientific literature with regards to the issue of "permanence" in terms of carbon sequestration, whereby Miko Kirschbaum has argued that temporary sequestration has no value (Kirschbaum, 2006). His statements have been criticized in subsequent literature, for reasons very similar to those outlined in Appendix A; namely, that carbon carries a time-value and that a temporary sequestration can serve to help push out the realization of a tipping point, thus allowing more time for other means of uptake to occur (Dornburg & Marland, 2008; Fearnside, 2008). This issue is partially captured in both the concept of carbon equity, and in the implementation framework for the ECCO.

First, the carbon equity scheme will inherently encourage longer-term sequestrations over shorter term ones, given that short-term schemes will not be able to pay dividends for as long as more permanent sequestrations. Secondly, the indexing function should inherently re-capture and re-value any emissions released from a prior sequestration. However, there remains a small area which would need to be clarified and agreed upon by validators/verifies, regulators, and the indexing body. Primarily, it will need to be ensured that through the validation and verification processes, releases from temporary sequestrations are accounted for when calculating the dividend share of a sink; one example would be the litter fall from a forest (Alongi D. M., 2011). Secondly, sequestration securities should only be made available for projects that inherently sequester carbon for an indefinite, but long-term expected time-period. Credits sold on something like an agricultural plot that would be entirely harvested within a year would not be eligible, whereas projects subject to things such as natural disaster or "unintended[23]" destruction would be. Things such as afforestation could be considered, although perhaps entail an extra externality discount for unknown ecosystem (or other) disturbances. Furthermore, certain clear lines should be drawn in terms of projects that may not be eligible under any condition; this might include something like a project that wants to introduce a non-endemic species that is known to be invasive and cause local ecosystem destruction. All project implementers and landowners should be responsible for encouraging sink conservation after the sequestration has occurred, to a reasonable and feasible extent.

While it was initially thought that an insurance market might be needed to ensure the permanence of sequestration value (e.g. in the event of a mangrove forest being destroyed by a hurricane), the notion of carbon equity and a dynamic indexing function allows for these sorts of uncertainties to be (re)captured and quantified on an ongoing basis. However, the potential for an insurance market still exists in that carbon equity holders may be looking for ways to ensure that they are covered in the event of losses from natural disasters. Furthermore, if there is a persistent threat that is out of the land owner's feasible control, it may be possible for a project to "graduate" to an avoided emissions project after having been a successful sequestration project. For example, if a remote area was restored and lacks the funding for ongoing maintenance, while a threat exists from individuals entering and degrading the land, then the organization may apply for a validation (which should incorporate a methodology to account for and prevent the possibility of fabricated threats) and subsequently have avoided emissions credits issued as part of another listed security. Indexed pricing needs to be such that the price of avoided emissions credits is only sufficient to incrementally alter the opportunity cost of destroying a carbon sink in relation to its long-term carbon equity yield, while not being so high as to incentivize the threatening of a sink; basically, the equity yield should be significantly higher.

Some attempt to argue that the carbon equity scheme devised in this document will unduly pay dividends in disproportion to large landowners at the expense of the common taxpayer, however, in examining the proportion of conservation land under various management sources, it seems likely that this premise would be likely unfounded. Assuming that carbon stocks are held in equal proportion amongst all managed areas it could reasonably be assumed that U.S. based dividends would be split with about 60% of revenues going to taxpayers, about 20% to

[23] "Unintended" is referred to from the perspective of the project implementer. For instance, an operator of a forest project would not intend for tree poachers to enter the forest and harvest wood, therefore it would be seen as acceptable that this sort of destruction be inherently re-accounted for in the indexing function, if the implementer's negligence or collusion played no role.

NGOs, and only about 7% going directly to individual landowners. The remaining proportion would likely be split amongst governments (to be further paid to respective taxpayers) and project operators (e.g. joint governance schemes) or has not yet been reported in the dataset that was available (ProtectedPlanet, 2017)[24]. Additionally, wetland areas that are rich in carbon, such as Everglades National Park would appear to be more likely under public, rather than private ownership. Furthermore, considering that untapped fossil fuel reserves would qualify as carbon sinks under the dividends program, and that substantial amounts of fossil fuels are found on offshore drilling sites (i.e. under federal jurisdiction), public lands in Western states and in uninhabited parts of the arctic, it becomes even more likely that the proportion of dividends paid to the public would even be higher and would be unlikely to be affected significantly by any major individual private actor (U.S. EIA, 2015). Native American reservations also contain a significant amount of fossil fuel reserves, and therefore would be eligible for a large share of dividends, something that could essentially help to compensate for historical displacement (U.S. EIA, 2015).

Furthermore, by allowing dividends to be split at all levels of sink ownership, a new era of community-based conservation, environmental restoration, and even local political participation could be ushered in with individuals being more incentivized to vote for things such as municipal restoration projects. Bayraktarov *et. al.,* 2016 mention that many of the project estimation costs are likely underestimated, due to the use of volunteers for labor (Bayraktarov, et al., 2016). However, under a carbon equity scheme, local residents may be further incentivized to volunteer for municipal restoration projects if they could increase their local carbon stocks and thus their dividend shares.

A final notion to quickly postulate, but which could be a major effect of a carbon equity scheme would be as it relates to rural poverty, at least in the United States. With rural areas most likely having higher sink concentrations, it's quite possible that rural land values would increase, and the gap between urban and rural land values would tighten. Not only would rural landowners be able to receive dividend payments for sink conservation, helping to solve the "land rich, cash poor" dilemma; but individuals who wish to urbanize may have be able to sell rural land more easily and be able to afford moving to urban areas (Christensen, 1997). This could help combat rural poverty in another way, by offering greater ease for individuals in struggling economic areas, such as those of Appalachia, wishing to move to find work in urban areas, but have struggled to be able to sell homes and find financially feasible ways to move

[24] From this dataset, it could not be determined what proportion of areas that would qualify as conservation areas were related to Native American Reservations.

(Vance, 2016). Development of these areas would not be encouraged under the framework, so an interesting equilibrium may be realized, whereby rural landowners wishing to move may do so, while others who are economically strained, but without desire to move may stay.[25]

4.2.3 Policy Framework

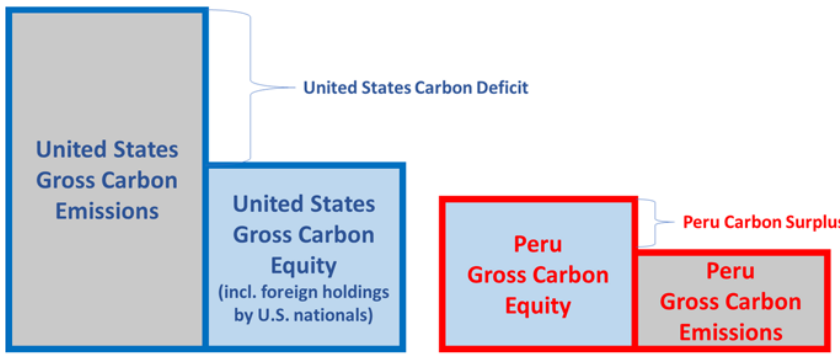
A tradeoff exists as it seems that the most cost-effective projects for ECCO implementation are those which are located in developing countries, while the carbon dividends scheme appears to be more feasible to implement on a national level, especially given the Trump administration's resistance to adherence to global standards (The Economist, 2017). Therefore, the ideal framework will likely be a blended approach between national and international governance, whereby trade agreements can be used as bilateral establishment mechanisms between countries that would allow for the benefits of cheaper implementation costs, while ensuring that dividend returns are appropriately allocated to local populaces and not subject to graft. Additionally, such agreements should entail provisions to ensure that the same standards for indexing and verifying projects would be conducted within the borders of all participating nations.

Under renegotiated agreements, signatories could agree to implement domestic dividends schemes that calculate payments and obligations using the standardized indexing function. While tax rates may vary from country to country, indexed credits would carry the same market price as they would in the United States (i.e. a global rate). Due to differences in purchasing power parity (PPP), it's quite likely that U.S. inflows into places like Colombia for sequestration credits would be high, while Colombian firms may find it much less feasible to pay for restoration activities, and therefore pay the Colombian taxes. However, this may mean that dividend payments to the Colombian population and holders of Colombian carbon equity would be higher than they would be otherwise. With that said, considerations must be made for the variation in per-capita carbon stock from country to country; countries that have extremely high carbon stocks per person and low emissions (i.e. many developing countries) should be compensated for these cross-border deficits. Essentially, what this means is that on a per-capita, purchasing-power-parity (PPP) basis, the return on equity (ROE) from carbon dividends should be the same regardless of which country an individual resides in, as the benefits provided from decreased atmospheric carbon concentrations are spread globally. The standardization for indexing, and reconciliation between nations in terms of ROE could also potentially help to

[25] None of this is to discount a potential widespread negative effect where all land areas greatly increase greatly in value, with more demand increasing urban prices, however, this discussion would be reserved for in a context that is more economic-centric, and therefore beyond the scope of this document.

address some environmentally-based concerns that have fueled criticisms of trade agreements, such as the recent attempts for implementing the Trans-Pacific Partnership – TPP (Brune, 2015). The figure below shows the example of Peru and the United States (please note that it is not drawn to scale and presented for illustrative purposes only).

Figure 4.3: Cross-Border Carbon Imbalance



The Climate Leadership Council (CLC) proposal already includes a provision for border-adjusted carbon taxes for countries that do not have robust emissions reductions schemes in place (Baker, et al., 2017); however, this concept could be slightly expanded in that countries with carbon surpluses against the United States, whom are signatories to trade agreements, would be entitled to import tariff discounts proportional to the difference in the country's surplus versus the deficit of the United States (it's also possible that the U.S. would run a surplus and in turn be eligible for tariff discounts in other countries). It should be noted that under this scheme, tax adjustments can only come in the form of discounts for participating nations, and not manifest as surplus charges (however, countries who are not signatories to trade agreements would be subject to these levies). The ultimate goal is for residents of participating nations to have an equivalent PPP-adjusted ROE.

In terms of the indexing process, several organizations exist both nationally, and internationally which could likely provide the foundation from which the indexing body can be built. Perhaps the most well-suited organization for the task would be the Integrated Assessment Model Consortium (IAMC), which has taken the lead in terms of IAM modeling since the IPCC decided to not engage in further RCP modeling and instead rely on the broader scientific community (Moss, et al., 2010; IAASA, 2012). With a global network of organizations experienced in IAM and climate modeling (CM), and a stated mission to facilitate further development of models, coordinate interactions between members, and act as a relay point for modeling experts, the IAMC is well placed to serve as the central point for housing the dynamic concentration probability pathway (DCPP) model (IAASA, 2012). Although it's not explicitly stated on its website, the IAMC website is housed within the University of Maryland's website (IAASA, 2012). Therefore, by being comprised of international organizations, the IAMC could serve the role (or a significant portion thereof) of the indexing body under a global framework; while on the other hand, by being housed within a U.S.-based public university it may be easier to accommodate and regulate within a national US-based framework (UMD, n.d.).

While the IAMC may be best placed to consolidate the inputs for the DCPP, a system will need to be developed to consolidate indexing information, reconcile outstanding carbon obligations, and maintain geospatial sink data and respective ownership. While each of these functions could be served by an individual system; one central system that also serves as a trading platform may be the most efficient way to implement the carbon equity framework. Perhaps the best place to house the platform would be through a site similar to the Treasury Direct website where individuals can buy U.S. treasury bonds (U.S. Treasury, n.d.). The IRS could either operate the site or a sub-component of it where it can track outstanding tax obligations for various entities based on payments, credit purchases, and amortizations from ECCO-like securities; international frameworks would likely require that this platform be operated by a non-governmental party. The indexing authority could either provide indexing information directly onto the site (if operated by a third party), or to the IRS, along with suggested carbon tax rates for the coming tax year. Depending on the issuer of the security, the entity could either list on the platform directly, or privately list the security on a part of the platform where banks can view offerings and choose which securities to underwrite. Development for the platform and the indexing model will require a significant amount of technical input, which could either be contracted out directly, or solicited through in-kind support that is tax-deductible from big data firms, such as Amazon or Google.

All trades on the platform should be monitored by the SEC and other local regulators, depending on the countries of implementation; and regulatory reconciliations between different nations could be overseen by an organization such as the WTO. Verifiers should adhere to the same verification standards, and environmental authorities should have the ability to audit projects at any time. The indexing process itself should be entirely transparent and open to public comment and an oversight panel should ensure that best practices are being adhered to. Risk aversion preferences for the indexing function could be provided by the U.S. Congress or U.S. governors in a national framework, or done through U.N. delegations under an international framework.

4.3: Mangroves as an Ecological Carbon Sink

Although exact figures are unknown for total coastal mangrove loss to anthropogenic activities, estimates range as high as 50% in the latter half of the 20th century (Alongi D. , 2009; McLeod, et al., 2011). While it's likely not feasible to assume that all of this land can be restored, estimates can be extrapolated for the potential sequestration via different levels of restoration, based on the readily available information. It should be stressed that there remains a high level of uncertainty as productivity varies significantly by site, and net carbon sequestration has even been estimated to be practically zero for certain areas (Alongi D. M., 2011). Therefore, estimates below should be taken to be only representative, despite conservative assumptions having been applied. WRI mentions a loss of 1.38% of global coverage from 2000 to 2012 of 192,000ha., indicating a total land area of about 13.9m ha. in 2000 (Strong & Minnemeyer, 2015); this falls within the range of studies presented by FAO from 1980 to 2000, albeit on the lower-end, while there is significant variability towards the higher-end (FAO). Assuming that 13.9m ha. were lost before the year 2000 (i.e. 50%), and 192,000 ha. were lost from 2000 to 2012 (based on WRI's numbers), and assuming that another 90,000 ha (in line with the annualized rate of 0.13% loss of total coverage presented by WRI) were lost from 2012 to 2017, a total loss of approximately 14.18m ha. can be estimated (Strong & Minnemeyer, 2015). Thus, assuming net ecosystem productivity (NEP) levels in line with the model used for calculating the Florida mangrove project[26], total carbon sequestration over a 20-year period from mangrove restoration could be estimated, based on the percentage of degraded areas restored:

Recovered (% of lost area)	Total Area Recovered (ha.)	Total Carbon Capture (tCO_{2E})
10%	1,418,200	119,002,814
20%	2,836,400	238,005,629
30%	4,254,600	357,008,443
40%	5,672,800	476,011,257
50%	7,091,000	595,014,072
60%	8,509,200	714,016,886
70%	9,927,400	833,019,700

While these numbers may look significant, they're surprisingly small in relation to annual emissions. Under the best-case scenario above (70% recovery of lost areas), over a 20-year period

[26] This assumption was seen to be a low-end assumption given that most mangrove loss has been occurring in Asia and that the indications of NEPs presented for the Asian mangroves were significantly higher overall than those found in the Western Hemisphere (Strong & Minnemeyer, 2015; Komiyama, Ong, & Poungparn, 2007).

this level of carbon sequestration (approximately 0.83 $GtCO_{2E}$) is roughly equal to the emissions (approximately 0.80 $GtCO_{2E}$) of the Democratic Republic of the Congo for the year 2012 (The World Bank Group, 2017).

Furthermore, by extrapolating an estimated land area coverage of mangrove forests in 2017 of 13.6m ha., which is consistent with estimates provided by McLeod *et. al.,* 2011 of between ~13.8m ha. and ~15.2m ha.; and assuming an NEP of 5.61 t/ha./yr., the annual uptake from conserving mangrove forests could be estimated to be ~0.08 Gt./CO_{2E}/yr.; or ~1.526 $GtCO_{2E}$ over a 20-year period, which is roughly the level of emissions in 2012 for Japan (The World Bank Group, 2017). If an average uptake of about 2.1 t/ha./yr. (from the Chmura, et al., 2003 data) is used, annual uptake decreases by about 0.05 $GtCO_2$/yr, or 0.57 $GtCO_2$ over a 20-year period, which is roughly the level of emissions for the United Kingdom in 2012 (The World Bank Group, 2017). However, the figures provided by McLeod *et. al.*, 2011 indicate global annual carbon burial from mangroves to be between ~0.03 $GtC0_{2E}$/yr. and ~0.04 $GtC0_{2E}$/yr., slightly lower than the estimates derived from the NEP figures of the modeled estimates (McLeod, et al., 2011). While it's likely that NEP rates for earlier years of growth may be higher than for later years, it remains difficult to tell whether or not the NEP application to mangrove restoration in accordance with the Florida model provides for a fair representation of sequestration potential for a 20-year period. Therefore, without a much more in-depth analysis, the best expression of potential sequestration growth from overall ecosystem restoration may be presented in terms of absorption capacity through enrichment after maturity is reached.

Figures presented by McLeod *et. al.,* 2011, supplemented with figures for temperate and tropical forest loss estimates from other sources (McLeod, et al., 2011; Roser, n.d.), can be used to obtain an idea of annual sequestration potential through restored ecosystems. Loss figures for boreal forests were excluded as data were not relatively available with regards to total loss, however, one report did note that such loss has been negligible since 1990 (FAO, 2016); nonetheless, there exists a current threat and opportunity with regards to these types of forests which will be discussed below. The estimates are presented in Appendix E, and show a total potential increase of ~0.025 $GtCO_{2E}$ to ~0.056 $GtCO_{2E}$, assuming that 25% of destroyed lands are restored.

When comparing the figures above to the emissions budgets for various levels of warming presented by the IPCC for 2011 onwards, as well as annual emissions data, this number looks quite small (IPCC, 2014; The World Bank Group, 2017). However, the potential increases in the global carbon budget from restoration amount to about 1.32% to 2.96% increases from land sources, and or 0.52% to 1.17% for total annual uptake from all sources (Sarmiento & Gruber, 2002; van Vuuren, et al., 2011). While these numbers appear depressingly small, a silver lining may exist in that they are somewhat disproportional to the proposed areas for restoration that underlie the calculations (7.93% and 8.24% of total existing coverage). This speaks to the value of carbon stocks, and indicate that in instances with fast growing species, carbon sequestration could be heavily front-loaded. Furthermore, this enhances the validity of the concept of carbon equity, and echoes the general economic dynamic of capital preservation and enhancement (i.e. conservation), versus savings depletion and debt (i.e. emissions).

4.4: The Merit of Ecosystem Sequestration

Contrary to the notion of sequestration through restoration, the RCP 2.6 scenario for mitigation actually accounts for an increased change in land-use, and thus emissions from land-use change (LUC) because of an expansion of bioenergy (van Vuuren, et al., 2011). While the RCP 2.6 model does account for some reforestation, the heavy focus on reducing emissions, rather than exploring sequestration and conservation is highlighted by this example. Net carbon emissions may be reduced by such a level of conversion, but externalities such as the loss of biodiversity, soil protection, and chemical leaching into the environment through pesticide and herbicide application are not accounted for (FAO, 2008). Additionally, N_2O emissions from soil conversion rise under the RCP 2.6 model (although total N_2O emissions fall in aggregate), but the authors note a level of uncertainty in the magnitude of the impact (van Vuuren, et al., 2011). Furthermore, questions of other externalities arise when looking at RCP 2.6, as carbon capture and storage (CCS) is modeled to be more economic than solar and wind, thus carrying the risks associated with coal extraction and non-GHG emissions, such as particulate matter; additionally, the authors note that bio-energy production leads to increased NH_3 (ammonia) emissions (van Vuuren, et al., 2011). This is not to state that environmental restoration and conservation carries no externality risk, nor that the tradeoffs may not be too costly; however, the amount of uncertainty in switching from a naturally occurring ecosystem to an anthropogenically controlled area is much greater than in cases of conservation, and likely to also be much greater than well-planned restoration projects.

While mangrove restoration may not have the capacity for sequestration that was initially hoped for in relation to the global carbon budget; nonetheless, it can offer a cost-effective way for entities to offset emissions in relation to paying a carbon tax, thus smoothening expenses over time and absorbing some of the financial shock that having to immediately pay a tax might entail. Other studies may in turn yield promising results with regard to terrestrial restoration, or sequestration through other means. Machines that directly capture carbon from the atmosphere are already in nascent stages of deployment, and as time proceeds, these devices may prove to be more cost-effective (Peters A. , 2017). Climeworks - the company behind one such technology, runs off of a business model whereby it sells captured CO_2 to other companies such as beverage manufacturers (Climeworks, 2017a). It would likely not be desirable for all captured CO_2 to be added to products where it will be released in a short period of time; and removing a significant level of carbon from the atmosphere in relation to atmospheric stock based on this business model would not likely be feasible. However, capture and storage through these means may be an efficient option for CO_2 removal. The company claims that sequestration through its technology costs less than $100 per tonne of CO_2, which appears to be higher than the tax price proposed in this document (Climeworks, 2017b). Nonetheless, the price of such technologies is likely to decrease, while the cost of carbon is likely to increase, and therefore, financing capture through a financial instrument with this type of technology as the basis, and paying dividends on the carbon equity in the stored carbon could be a very interesting option to explore.[27] The company outlines storage as the one adverse side effect of this type of capture, however, under the carbon equity framework the company could be compensated for this storage as it would constitute a sink (Climeworks, 2017a).

4.5: Areas for Refinement & Enhancement

Regarding indexing, uncertainty will be high in the nascent stages of execution; however, as time progresses, data are gathered, and observations of climate change indicators such as radiative forcing (RF) are made, algorithms can be further refined and used as better predictors for relative contributions and values of the plethora of variables that are at play. The importance of indexing becomes paramount as it allows for a standardized, consolidated approach to analyzing the best available science to inform policy decisions. Given the vast complexity of the issues presented in this document, the proposed model contains many areas of uncertainty which will need to be refined through further research and deliberation, as well as data gathering and analytics. For instance, while an extensive literature review was undertaken to model the expected sequestration rates from the mangrove restoration projects; due to the multitude of factors that can affect growth rates -such as salinity, weather patterns, solar radiation, ecological competition, and soil conditions - various assumptions had to be taken for the purposes of modeling for this document (Hutchings & Saenger, 1987; Morris, 2006).

[27] Questions related to the energy source running the technology itself were taken to be beyond the scope of this document, although merit consideration.

Modeling sequestration rates proved to be a more difficult task than was initially anticipated. An extensive literature review did not yield results for modeling the growth and soil root penetration rates for young mangroves (specifically red mangroves, *Rhizophora mangle* and *Rhizophora mangle L.,* which initially appeared to be the dominant mangrove species in the various cases examined), which appears to be at least partially attributable to the difficulty of capturing the multitude of factors that would contribute to growth, and also largely due to a general lack of data and analysis (Chmura, Anisfeld, Cahoon, & Lynch, 2003; Encourage Capital, 2016; Rivera-Monroy, et al., 2006; Mitsch & Gosselink, 1993; Hutchings & Saenger, 1987; Alongi D. , 2009; Hill, 2001). From what was found, it was discernible that mangrove roots can float above water for as long as six months before penetrating soil, therefore the conservative rate of six months was chosen as the date from which sequestration would begin after project initiation (Hutchings & Saenger, 1987). However, acquiring any further extrapolations based on these premises proved to be fruitless. The sequestration rates which could be located were compared amongst sources, although complete datasets were quite difficult to locate, and the credence of many studies came into question for various reasons. Even the most comprehensive datasets that were reviewed were quite incomplete, and had almost no information regarding things such as expected growth rates corresponding to carbon uptake and/or NEP. Of the data located, the work of Komiyama, Ong, and Poungparn, 2008[28], and that of Chmura *et. al.*, 2003 appeared to be the most robust, and were relied upon most heavily for assumptions.

A major setback occurred upon the realization of significant flaws with the Bayraktarov *et. al.*, 2016 study, which had been one of the only studies that was found with what appeared to be extensive data on restoration costs. For instance, the dataset contains a restoration project in Broward County Florida which is noted to have restored an area of 500 ha.; however, upon visiting the primary source it was realized that only 80 ha. was restored, with another 420 ha. only having been "enhanced" (Bayraktarov, et al., 2016; Society for Ecological Restoration, 2007). Significant errors were also found to have existed in the basis for the inflation calculation, as well as the calculation for the per hectare, CPI-adjusted restoration cost for the Colombia project which was used to build the $ECCO_I$ model (Bayraktarov, et al., 2016; Rivera-Monroy, et al., 2006). Having realized these errors somewhat later in the study necessitated further assumptions to be taken than one would have preferred, although an alternative dataset has still not been located. This further emphasizes the need for more robust, comprehensive, and well-communicated research.

[28] Further examination after document completion has since brought this premise into question with regards to the species identification methodology.

Perhaps most surprising from the literature review was how difficult it was to find estimated baseline figures for naturally occurring global carbon absorption in the more prominent policy documents such, as those of the IPCC, and derivatively, from the four prominent RCP models (van Vuuren, et al., 2011; Masui, et al., 2011; Riahi, et al., 2011; Thomson, et al., 2011; IPCC, 2014). While this may somewhat be due to the high level of difficulty in modeling such estimates (Moss, et al., 2010), the centrality of this variable in the equation coupled with a lack of communication about this variable creates an immense logical gap in the common literature that is shared with policymakers and other influential stakeholders. While there appears to be some mention of this importance in certain, more specialized publications (e.g. Canadell & Raupach, 2007, McLeod *et. al.,* 2011), by and large it seems as if this aspect is largely "swept under the rug" in public discussions.

An extensive literature review revealed a large knowledge gap, as annual uptake is not easily discernible and estimates seem to widely vary. An examination of the prominent representative concentration path (RCP) model for 2.6 w/m^2 of radiative forcing, seems to portray a total annual uptake of ~4.6-4.8 $GtCO_{2E}$/yr. in the early years of the model (circa 2010), which decreases as the year 2100 is approached, due to a lower atmospheric carbon concentration (van Vuuren, et al., 2011). It is unclear the degree to which coastal ecosystems were accounted for in this analysis, and previous studies have suggested that rates for coastal burial in unvegetated sediments have been greatly underestimated, perhaps by a factor of two (Duarte, Middelburg, & Caracao, 2005).

The work of Sarmiento and Gruber, 2002 suggests 3.8 $GtCO_{2E}$/yr of global uptake. (Sarmiento & Gruber, 2002). However, these estimates are not supported by the atmospheric carbon flux (R_{AF}) ratio of approximately 2.0 (based on two models with means of 1.9 and 2.1, respectively, and each with standard deviations of 0.2) presented by Walsh *et. al.,* 2016 (of which van Vuuren was a contributor); which indicate that about half of global emissions were absorbed via sinks for the period 2002-2011 (Walsh, et al., 2017). Following the World Bank dataset, which indicates total anthropogenic emissions from 2002-2011 to be about 490 $GtCO_{2E}$, or ~49 $GtCO_{2E}$/yr. on average, would mean that annual uptake could be estimated at ~24.5 $GtCO_{2E}$/yr. based on the R_{AF} mentioned above. This is nearly five times the uptake which has been modeled into RCP 2.6 (van Vuuren, et al., 2011; The World Bank Group, 2017). The R_{AF} model is differentiated in that it accounts for net anthropogenic emissions (total emissions, Ω, minus "artificial" emissions, S_A), divided by natural uptake, S_n (Walsh, et al., 2017):

$$R_{AF} = \frac{\Omega - S_A}{Sn}$$

Solving for this equation using the numbers ($\Omega = 49$, $S_n = 3.8$, $R_{AF} = 2.0$) above yields an S_A value of 41.4. While these numbers are quite rough, the magnitude cannot be ignored in that "artificial sink" uptake could already be in the neighborhood of ~40 Gt/CO_{2E} per year. While it's unclear from the study as to what exactly constitutes an "artificial sink," a 10% increase in this capacity would be roughly equivalent to the level of natural uptake mentioned above. This would indicate that perhaps mitigation through sequestration is achievable by some existing, yet unspecified means.

4.6: The ECCO in the Void

4.6.1. Echoes of the ECCO

While the ECCO completely separates sequestration and avoided emissions credits as a means for communicating the "time-value" of carbon, other securities need not be as complex. For example, a simpler version of the ECCO could be created whereby the security is only tied to a single underlying sequestration project, but the amortization would require sequestering a higher level of carbon than was initially emitted. On the other hand, a more complex security could also be created whereby multiple underlying projects are supported, and thus investment risk could be spread out accordingly.

Further fears of certain large economic players dominating the market (in addition to the ones mentioned before) could also be abated with the introduction of other types of securities that do not necessarily require a project with a large budget and technical effort as the underlying catalyst for investment. One theoretical security could be a "Collateralized Community Capture" (CCC), where individuals engage in things such as tree planting and verify through GPS-linked mobile phone photos at regular intervals to verify growth. The collection of several thousand individuals could in turn be consolidated in an issuer's central system that uses image recognition software to estimate growth rates, and thus carbon capture, and subsequently sold in a similar manner to the ECCO on the open market (Walkowiak, 2016). Whatever funds would be raised from the listing of the CCC, minus the issuer's and underwriter's costs, could be channeled to individuals directly; plus, the added ecological stock would entitle them to individual dividend payments via direct sink ownership. Such a scheme could be particularly appealing in places such as East Africa where payments could be made directly via "mobile money," thus not necessitating access beyond a mobile phone to participate in the entire process.

While many environmentalists might scoff at such a proposition, the notion of an "avoided extraction" credit holds much of the same merit as a REDD+ credit, and given the density of fossil fuels, avoided extraction credits could be quite appealing. Because untapped fossil fuels are (a major) part of the non-atmospheric sink, these should be eligible for carbon equity dividends and in turn discourage sink destruction (i.e. extraction). This notion of fossil fuel sink preservation is particularly salient in relation to the current situation regarding boreal forest destruction and tar sands extraction in Canada (Petersen, Sizer, & Lee, 2014). By requiring extractors to pay a tax under a dividend scheme (were Canada to adopt one), and having stocks pay dividends on highly-valued public lands that contain these stocks, an extra layer of discouragement could be leveraged, further helping to reduce emissions.

It is worth noting that non-ecosystem based securities will need to be carefully designed, and perhaps carry an externality insurance premium, which could be held in a larger pool to fix unintended damages. For instance, tree-planting initiatives may only be permitted for native species, with non-native species (that are not known to have adverse effects to the local ecology) requiring a small insurance fee to be added to the cost of the security. All projects should be subject to a broader environmental review to be taken into account during the validation and verification processes. Although a more extensive review might cost more than traditional validations and verifications, based on the models for the ECCO, the cost increase may be rather insignificant.

4.6.2: Monetizing the "Commons"

The concept of carbon equity introduces an interesting notion that lies at the heart of Hardin's paramount writing on the "Tragedy of the Commons" (Hardin, 1968). By providing for equity-based payments to registered taxpayers from underlying publicly owned lands, the incentive to destroy natural resources is reduced as it will directly affect an individual's dividend share. This concept could be carried over into other examples at all levels where an environmental risk may arise. On a much smaller scale than climate change, another example where a "tipping point" could be realized, and is relatively easy to define (i.e. full depletion beyond the ability to naturally recharge), would be that of the Ogallala Aquifer in the Western U.S., which risks depletion in the coming decades from overuse (Bjera, 2015; Plumer, 2013; Steward, et al., 2013). A multi-state scheme could be devised whereby states under which the aquifer lies could levy taxes on water for agricultural use[29] (drinking water could be seen as "essential" and within the allowed "natural" budget), and "water equity" be divided in proportion to the amount of water from the aquifer located in each state, and dividends split amongst state taxpayers.

[29] Legal implications as they relate to interstate commerce may affect the feasibility of this example, but was seen to be beyond the scope of this document (US Legal, Inc., 2016).

By introducing a broader “environmental equity” concept, framework mechanisms such as payment for ecosystem services (PES) schemes may become much more feasible. When considering the high values placed on certain ecosystems (such as $194,000/ha./yr. for mangrove forests), tax payers and voters may be much more incentivized to support environmental conservation than before (Duncan, et al., 2016). Various schemes could be derived based on a plethora of normalization factors ranging from watershed protection to erosion prevention, and perhaps even biodiversity preservation with better attribution models. Implementing these types of schemes could in turn allow for restoration activities of areas that are prohibitively expensive in the limited context of carbon, but are still of high value to society at large.

Chapter 5: Conclusion

One of the biggest findings from this study was the magnitude of needed research in various parts of both climate science, mangrove ecology, and the economics of ecological restoration (especially as it relates to mangrove forests); as well as more concerted, standardized and scientifically sound communications conveyed to the public. Namely, natural uptake cycles need to be better understood and considered than have been previously incorporated into various RCP models and communicated by and large. With regards to mangrove ecology, life-cycle and growth rates were two factors for which surprisingly little data was found. Even attempting to find an average time to maturation for *Rhizophora* species could not be discerned from the literature which was reviewed; something that one would have thought to be the most basic type of ecological descriptor.

Furthermore, while much of the work with regards to climate modeling has been done, without a standardized agreement upon which models to act, one can get lost in the plethora of literature and never be able to gain confidence in possible actions. This is further complicated by differences in nomenclatures and units (e.g. the use of Gt in some literature and Pg in others, which are equivalent in value), and obscurities in how things such as global carbon budgets are communicated. Navigating this landscape from the perspective of a relatively well-informed policy advisor could be seen as a daunting and fruitless effort, which is simply unimaginable for average citizens. Without standardizing nomenclature and being fully transparent about known uncertainties and their potential implications, current climate communications appear to only serve to confuse and overwhelm the general public, who in turn may be shying away from action.

Although the macro-level indications for sequestration potential from mangrove restoration were not nearly as high as would have been hoped for at the beginning of the study, the $ECCO_I$ was still able to demonstrate a cost-effective way to truly offset emissions. Truly "offsetting" involves undoing what has been done; offsetting by avoidance could be analogous to attempting to diet by eating a cheeseburger each night for dinner, and "offsetting" it with a salad the next day for lunch, something that is not likely to yield results. By reexamining what a true offset should entail, an overall clarity begins to emerge from the cloud of obscurity created by the current conglomeration, and one can begin to see a near-perfect reflection of traditional economic theory and global carbon dynamics.

While securities similar to the ECCO may not be a panacea for greatly increasing the carbon budget, they could be used as a way to smooth a potential market shock from the introduction of a carbon tax, and give firms greater flexibility in adapting to a low-carbon economy. Mangrove restoration, via instruments such as the ECCO, could be viewed as a "low hanging fruit" in terms of climate mitigation strategies. By finding and exploiting as many "easy wins" as possible, at the very least the room for error in overall mitigation as it relates to tipping points will be increased (an especially appealing notion to Pareto enthusiasts). Given the indications of the reductions needed to avoid these realizations in comparison to global actions that have been taken, these marginal efforts may be significant enough to make the difference in staying below 1.5^{o} or 2.0^{oC} average global warming levels.

While the potential to increase global carbon uptake via ecological restoration (at least for mangroves) may not be as robust as initially hypothesized and hoped for, some encouraging results have followed the study nonetheless. Most important is the introduction of the concept of "carbon equity," which appears to have the potential to be an immense catalyst for change. Carbon equity has the potential to finally overcome the psychological hurdle of "loss aversion" that has likely stymied much of the public's interest in addressing the issue in the past (Halstead, 2017). While the Climate Leadership Council (CLC) uses this concept as a founding premise for its explanation as to why climate change is such a difficult issue to tackle, the carbon dividends plan – as currently presented by the CLC - falls subject to this very problem itself (Halstead, 2017) . Introducing carbon equity adds an element of ownership to the equation, and the public will have been communicated a clear message of the monetary value of sink conservation.

REDD and REDD+ have always implicitly carried a "dirty secret," which is intrinsic to many discussions. Since avoiding deforestation on threatened lands can generate carbon credits, would there be any reason to prohibit avoided fossil fuel extraction from generating credits as well? Aside from the optics, the answer seems to be no, especially when considering REDD+, and comparing its principle to the inherent carbon stock of a fossil fuel reserve and the threat level that it faces. Does this mean that avoided emissions credits from fossil fuel reserves should be allowed under the current frameworks? The answer remains unequivocally "no," simply because of the sheer volume of known fossil fuel reserves in relation to the remaining carbon budget. The 2014 IPCC Synthesis Report noted that in 2011 there was between 3,670 and 7,100 $GtCO_{2E}$ in reserves (and possibly ten times as much in "resources"), while the remaining carbon budget to remain within 1.5^{o} C (66% probability) of global warming was 400 $GtCO_{2E}$, and 1,000 $GtCO_{2E}$ to remain within 2^{o} C (66% probability) global warming (IPCC, 2014).

Since ~5-14% of known reserves may likely be enough to trigger the threshold, offering avoided extraction credits on vast reserves would likely not do anything but allow for some of the bigger players in the geo-petroleum market to essentially collect a "ransom;" while others proceed with levels of extraction that would be sufficient to exceed the threshold. Therefore, the concept of "avoided emissions" must be entirely revamped, with carbon equity providing the segue to an effective mitigation strategy. In a way, carbon equity could be seen as a second REDD revolution that builds off of the initial issues addressed in REDD+, and goes one step further in considering how forest carbon is only one part of the entire equation.

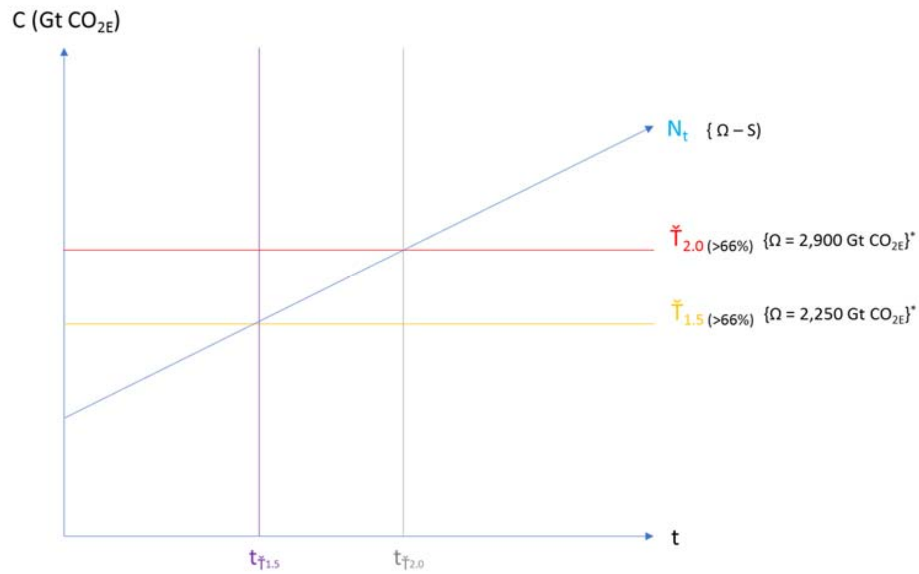
Because fossil fuels are such a dense source of carbon sink, taxpayers may begin to mobilize more to protect public lands from activities such as oil drilling (and other extractives as well), and put greater thought and analysis into the tradeoffs involved when deciding whether destroying a sink is worth the overall economic gain, or if a short-term payoff with long-term consequences is not worth the investment. This in turn translates to the emergence of truer economic equilibriums, where costs are fully reflected, and agents are better informed and motivated to preserve the equilibrium.

Overall, carbon equity appears to be quite powerful and capable of leveraging environmental action on a much larger scale than before, and perhaps ushering in a new era of conservation. Climate change mitigation via carbon equity provides an even further-reaching potential to catalyze a paradigm shift in economics at large. By better identifying the owners of "assets" that incur costs from transactions of which these owners have no part, and appropriating respective compensation accordingly, externalities can finally be properly priced in markets, and the "Invisible Hand" can work as intended, with an occasional slap on the wrist when it gets greedy and tries to take what it doesn't own.

Appendix A: Carbon as Money

A simple model of climatic tipping points can be graphically expressed as follows (please note that this figure, and subsequent figures in this chapter are only meant to serve as a guide for conceptualization, and are not meant to be representative of actual scenarios):

Figure 1.1: Simplified Expression of Climatic "Tipping - Points"



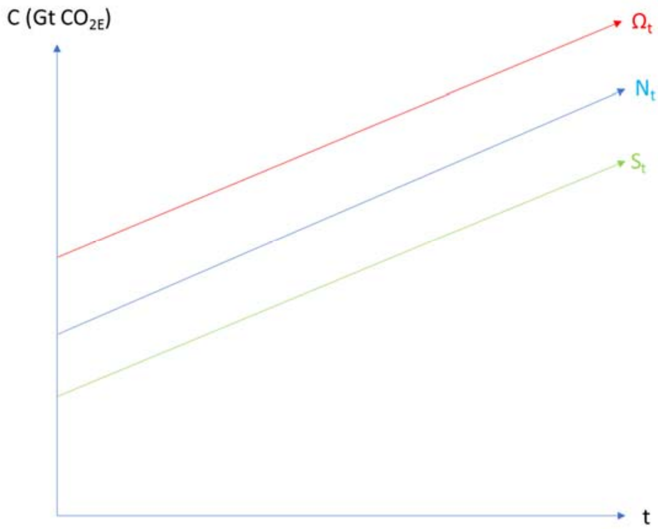
*Source: "Climate Change 2014 Synthesis Report," Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, pp. 63-64

The total atmospheric carbon stock (C) is expressed in gigatons of CO_2 equivalent ($GtCO_{2E}$) and is measured over time (t). N_t is equivalent to the net cumulative anthropogenic emissions at a given point in time, also measured in $GtCO_{2E}$, and is closely related to C. N is dependent on Ω (cumulative emissions to date) and S (cumulative sequestration to date), both of which are measured in $GtCO_{2E}$ as well. Ť is the level at which C reaches a threshold that will manifest as irreversible damage (the point of "no return"); in the model above it is represented by the levels outlined by the Intergovernmental Panel on Climate Change (IPCC) to carry a greater than 66% probability of averting average global warming of either 1.5° C ($Ť_{1.5\ (>66\%)}$), or 2.0° C ($Ť_{2.0\ (>66\%)}$) [(IPCC, 2014)].

An interesting point to observe, which may help to highlight the postulation that sequestration is not adequately communicated as a key variable, is that the graphical representations and numerical expressions related to the threshold values in the IPCC report are denoted by cumulative anthropogenic emissions, rather than the net emissions currently persistent in the atmosphere (of which Ť is much more dependent). The report makes passing mention of the role that sequestration plays, in that only 40% of the cumulative emissions to date (since 1860) remain persistent in the atmosphere at present (2014), therefore it is reasonable to assumed that the exclusion is not due to an insignificance of the variable (which would still warrant mentioning, even if so) [(IPCC, 2014)].

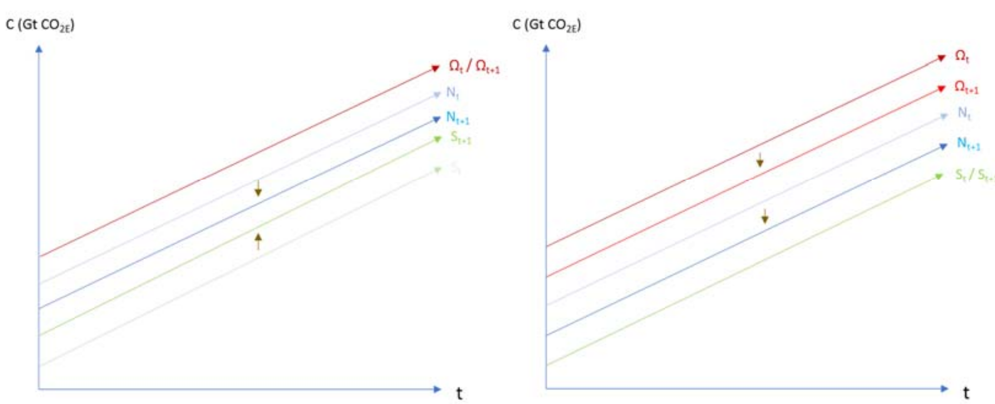
A representation for the derivation of N_t can be expressed as follows:

Figure 1.2: Simplified Expression of Cumulative Net Emissions



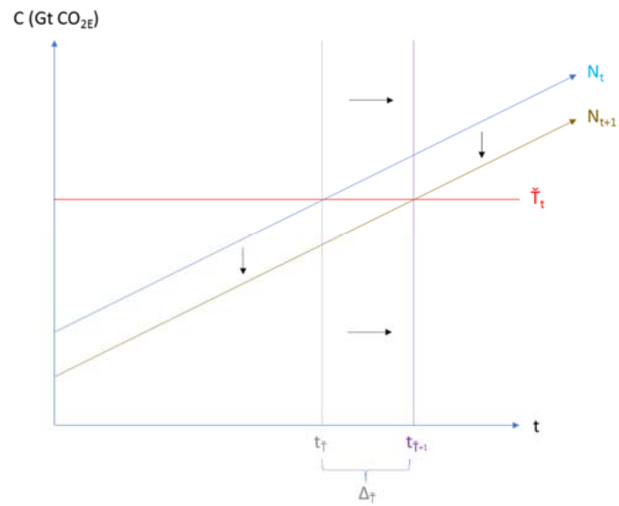
In reality, the curves likely follow logarithmic paths, whereby Ω and N show increases in the rate of change, whereas S shows a decrease (due to destruction and degradation of carbon sinks). However, this simple illustration can serve to understand the relationship that the variables play:

Figure 1.3: Simplified Expression of the Relationship Between Ω, N,and S



In turn, an understanding of the relationship shown in Figure 1.3 allows for an understanding of how N has an effect on the times at which Ť is realized:

Figure 1.4: Simplified Expression of Relationship Between N and Ť



The usefulness in using the simple models shown in Figures 1.1 to 1.4 is that they facilitate the conceptualization of $\Delta_{Ť}$, or the delay in the realization of an undesirable level of average global warming, which allows for the conceptualization of the "time-value of carbon." Just as there's a time-value of money, which manifests in inflation and interest rates, there's also a time-value of carbon, meaning that an emission" today" is not the equivalent of a sequestration "tomorrow." This notion of a "time-value" of carbon has been somewhat articulated in other research, most notably that of WRI, although the work which was reviewed seemed to present this notion from a much more narrow perspective (Marshall & Kelly, 2010). All GHGs have a lifespan of persistence in the atmosphere and will (most likely) eventually be sequestered by the Earth's various systems, however, it almost needs not be mentioned that we simply consider all emissions as inherently sequestered, and thus already "offset" when released. However, this notion serves to articulate that combating climate change is both a matter of the magnitude by which net emissions are reduced, as well as the timeframe by which such a reduction is realized.

The magnitude can be easily expressed as follows:

Figure 1.5: Illustration of Global "Carbon Budget"

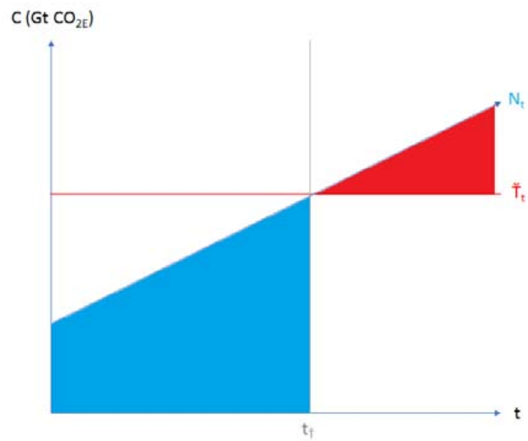
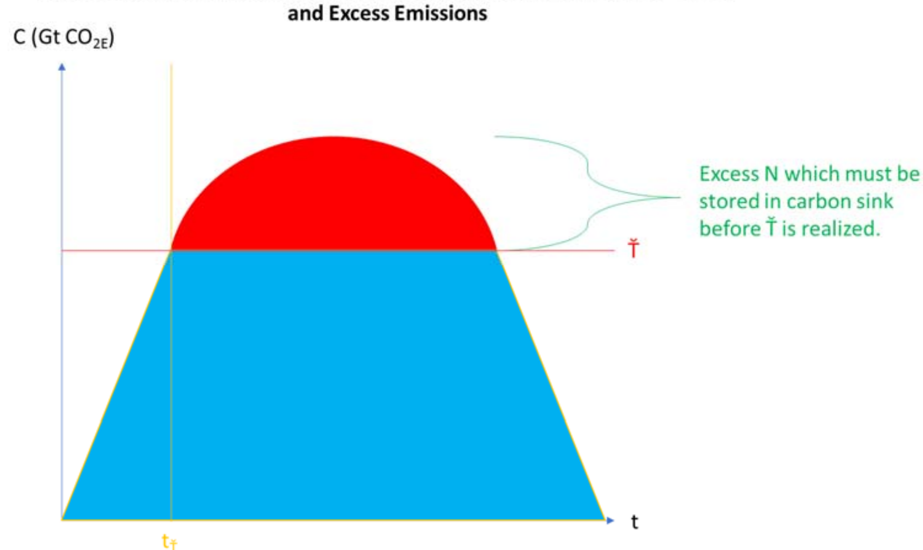


Figure 1.5 illustrates the levels of net emissions persistent in the atmosphere before which Ť is realized (the "safe" zone, illustrated in by the blue-shaded area), and after the realization of Ť (the "danger zone," illustrated by the red-shaded are). Following an assumption that sufficiently reducing emissions to avoid the realization of Ť is not going to be feasible, or simply that it is not desirable because of the sacrifices that would be needed, one can turn the question around, and answer it from the perspective of how much sequestration could feasibly be realized to keep the maximum of N below Ť in absolute terms, and in turn, what levels of reductions would be needed to shift out the time by which Ť is realized sufficiently to allow for that maximum to fall below Ť.

Expanding on Figure 1.5, a much longer timeframe for the persistence of GHGs in the atmosphere may be expressed as follows:

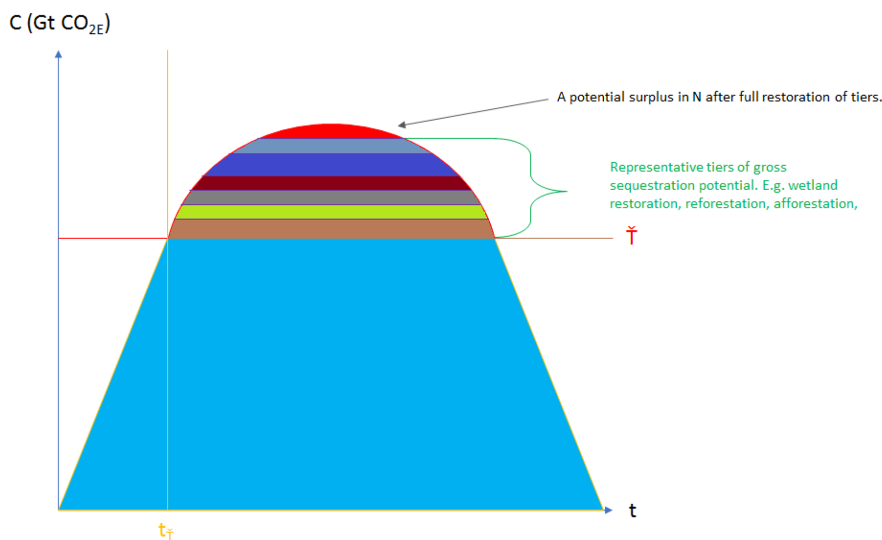
Figure 1.6: Simplified Representation of the Natural Persistence of GHGs, and Excess Emissions



This is generally representative of a "business as usual" scenario, and shows the excess carbon at any given time above the threshold level. It should be emphasized that the model is not prohibitive of either reductions in emissions or sequestration to reduce the excess; the purpose is to approach the traditional issue from a different angle given the difficulties that have prevented reductions in emissions. Having the central concept of the full "carbon budget" established, and knowing the "time-value" of carbon, a robust, multi-pronged approach can be implemented by which a tangible market can be established (please refer to Chapters 2, 3, and 4).

Figure 1.7 shows how different "tiers" of carbon sink may be aggregated to reduce the magnitude of the carbon surplus overall. While the tiers in the model are not representative of any individual, specific type of carbon sink that could be created, examples such as wetland restoration, forestation, afforestation, and technological sequestration can be postulated, among others. The lower tiers represent a greater potential in terms of cost-effectiveness; thicker tiers would be representative of greater absolute contributions to the reduction in the carbon surplus. Ideally, the thickest tiers will be proven to be the most feasible (i.e. cost-effective), however, how this ultimately looks will be unknown, and there remains a possibility that the red area at the top (what cannot be sequestered), will still remain large.

Figure 1.7: Theoretical Presentation of Tiered Conceptualization of Sink Restoration



Appendix B: $ECCO_I$

B.1: $ECCO_I$ Θ Model (Mangrove Restoration in Colombia)

Project Size (ha.)	35,000
Discount Rate	25%

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
NEP (tC ha.-1/yr-1)	0.000	5.885	6.656	7.146	7.578	7.960	8.301	8.606	8.879	9.125
Total Expected Θ Potential	-	205,966	232,948	250,113	265,226	278,615	290,537	301,198	310,765	319,375
Expected Surivival (%)		75%	75%	75%	75%	75%	75%	75%	75%	75%
Expected Θ	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531
Ï(Θ)t Adjustment	-	(30,895)	(62,896)	(91,542)	(117,442)	(140,489)	(160,781)	(178,524)	(193,970)	(207,382)
Required θ/year	-	30,894.95	62,896	91,542	117,442	140,489	160,781	178,524	193,970	207,382
Mangrove Restoration	$ 9,619,767	$ 9,764,063	$ 9,910,524	$ 10,059,182	$ 10,210,070	$ -	$ -	$ -	$ -	$ -
Conservation Maintenance (Gross)	$ -	$ -	$ -	$ -	$ -	$ 2,590,805	$ 2,629,667	$ 2,669,112	$ 2,709,149	$ 2,749,786
Validation/Verification	$ 20,000				$ 53,068					$ 57,169

	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
NEP (tC ha.-1/yr-1)	9.125	9.125	9.125	9.125	9.125	9.125	9.125	9.125	9.125	9.125
Total Expected Θ Potential	319,375	319,375	319,375	319,375	319,375	319,375	319,375	319,375	319,375	319,375
Expected Surivival (%)	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%
Expected Θ	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
Ï(Θ)t Adjustment	(213,812)	(218,956)	(223,071)	(226,363)	(228,997)	(231,103)	(232,789)	(234,137)	(235,216)	(236,079)
Required θ/year	213,812	218,956	223,071	226,363	228,997	231,103	232,789	234,137	235,216	236,079
Mangrove Restoration	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Conservation Maintenance (Gross)	$ 2,791,033	$ 2,832,898	$ 2,875,392	$ 2,918,523	$ 2,962,301	$ 3,006,735	$ 3,051,836	$ 3,097,614	$ 3,144,078	$ 3,191,239
Validation/Verification					$ 61,588					$ 66,348

Project Costs		
Mangrove Restoration	$	49,563,606
Conservation Maintenance	$	44,376,353
Validation/Verification	$	258,173
Indexing Fee ($5/ha)	$	175,000
Sequestration Project Cost	**$**	**94,373,132**
Total Expected Θ		4,236,370
Cost Per Θ	$	22.28
Required θ		3,464,444
Cost for θ from Peru REDD+	**$**	**12,801,708**
Underwriter Fee (2%)	$	2,143,497
Total $ECCO_{US}$ Cost	$	109,318,336
Ï(Θ) Available		4,236,370
Cost Per Ï(Θ)	**$**	**25.80**
Index Ratio		**0.061**

B.2: ECCO$_I$ θ Model (Avoided Deforestation, Peru)

Project Size (ha.)	182,000																			
Year (Model)	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Estimated θ (Gross)	364,423	364,423	364,423	364,423	364,423	472,303	472,303	477,566	502,990	555,762	634,553	691,138	562,873	562,873	562,873	562,873	562,873	562,873	562,873	562,873
Estimated Buffer θ	40,185	40,185	40,185	40,185	40,185	50,319	50,319	50,270	52,733	57,211	64,259	69,114	56,287	56,287	56,287	56,287	56,287	56,287	56,287	56,287
Estimated θ (Net)	404,608	404,608	404,608	404,608	404,608	421,985	421,985	427,296	450,257	498,551	570,294	622,024	506,586	506,586	506,586	506,586	506,586	506,586	506,586	506,586
Project Costs ($USD)	$ 1,465,686	$ 1,487,671	$ 1,509,986	$ 1,532,636	$ 1,555,626	$ 1,578,960	$ 1,602,644	$ 1,626,684	$1,651,084	$ 1,675,851	$ 1,700,988	$ 1,726,503	$1,752,401	$ 1,778,687	$ 1,805,367	$ 1,832,448	$ 1,859,934	$ 1,887,833	$1,916,151	$ 1,944,893
Validation/Verification (Basel	$ 20,000				$ 53,068					$ 57,169					$ 61,588					$ 66,348
Indexing Fee ($5/ha)	910,000																			
Project Operating Costs	2,395,686	1,487,671	1,509,986	1,532,636	1,608,694	1,578,960	1,602,644	1,626,684	1,651,084	1,733,020	1,700,988	1,726,503	1,752,401	1,778,687	1,866,955	1,832,448	1,859,934	1,887,833	1,916,151	2,011,241

REDD+ Project Costs	
Estimated θ (Gross)	10,131,715
Estimated Buffer θ	1,045,448
Estimated θ (Net)	**9,488,119**
Conservation Costs	33,892,035
Validation/ Verification	258,173
Indexing Fee	910,000
Total Project Costs	**35,060,208**
Price of REDD+ Security	35,060,208
Estimated θ	9,488,119
Cost Per θ	**$ 3.70**

B.3: ECCO$_I$ Baseline – Life of Security ($\Theta_{Ï}$)

ECCO-I Baseline	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
Discounted θ		55,742	30,968	22,845	18,883	16,582	15,109	14,107	13,396	12,877	12,489	12,196	11,971	11,797	11,661	11,555	11,471	11,405	11,353	11,311
Discounted θ Reconcile (per annum)		(46,297)	(20,286)	(11,376)	(6,721)	(3,806)	(1,786)	(295)	855	1,768	2,156	2,449	2,674	2,848	2,984	3,090	3,174	3,240	3,292	3,334
Realized θ to Reconcile (per annum)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generated Θ	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
Realized Credits to Reconcile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deficit (Excess) in θ (Indexed)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deficit (Excess) in Θ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Reconciliation Ï(Θ)					-					-					-					-
θ to Meet Obligation					-					-					-					-
Θ to Meet Obligation					-					-					-					-

Appendix C: ECCOUS

C.1: ECCOUS Θ Model (Mangrove Restoration in Florida)

Project Size (ha.)	1,000
Discount Rate	20%

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
NEP (tC ha.-1/yr-1)	0.000	0.459	1.649	2.445	3.027	3.473	3.822	4.101	4.326	4.510
Total Expected Θ	-	459	1,649	2,445	3,027	3,473	3,822	4,101	4,326	4,510
Expected Surivval (%)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Expected Θ	-	436	1,566	2,323	2,876	3,299	3,631	3,896	4,110	4,285
Ï(Θ)t Adjustment	-	(73)	(479)	(979)	(1,489)	(1,973)	(2,415)	(2,809)	(3,154)	(3,454)
Required θ/year	-	73	479	979	1,489	1,973	2,415	2,809	3,154	3,454
Mangrove Restoration	1,591,448	1,615,319	1,639,549	1,664,142	1,689,104					
Conservation Maintenance (Gross)	-	-	-	-	-	428,610	435,039	441,565	448,188	454,911
Validation/Verification	20,000				53,068					57,169

	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
NEP (tC ha.-1/yr-1)	5.610	5.610	5.610	5.610	5.610	5.610	5.610	5.610	5.610	5.610
Total Expected Θ	5,610	5,610	5,610	5,610	5,610	5,610	5,610	5,610	5,610	5,610
Expected Surivval (%)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Expected Θ	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330
Ï(Θ)t Adjustment	(4,469)	(4,612)	(4,732)	(4,831)	(4,914)	(4,984)	(5,041)	(5,089)	(5,129)	(5,163)
Required θ/year	4,469	4,612	4,732	4,831	4,914	4,984	5,041	5,089	5,129	5,163
Mangrove Restoration										
Conservation Maintenance (Gross)	461,735	468,661	475,691	482,826	490,069	497,420	504,881	512,454	520,141	527,943
Validation/Verification					61,588					66,348

Project Costs		
Mangrove Restoration	$	8,199,563
Conservation Maintenance	$	4,941,821
Validation/Verification	$	258,173
Monitoring & Indexing ($5/ha)	$	5,000
Sequestration Project Cost	**$**	**13,404,556**
Total Expected Θ		79,716
Cost Per Θ	$	168.15
Required θ		65,788
Cost for θ from Tennessee	**$**	**163,273**
Underwriter Fee (2%)	$	271,357
Total ECCOUS Cost	$	13,839,185
Indexed Θ Available		79,716
Price Per Θ	**$**	**173.61**
Index Ratio		**0.061**

C.2: U.S.-Based VCS Forest Carbon Projects

U.S. Forest Carbon Projects Considered for $ECCO_{US}$

Project	Location (State)	Project Description (Direct from VCS Website)	Project Size (ha.)[30]	Estimated Carbon Stock (tCO_{2e})	Carbon Stock Intensity (tCO_{2e}/ha)
Blue Source-Three Steps Improved Forest Management Project	Georgia	The Blue Source-Three Steps Improved Forest Management Project takes place on ~25,765 acres of pine, mixed hardwood, and cypress forest in eastern Georgia. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Three Steps Forest LLC, 2016).	16,468	3,288,681	199.70
Blue- Source Bear Island Improved Forest Management	Virginia	The Blue Source-Bear Island Improved Forest Management Project takes place on over 12,000 acres of oak and pine forest in the Northern Atlantic Coastal Plain of Virginia. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Bear Island Forest LLC , 2016).	4,858	1,230,758	253.35
Blue – Source Middlebury Improved Forest Management Project,	Vermont	The Blue Source-Middlebury Improved Forest Management Project takes place on approximately 3,000 acres of mixed northeastern conifer and northern hardwood forest in central Vermont. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (President and Fellows of Middlebury College, 2016).	1,205	617,638	512.56
Blue Source- Coal Creek Improved Forest Management Project	Tennessee	The Blue Source- Coal Creek Improved Forest Management Project takes place on approximately 61,000 acres of predominantly mixed hardwood forest in western Tennessee. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration. (The Coal Creek Company, 2016)	24,739	7,095,839	286.83
Blue Source-Sumter Wateree Improved Forest Management Project	South Carolina	The Blue Source-Sumter Wateree Improved Forest Management Project is located on 3,724 acres of pine, cypress and swamp hardwood forest, in South Carolina's coastal plain. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Sumter Wateree Club, Inc, 2016).	1507	630,814	418.57
Blue Source-Cantusee Improved Forest Management Project	South Carolina	The Blue Source-Cantusee Improved Forest Management Project takes place on approximately 12,000 acres of pine, cypress, and swamp hardwood forest across South Carolina's coastal plain. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Cantusee Timberlands LLC, 2016).	4,765	1,697,183	356.16
Blue Source – HMC Improved Forest Management Project	Pennsylvania	The Blue Source – HMC Improved Forest Management Project takes place on approximately 30,000 acres of predominantly northern hardwood forest in northwestern Pennsylvania. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Pennsylvania Timber, LP, 2016).	11,981	3,377,977	281.94
Blue Source-Big Oak Improved Forest Management Project	Pennsylvania	The Blue Source-Big Oak Improved Forest Management Project is located on approximately 10,000 acres of mixed hardwood and pine forest across the northern and western portions of the Allegheny Plateau in Pennsylvania. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Big Oak LLC, 2016).	4,824	2,099,407	435.21
Blue Source - Grandshue Improved Forest Management Project	New York	The Blue Source - Grandshue Improved Forest Management Project takes place on approximately 17,000 acres of mixed northern conifer and hardwood forest in upstate New York. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Danzer Forestland Inc, 2016).	6,878	1,771,198	257.51
Blue Source-Alford Improved Forest Management Project	Missouri	The Blue Source-Alford Improved Forest Management Project takes place on approximately 3,300 acres of broadleaf forest in the Ozark Highlands of Missouri. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Ozark Regional Land Trust, 2016).	1,330	342,935	257.81
Blue Source-Big Six Improved Forest Management Project	Maine	The Blue Source-Big Six Improved Forest Management Project takes place on over 20,000 acres of northern hardwood and northeastern spruce-fir forest in the White Mountains of Maine. By committing to main forest CO2 stocks above the regional common practice, the project will provide significant climate benefits through carbon sequestration (Big Six Land and Timber, Inc., 2016).	8,836	1,798,276	203.51

[30] *Project size has been converted from acres (the unit of measure presented for all projects), as found in the "Offset Project Listing Form" for each project, to hectares and rounded to the nearest whole number.*

C.3: ECCO$_{US}$ θ Model (Forest Carbon, Tennessee)

Project Size (ha.)	61132									
Year (Model)	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Estimated θ (Gross)	2,676,924	2,676,924	2,275,385	2,275,385	1,934,077	1,934,077	1,643,966	1,643,966	1,397,371	1,397,371
Estimated θ Buffer	267,692	267,692	227,538	227,538	193,408	193,408	164,397	164,397	139,737	139,737
Estimated θ (Net)	2,409,231	2,409,231	2,047,846	2,047,846	1,740,670	1,740,670	1,479,569	1,479,569	1,257,634	1,257,634
Project Costs ($USD)	4,088,508	4,149,836	4,212,083	4,275,265	4,339,394	4,404,484	4,470,552	4,537,610	4,605,674	4,674,759
Validation/Verification (Baseline)	20,000				52,284					56,325
Indexing Fee ($$/ha)	305,660									
Project Operating Costs	4,414,168	4,149,836	4,212,083	4,275,265	4,391,677	4,404,484	4,470,552	4,537,610	4,605,674	4,731,084

Project Size (ha.)										
Year (Model)	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Estimated θ (Gross)	1,187,765	1,187,765	1,009,600	1,009,600	858,160	858,160	729,436	729,436	620,021	620,021
Estimated θ Buffer	118,777	118,777	100,960	100,960	85,816	85,816	72,944	72,944	62,002	62,002
Estimated θ (Net)	1,068,989	1,068,989	908,640	908,640	772,344	772,344	656,493	656,493	558,019	558,019
Project Costs ($USD)	4,744,881	4,816,054	4,888,295	4,961,619	5,036,043	5,111,584	5,188,258	5,266,082	5,345,073	5,425,249
Validation/Verification (Baseline)					60,678					65,367
Indexing Fee ($$/ha)										
Project Operating Costs	4,744,881	4,816,054	4,888,295	4,961,619	5,096,721	5,111,584	5,188,258	5,266,082	5,345,073	5,490,616

Forest Carbon (FC) Project Costs	
Estimated θ (Gross)	28,665,410
Estimated θ Buffer	2,866,541
Estimated θ (Net)	**25,798,869**
Conservation Costs	94,541,302
Validation/Verification	254,653
Indexing Fee	305,660
Total Project Costs	**95,101,615**
Price of FC Security	95,101,615
Estimated θ	25,798,869
Cost Per θ	**$ 3.69**

C.4: $ECCO_{US}$ Baseline – Life of Security ($\Theta_{Ï}$)

ECCO-US Baseline	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	436	1,566	2,323	2,876	3,299	3,631	3,896	4,110	4,285	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330
θ/yr. (Projected)	-	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463
% rights from Tennessee FC		0.144%	0.169%	0.169%	0.199%	0.199%	0.234%	0.234%	0.275%	0.275%	0.324%	0.324%	0.381%	0.381%	0.448%	0.448%	0.527%	0.527%	0.621%	0.621%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463
Realized θ to Reconcile (per annum)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generated Θ	-	436	1,566	2,323	2,876	3,299	3,631	3,896	4,110	4,285	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330
Realized Credits to Reconcile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deficit (Excess) in θ (Indexed)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deficit (Excess) in Θ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Reconciliation Ï(Θ)					-					-					-					-
θ to Meet Obligation					-					-					-					-
Θ to Meet Obligation					-					-					-					-

Appendix D: ECCO Model Scenarios

Appendix D.1: ECCO Scenario 1 (Upside Scenarios for Both θ and Θ)

D.1.1: $ECCO_I$ Scenario 1

ECCOI - Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	256,229	256,229	256,229	256,229	355,342	340,710	284,337	295,891	310,921	321,211	306,273	228,690	280,802	280,802	280,802	280,802	280,802	280,802	280,802
Realized θ to Reconcile (per annum)		**(73,890)**	**(73,890)**	**(73,890)**	**(73,890)**	**(173,003)**	**(158,371)**	**(101,998)**	**(113,552)**	**(128,582)**	**(138,871)**	**(123,934)**	**(46,350)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**
Generated Θ	-	175,071	198,005	212,596	225,442	236,823	246,957	256,018	264,150	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469
Realized Credits to Reconcile	-	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Deficit (Excess) in θ (Indexed)	-	**(73,890)**	**(73,890)**	**(73,890)**	**(73,890)**	**(173,003)**	**(158,371)**	**(101,998)**	**(113,552)**	**(128,582)**	**(138,871)**	**(123,934)**	**(46,350)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**
Deficit (Excess) in Θ	-	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Reconciliation Ï(Θ)					**(390,986)**					**(825,554)**					**(665,770)**					**(652,003)**
θ to Meet Obligation					**(1,550,412)**					**(3,273,642)**					**(2,640,037)**					**(2,585,447)**
Θ to Meet Obligation					**(390,986)**					**(825,554)**					**(665,770)**					**(652,003)**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83**					**0.57**					**0.28**					**-**
ϒ (2017 Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales	$ 25.80				4.82					11.63					10.36					10.92
NPV (8%) - Ï(Θ - 2017) Sales Only	**$ (10.38)**																			
Potential Revenue from Ï(Θ) Sales (Re-Indexed)										*10.87*					*9.13*					*10.30*
Reduction Option / Ï(Θ)					0.09					0.23					0.28					0.15
Re-Indexed Obligation					0.79					0.33					(0.10)					(0.15)
Index Ratio	-	0.061	0.061	0.061	0.057	0.057	0.057	0.057	0.057	0.050	0.050	0.050	0.050	0.050	0.047	0.047	0.047	0.047	0.047	0.047
Cumulative Θ		*175,071*	*373,077*	*585,673*	*811,115*	*1,047,938*	*1,294,895*	*1,550,913*	*1,815,063*	*2,086,532*	*2,358,001*	*2,629,469*	*2,900,938*	*3,172,407*	*3,443,876*	*3,715,344*	*3,986,813*	*4,258,282*	*4,529,751*	*4,801,219*
*ECCO Equity Basis (Entire Security)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*64,256*					*163,120*
ECCO Equity Conversion Stake (%) @ t=20															***1.34%***					***3.40%***

**The equity conversion basis at t=20 includes all credits (converted to shares) gained to date (i.e. those at t=15 in the above model)*

D.1.2: $ECCO_{US}$ Scenario 1

ECCO-US - Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	436	1,566	2,323	2,876	3,299	3,631	3,896	4,110	4,285	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330	5,330
θ/yr. (Projected)	-	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463	3,463
% rights from Tennesse FC		0.1437%	0.1691%	0.1691%	0.1989%	0.1989%	0.2340%	0.2340%	0.2753%	0.2753%	0.3239%	0.3239%	0.3811%	0.3811%	0.4483%	0.4483%	0.5274%	0.5274%	0.6205%	0.6205%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	4,882	5,744	4,882	5,744	4,882	7,618	6,475	6,273	5,332	6,273	5,332	6,273	5,332	6,273	5,332	6,273	5,332	6,273	5,332
θ to Reconcile (per annum)		**(1,420)**	**(2,281)**	**(1,420)**	**(2,281)**	**(1,420)**	**(4,155)**	**(3,012)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**
Generated Θ	-	445	1,599	2,372	2,936	3,368	3,707	3,978	4,196	4,375	5,442	5,442	5,442	5,442	5,442	5,442	5,442	5,442	5,442	5,442
Θ to Reconcile	-	**(9)**	**(33)**	**(49)**	**(61)**	**(69)**	**(76)**	**(82)**	**(87)**	**(90)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**
Deficit (Excess) in θ (Indexed)	-	**(1,420)**	**(2,281)**	**(1,420)**	**(2,281)**	**(1,420)**	**(4,155)**	**(3,012)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**	**(2,811)**	**(1,870)**
Deficit (Excess) in Θ	-	**(9)**	**(33)**	**(49)**	**(61)**	**(69)**	**(76)**	**(82)**	**(87)**	**(90)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**	**(112)**
Reconciliation Ï(Θ)					**(7,553)**					**(13,672)**					**(12,733)**					**(11,792)**
θ to Meet Obligation					**(12,569)**					**(22,752)**					**(21,189)**					**(19,623)**
Θ to Meet Obligation					**(7,553.27)**					**(13,672)**					**(12,733)**					**(11,792)**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.91**					**0.67**					**0.33**					**-**
ϒ (2017Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales					4.95					10.24					10.52					10.50
NPV (8%) - Ï(Θ - 2017) Sales Only	**$(159.84)**																			
Potential Revenue from Ï(Θ) Sales (Re-Indexed)										*9.57*					*9.28*					*9.90*
Reduction Option / Ï(Θ)					0.09					0.19					0.24					0.15
Re-Indexed Obligation					0.87					0.47					0.01					(0.15)
Index Ratio	-	0.061	0.061	0.061	0.057	0.057	0.057	0.057	0.057	0.050	0.050	0.050	0.050	0.050	0.047	0.047	0.047	0.047	0.047	0.047
Cumulative Θ	-	*445*	*2,044*	*4,416*	*7,352*	*10,721*	*14,428*	*18,406*	*22,602*	*26,977*	*32,419*	*37,860*	*43,302*	*48,744*	*54,185*	*59,627*	*65,069*	*70,510*	*75,952*	*81,394*
ECCO Equity Basis (Entire Security)	-	-	-	-	-	-	-	-	-	-	-	-	-	-						*1,718.51*
ECCO Equity Conversion Stake (%) @ t=20																				***2.11%***

Appendix D.2: ECCO Scenario 2 (Downside Scenarios for Both θ and Θ)

D.2.1: $ECCO_I$ Scenario 2

ECCOI - Scenario 2	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	108,449	108,449	108,449	108,449	24,998	23,969	84,932	88,383	92,872	95,946	91,484	68,310	83,876	83,876	83,876	83,876	83,876	83,876	83,876
Realized θ to Reconcile (per annum)		**73,890**	**73,890**	**73,890**	**73,890**	**157,341**	**158,371**	**97,407**	**93,956**	**89,467**	**86,393**	**90,855**	**114,029**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**
Generated Θ	-	102,983	116,474	125,057	132,613	139,307	145,269	150,599	155,382	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688
Realized Credits to Reconcile	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Deficit (Excess) in θ (Indexed)	-	**73,890**	**73,890**	**73,890**	**73,890**	**157,341**	**158,371**	**97,407**	**93,956**	**89,467**	**86,393**	**90,855**	**114,029**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**	**98,463**
Deficit (Excess) in Θ	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Reconciliation Ï(Θ)					**534,124**					**971,665**					**887,422**					**891,534**
θ to Meet Obligation					**5,004,162**					**9,103,442**					**8,314,184**					**8,352,710**
Θ to Meet Obligation					**534,124**					**971,665**					**887,422**					**891,534**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83**					**0.57**					**0.28**					**-**
ϒ (2017 Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Reconcilation Cost per Ï(Θ - 2017) - Tax Cost					(6.36)					(12.47)					(12.27)					(13.28)
NPV (8%) - Ï(Θ - 2017) Tax Price	**$ (43.97)**																			

NPV (8%) - Ï(Θ - 2017) Market Price **$ (45.65)**

Appendix D.3: ECCO Scenario 3 (Downside Scenarios for θ, and upside for Θ)

D.3.1: ECCO$_I$ Scenario 3

ECCOI - Scenario 3	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	256,229	256,229	256,229	256,229	355,342	340,710	284,337	295,891	310,921	95,946	91,484	68,310	83,876	83,876	83,876	83,876	83,876	83,876	83,876
Realized θ to Reconcile (per annum)		**(73,890)**	**(193,333)**	**(164,688)**	**(138,787)**	**(214,853)**	**(179,929)**	**(105,812)**	**(101,921)**	**(103,539)**	**117,866**	**127,471**	**154,761**	**142,487**	**145,121**	**147,227**	**148,913**	**150,261**	**151,340**	**152,203**
Generated Θ	-	175,071	198,005	212,596	225,442	236,823	246,957	256,018	264,150	271,469	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688
Realized Credits to Reconcile	**-**	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Deficit (Excess) in θ (Indexed)	-	**(73,890)**	**(193,333)**	**(164,688)**	**(138,787)**	**(214,853)**	**(179,929)**	**(105,812)**	**(101,921)**	**(103,539)**	**117,866**	**127,471**	**154,761**	**142,487**	**145,121**	**147,227**	**148,913**	**150,261**	**151,340**	**152,203**
Deficit (Excess) in Θ	-	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Reconciliation Ï(Θ)					**(666,124)**					**(856,103)**					**1,086,924**					**1,149,164**
θ to Meet Obligation					**(2,641,442)**					**(3,394,783)**					**4,310,079**					**4,556,885**
Θ to Meet Obligation					**(666,124)**					**(856,103)**					**1,086,924**					**1,149,164**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83106**					**0.57**					**0.28**					**-**
ϒ (2017 Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales	$ 25.80				8.21					12.06					(9.33)					(10.63)
NPV Basis	$ (25.80)	$ -	$ -	$ -	8.21	$ -	$ -	$ -	$ -	-	$ -	$ -	$ -	$ -	(9.33)	$ -	$ -	$ -	$ -	(10.63)
NPV (8%) - Ï(Θ - 2017) Sales / tax Price Only	**$ (25.40)**																			
Reduction Option / Ï(Θ)					0.16					0.24					(0.45)					(0.27)
Re-Indexed Obligation					0.72079					0.35					0.18					0.27
Index Ratio	-	0.061	0.061	0.061	0.057	0.057	0.057	0.057	0.057	0.050	0.050	0.050	0.050	0.050	0.047	0.047	0.047	0.047	0.047	0.047

Appendix D.4: ECCO Scenario 4 (Gains in Verifications 1 – 2, Losses in 3-4)

D.4.1: $ECCO_I$ Scenario 4

ECCOI - Scenario 4	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	18,375	37,408	54,446	69,850	19,260	21,135	83,155	94,021	105,628	321,211	306,273	228,690	280,802	280,802	280,802	280,802	280,802	280,802	280,802
Realized θ to Reconcile (per annum)		**163,964**	**144,931**	**127,893**	**112,489**	**163,079**	**161,204**	**99,184**	**88,318**	**76,711**	**(138,871)**	**(123,934)**	**(46,350)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**
Generated Θ	-	102,983	116,474	125,057	132,613	139,307	145,269	150,599	155,382	159,688	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469
Realized Credits to Reconcile	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Deficit (Excess) in θ (Indexed)	-	**163,964**	**144,931**	**127,893**	**112,489**	**163,079**	**161,204**	**99,184**	**88,318**	**76,711**	**(138,871)**	**(123,934)**	**(46,350)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**	**(98,463)**
Deficit (Excess) in Θ	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Reconciliation Ï(Θ)					787,840					963,620					(665,770)					(652,003)
θ to Meet Obligation					**21,665,177**					**26,499,015**					**(18,308,304)**					**(17,929,732)**
Θ to Meet Obligation					**787,840**					**963,620**					**(665,770)**					**(652,003)**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83**					**0.57**					**0.28**					-
Υ (2017 Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
Υ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales					(9.39)					(12.37)					10.36					10.92
NPV (8%) - Ï(Θ - 2017) Sales Only	**$ (32.83)**																			
Potential Revenue from Ï(Θ) Sales (Re-Indexed)										*(12.37)*					*10.36*					*8.49*
Reduction Option / Ï(Θ)					-					-					0.28					0.15
Re-Indexed Obligation					0.83					0.57					0.02					(0.15)
Index Ratio	-	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.047	0.047	0.047	0.047	0.047	0.047
Cumulative Θ		*102,983*	*219,457*	*344,514*	*477,127*	*616,434*	*761,703*	*912,302*	*1,067,684*	*1,227,372*	*1,498,840*	*1,770,309*	*2,041,778*	*2,313,247*	*2,584,715*	*2,856,184*	*3,127,653*	*3,399,122*	*3,670,590*	*3,942,059*
ECCO Equity Basis	-	-	-	-	-	-	-	-	-	-	-	-	-	-						*98,864*
ECCO Equity Conversion Stake (%)																				***2.51%***

Appendix D.5: ECCO Scenario 5 (Gains in One Project, Losses in One Project)

D.5.1: $ECCO_I$ Scenario 5.1 (Gains in Mangrove, Losses in REDD+)

ECCOI - Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	18,375	37,408	54,446	69,850	19,260	21,135	83,155	94,021	105,628	112,507	109,856	83,569	104,127	105,338	106,308	107,083	107,703	108,199	108,596
Realized θ to Reconcile (per annum)		**163,964**	**144,931**	**127,893**	**112,489**	**163,079**	**161,204**	**99,184**	**88,318**	**76,711**	**69,832**	**72,484**	**98,770**	**78,212**	**77,001**	**76,032**	**75,256**	**74,636**	**74,140**	**73,743**
Generated Θ	-	175,071	198,005	212,596	225,442	236,823	246,957	256,018	264,150	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469	271,469
Realized Credits to Reconcile	-	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Deficit (Excess) in θ (Indexed)	-	**163,964**	**144,931**	**127,893**	**112,489**	**163,079**	**161,204**	**99,184**	**88,318**	**76,711**	**69,832**	**72,484**	**98,770**	**78,212**	**77,001**	**76,032**	**75,256**	**74,636**	**74,140**	**73,743**
Deficit (Excess) in Θ	-	**(20,597)**	**(23,295)**	**(25,011)**	**(26,523)**	**(27,861)**	**(29,054)**	**(30,120)**	**(31,076)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**	**(31,938)**
Reconciliation Ï(Θ)					**453,852**					**438,448**					**236,611**					**214,119**
θ to Meet Obligation					**12,480,671**					**12,057,084**					**6,506,681**					**5,888,142**
Θ to Meet Obligation					**453,852**					**438,448.11**					**236,611**					**214,119**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83**					**0.57**					**0.28**					**-**
ϒ (2017 Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales					(5.41)					(5.63)					(3.27)					(3.19)
NPV (8%) - Ï(Θ - 2017) Tax Price	**$ (34.44)**																			

D.5.2: $ECCO_I$ Scenario 5.2 (Gains in REDD+, Losses in Mangrove)

ECCOI - Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531
θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	43,415	88,383	128,637	165,034	273,784	300,427	278,388	314,766	353,623
Realized θ to Reconcile (per annum)		**138,924**	**93,956**	**53,702**	**17,305**	**(91,445)**	**(118,088)**	**(96,049)**	**(132,427)**	**(171,284)**
Generated Θ	-	102,983	116,474	125,057	132,613	139,307	145,269	150,599	155,382	159,688
Realized Credits to Reconcile	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**
Deficit (Excess) in θ (Indexed)	-	**138,924**	**93,956**	**53,702**	**17,305**	**(91,445)**	**(118,088)**	**(96,049)**	**(132,427)**	**(171,284)**
Deficit (Excess) in Θ	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**
Reconciliation Ï(Θ)					**542,451**					**(234,170)**
θ to Meet Obligation					**6,313,659**					**(2,725,534)**
Θ to Meet Obligation					**542,451**					**(234,170)**
Obligation [Baseline/ per Ï(Θ)]	**1.00**				**0.83**					**0.57**
ϒ (2017Ï / tCO2e) - CLC Basis	$ 47.56				$ 50.48					$ 54.38
ϒ (Ï + n) - CLC Basis	$ 47.56				$ 54.00					$ 65.00
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**
Potential Revenue per Ï(Θ - 2017) Sales					(6.46)					3.30
NPV Basis	$ (25.80)	$ -	$ -	$ -	(6.46)	$ -	$ -	$ -	$ -	3.30
NPV (8%) - Ï(Θ - 2017) Tax + Market Sales Only	**$ (25.02)**									
Potential Revenue from Ï(Θ) Sales (Re-Indexed)										*3.08*
Reduction Option / Ï(Θ)					(0.13)					0.07
Re-Indexed Obligation					1.03					0.64
Index Ratio	-	0.061	0.061	0.061	0.057	0.057	0.057	0.057	0.057	0.050
Cumulative Θ		*102,983*	*219,457*	*344,514*	*477,127*	*616,434*	*761,703*	*912,302*	*1,067,684*	*1,227,372*
ECCO Equity Basis	-	-	-	-	-	-	-	-	-	-
ECCO Equity Conversion Stake (%)										

ECCOI - Scenario 1	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Θ/yr. (Projected)	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
θ/yr. (Projected)	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	376,653	367,778	279,775	348,599	352,655	355,899	358,495	360,572	362,233	363,562
Realized θ to Reconcile (per annum)	**(194,314)**	**(185,438)**	**(97,436)**	**(166,260)**	**(170,316)**	**(173,560)**	**(176,156)**	**(178,233)**	**(179,894)**	**(181,223)**
Generated Θ	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688
Realized Credits to Reconcile	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Deficit (Excess) in θ (Indexed)	**(194,314)**	**(185,438)**	**(97,436)**	**(166,260)**	**(170,316)**	**(173,560)**	**(176,156)**	**(178,233)**	**(179,894)**	**(181,223)**
Deficit (Excess) in Θ	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Reconciliation Ï(Θ)					**(414,545)**					**(489,847)**
θ to Meet Obligation					**(4,824,945)**					**(5,701,393)**
Θ to Meet Obligation					**(414,545)**					**(489,846.77)**
Obligation [Baseline/ per Ï(Θ)]					**0.28**					**-**
ϒ (2017Ï / tCO2e) - CLC Basis					$ 58.59					$ 63.11
ϒ (Ï + n) - CLC Basis					$ 73.20					$ 78.85
Market Price for Ï(Θ)					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales					6.45					7.27
NPV Basis	$ -	$ -	$ -	$ -	6.45	$ -	$ -	$ -	$ -	7.27
NPV (8%) - Ï(Θ - 2017) Tax + Market Sales Only										
Potential Revenue from Ï(Θ) Sales (Re-Indexed)					*5.69*					*6.85*
Reduction Option / Ï(Θ)					0.17					0.12
Re-Indexed Obligation					0.16					(0.11)
Index Ratio	0.050	0.050	0.050	0.050	0.047	0.047	0.047	0.047	0.047	0.047
Cumulative Θ	*1,387,059*	*1,546,747*	*1,706,434*	*1,866,122*	*2,025,809*	*2,185,497*	*2,345,184*	*2,504,872*	*2,664,559*	*2,824,247*
ECCO Equity Basis	-	-	-	-						*55,803.39*
ECCO Equity Conversion Stake (%)										***1.98%***

D.5.2.2 Gains in REDD+ of half of the magnitude as in D.5.2.1, with losses unchanged for mangrove restoration.

ECCOI - Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
θ/yr. (Projected)	-	154,475	174,711	187,585	198,919	208,961	217,903	225,899	233,074	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531	239,531
Θ/yr. (Projected)		182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339	182,339
% rights from Peru REDD+		45%	45%	45%	45%	45%	43%	43%	43%	40%	37%	32%	29%	36%	36%	36%	36%	36%	36%	36%
Index Ratio		0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Generated θ	-	219,284	219,284	219,284	219,284	219,284	261,524	261,524	231,571	231,571	231,571	231,571	231,571	231,571	231,571	231,571	231,571	231,571	231,571	231,571
Realized θ to Reconcile (per annum)		**(36,945)**	**(36,945)**	**(36,945)**	**(36,945)**	**(36,945)**	**(79,185)**	**(79,185)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**
Generated Θ	-	102,983	116,474	125,057	132,613	139,307	145,269	150,599	155,382	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688	159,688
Realized Credits to Reconcile	**-**	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Deficit (Excess) in θ (Indexed)	-	**(36,945)**	**(36,945)**	**(36,945)**	**(36,945)**	**(36,945)**	**(79,185)**	**(79,185)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**	**(49,232)**
Deficit (Excess) in Θ	-	**51,492**	**58,237**	**62,528**	**66,306**	**69,654**	**72,634**	**75,300**	**77,691**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**	**79,844**
Reconciliation Ï(Θ)					**90,783**					**81,344**					**153,061**					**153,061**
θ to Meet Obligation					**420,641**					**376,904**					**709,205**					**709,205**
Θ to Meet Obligation					**90,783**					**81,344**					**153,061**					**153,060.90**
Obligation [Baseline/Ï(Θ)]	**1.00**				**0.83**					**0.57**					**0.28**					**-**
ϒ (2017 Ï) - CLC Basis	$ 47.56				$ 50.48					$ 54.38					$ 58.59					$ 63.11
ϒ (n - Ï) - CLC Basis	$ 47.56				$ 54.00					$ 65.00					$ 73.20					$ 78.85
Market Price for Ï(Θ)	**$ 47.56**				**$ 52.24**					**$ 59.69**					**$ 65.89**					**$ 70.98**
Potential Revenue per Ï(Θ - 2017) Sales					(1.08)					(1.04)					(2.12)					(2.28)
NPV (8%) - Ï(Θ - 2017) Sales Only	**$ (28.37)**																			

Appendix E: Representative Annual Carbon Budget Increase from Ecosystem Restoration

Terrestrial Forests	Area (ha.)	Annual Uptake (GtCO2E/yr)	Uptake (GtCO2E/ha.)	Area Degraded (%)	Area Degraded (ha.)	Area Restored (ha.) - 25% of lost area	Increase in Update GtCO2E
Temperate	1,040,000,000	0.053	0.0000000000509615	18%	235,000,000	58,750,000.00	0.00299
Tropical	1,962,284,600	0.0785	0.0000000000400044	26%	704,000,000	176,000,000.00	0.00704
Boreal	1,370,000,000	0.0493	0.0000000000359854	excluded			
Wetland Vegetation	Area (ha.) - Low	Annual Uptake (GtCO2E/yr) - low	Uptake (GtCO2E/ha.)	Area Degraded (%) - Low	Area Degraded (ha.) - Low	Area Restored (ha.) - 25% of lost area	Increase in Update GtCO2E
Mangroves	13,776,000	0.0257	0.00000000186556330	30%	5,904,000	1,476,000	0.0028
Seagrasses	17,700,000	0.048	0.00000000271186441	50%	17,700,000	4,425,000	0.0120
Salt Marshes	2,200,000	0.0043	0.00000000195454545	25%	733,333	183,333	0.0004
	Area (ha.) - High	Annual Uptake (GtCO2E/yr) - High	Uptake (GtCO2E/ha.)	Area Degraded (%) - High	Area Degraded (ha.) - High	Area Restored (ha.) - 25% of lost area	Increase in Update GtCO2E
Mangroves	15,236,100	0.0403	0.00000000264503383	50%	15,236,100	3,809,025	0.0101
Seagrasses	60,000,000	0.112	0.00000000186666667	50%	60,000,000	15,000,000	0.0280
Salt Marshes	40,000,000	0.0968	0.00000000242000000	25%	13,333,333	3,333,333	0.0081

Total Increase in Annual Carbon Budget - GtCO2E (Low)	0.0251
Total Increase in Annual Carbon Budget - GtCO2E (High)	0.056

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