Alternative approaches to valuing carbon sequestration in mangroves

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ABSTRACT

Mangroves are highly productive ecosystems, next only to tropical forests, with a global primary production of 218 ± 72 Tg C yr $^{-1}$. These tidal forests have the potential to act as highly efficient sinks of carbon as they sequester atmospheric carbon in their aboveground and belowground biomass, and in sediments. This carbon sequestration and storage service by mangroves provides global benefits by removing the harmful greenhouse gas carbon dioxide from the atmosphere. The undervaluation of this ecosystem service by society further exacerbates the rapid loss of mangroves through extensive degradation and over exploitation. Failure to link this significant ecosystem service to societal benefits leads to inefficient decision making regarding mangrove ecosystems. Unlike the tangible benefits of provisioning ecosystem services that carry market prices, benefits of regulating ecosystem services like carbon sequestration are less obvious. An economic valuation of this ecosystem service that makes a cogent case for the utilitarian benefits of carbon sequestration by mangroves resulting in real economic benefits to society is urgently needed. A robust valuation of this ecosystem service must be first supported by reliable, scientific methods that can estimate the total carbon stored in the mangrove ecosystem. The variability in mangrove production and carbon accumulation through space and time must be accounted for as it greatly influences the economic valuation of the sequestration service. As no single valuation method can encompass the value of carbon sequestration and storage to society and human welfare, this paper analyzes four different methodologies appropriate for carbon sequestration: market price analysis, damage cost assessment, damage avoidance method, and stated preference approach. Our review clearly indicates that there is no single price for carbon. The prices and costs of carbon sequestration widely vary within and among valuation methodologies. The social cost of carbon (SCC) ranges from $9/tC to50 $ /tC, showing significant uncertainties. Marginal abatement costs (MACs) vary from $70/tC to $616.17/tC and are generally higher than prices based on consumers' willingness to pay, indicating that the supply of carbon sequestration benefits currently exceed the demand for the ecosystem service. SCC and MACs are useful for setting a price for carbon in the absence of efficient carbon markets. Carbon prices also vary across countries and markets with several technological, regulatory, economic, and social factors influencing them. The market price for carbon ranges from $6.86/tC in the Regional Greenhouse Gas Initiative market in the United States to $75.24/tC in the European Union's Emissions Trading System. Market prices are an indication

of the value that society attaches to carbon sequestration services. People's willingness to pay is expected to correspondingly increase with their conviction that carbon sequestration by mangrove forests will provide significant and tangible benefits to them. Over time, a strong and stable price for carbon within a robust international carbon market that is representative of all societies is envisaged. When setting the price of carbon sequestered by mangroves in particular, we suggest that the geological age of the forest and its status as a protected area must be taken into account. Mature forests may have higher economic value than plantations. Carbon prices as governed by REDD+ projects and payments for ecosystem services (PES) that use net sequestration rates of carbon are appropriate for mangrove plantations. The economic value of a mature forest must also include the geological carbon stored within its ecosystem. Mangroves in protected areas with more restrictive management may have enhanced abilities for carbon storage. There is a need educate the general public as well as scientists that carbon can be priced, and inform them about the current status of carbon prices as seen in market based approaches and as derived from Integrated Assessment Models that estimate SCC and MACs. The knowledge of the value of the carbon stored by mangroves as indicated by carbon prices can encourage countries to lower the rates of deforestation of mangroves and improve the status of these natural carbon sinks. In addition, it can help meet climate change commitment goals by including the carbon sequestered and stored by mangrove forests in national and international inventories of greenhouse gases.

1. Introduction

Mangroves are intertidal forests that grow along coastal regions of the tropics and subtropics. They provide a wide array of essential ecosystem services like provision of nursery grounds for fish, birds, and mammals, sediment and nutrient retention, storm protection (Alongi, 2008), and carbon storage (Twilley et al., 1992; Alongi, 2002). The Millennium Ecosystem Assessment (2000) describes ecosystem services as benefits provided by ecosystems to human well-being, and categorizes them as provisioning (e.g., food), cultural (e.g., spiritual values, recreation), supporting (e.g., nutrient retention, soil accretion) and regulating (e.g., climate regulation, soil stabilization). Not unlike tropical forests, mangroves are highly efficient "biological scrubbers" (Stavins & Richards, 2005) that can sequester atmospheric carbon in their aboveground and belowground biomass and in sediments. The ecosystem service of carbon sequestration and storage provides significant global benefits as it removes the harmful greenhouse gas carbon dioxide from the atmosphere and thereby helps mitigate the effects of climate change. A failure to successfully establish the linkage between carbon sequestration services and the benefits they provide to society has led to an international free riding of this public good. Barbier et al. (2011) calculated the benefit of permanent carbon sequestration by mangroves globally to be $30.50 ha^{-1} yr^{-1}. However, the continued undervaluation of the benefits of carbon sequestration and storage service provided by mangroves exacerbates their degradation across the globe (Aburto-Oropeza et al., 2008).

According to the Intergovernmental Panel on Climate Change (IPCC), deforestation and land-use change account for 8-20% of the total global anthropogenic CO_2 emissions (IPCC, 2007). A third of the global area of mangroves has been lost over the last 50 years (Alongi, 2002) as a result of land use change and degradation. Climate change and sea level rise pose the greatest threat to mangroves (Gilman et al. 2008 as cited in Donato et al. 2011) in the next century. Mangroves respond to sea level changes by landward transgression but this movement can be complicated by the increasing pressures of urban development (Donato et al., 2011). Overall, mangroves are keeping pace with the rise in sea level according to current data (Alongi, 2008) but face extensive pressures from anthropogenic activities like deforestation, aquaculture and overexploitation of fisheries (Alongi, 2002).

There is now a common consensus for the need of a more integrative approach to environment science that views the environment as a social-ecological system and recognizes the linkages between the biophysical and social domains. Human impacts and environmental stressors on ecosystems can be chronic or sustained “press” events, or can be sudden or discrete “pulse” events. Both presses and pulses alter ecosystem functions which in turn affect the quantity and quality of ecosystem services. This change influences human behaviors and attitudes towards the environment and initiates feedbacks that affect the original dynamics and processes (Collins et al., 2010). In the case of mangroves, pulses like storms and hurricanes, and presses like land use change, sea level rise, and altered hydrology are stressors (Alongi, 2002) that can change the function of mangrove production and carbon accumulation (Rivera-Monroy et al., 2011) . Deterioration in benefits provided by carbon sequestration service of mangroves can alter human behavior and attitudes which may be manifested as change in public perceptions about climate change, development of climate change mitigation policy, the perceived value of carbon storage, and development of carbon markets. The growing realization among people of the value of carbon sequestration and storage by mangroves has the potential to initiate feedbacks that affect the original dynamics and processes.

Efforts to mitigate the effects of climate change include regulation of anthropogenic emissions of CO_2, avoiding deforestation, and management and protection of natural terrestrial carbon sinks (Laffoley & Grimsditch, 2009). However, failure to apply principles of ecosystem based management has led to unwise decisions and policies (Aburto-Oropeza, 2006). With the growing acknowledgement by recent studies of coastal ecosystems and mangroves as significant carbon sinks, there is a need to include them in decision making to meet climate change mitigation goals (Bouillon et al., 2009).

An ecosystem based approach to management of carbon sinks first requires the quantification of the carbon sequestered and stored by mangrove forests through reliable scientific measures. Reliable estimates of data on total carbon stored within mangrove forests are currently lacking (Donato et al., 2011). Secondly, an economic valuation of this ecosystem service is needed that makes a cogent case for the utilitarian benefits of carbon sequestration by mangroves that result in real economic benefits to society (Reid, 2006; Donato et al. 2011; Costanza, 2006). The persistent moral argument against valuation of ecosystem services gives credence to intrinsic values alone. But there is little doubt that the process of making choices with regard to ecosystems is in itself an exercise in valuation. Information regarding the value of carbon sequestration service is an invaluable tool for effective and sustainable management of carbon sinks as it helps underscore their linkage with climate change mitigation. Economists employ a suite of valuation methodologies to assess the welfare contribution of ecosystem services (Barbier et al. 2011). As no single valuation method can encompass the value of carbon sequestration and storage to society and human welfare, an analysis of appropriate methodologies becomes necessary to estimate a price range for carbon that would be scientifically justified and socially acceptable.

The tangible benefits of provisioning ecosystem services are easily valued as they are regularly bought and sold in the market. For example, the value of a structural attribute like the number of fish derived from a mangrove estuary is easy to calculate but the value and payment for an ecosystem function like fish production is more complex (Alongi, 2011). Similarly, the value and payment for the benefits obtained from regulating ecosystem services like carbon sequestration and storage are complicated by various factors. Being less explicit, these benefits continue to remain undervalued. There is a need educate the general public as well as scientists that carbon can be priced, and inform them about the current status of carbon prices as seen in market based approaches, as derived from integrated assessment models or through constructed economic experiments. The knowledge of the value of this carbon can encourage countries to lower the rates of deforestation of mangroves and improve the status of their natural carbon sinks (Yee, 2010). In addition, it can help meet climate change commitment goals by including the carbon sequestered and stored by mangrove forests in national and international inventories of greenhouse gases.

The purpose of this paper is to (a) review different valuation methodologies appropriate for carbon sequestration and (b) identify suitable criteria for choosing the right prices for mangroves carbon, depending on the ecological, management, and market contexts. We will analyze the underlying methodologies and the final carbon price estimates for four valuation techniques: market price analysis, damage cost assessment, damage avoidance method, and stated preference approach.

2. Mangroves are significant sinks of carbon

Mangroves are highly productive ecosystems, second only to tropical forests, with a standing plant biomass stock of 7990 g C m^{-2} (Laffoley & Grimsditch, 2009). Twilley et al. (1992) estimated the global carbon storage in mangroves to be 4.03 PgC. In an assessment of global primary production from literature, Bouillon et al. (2008) estimated the net primary production of mangroves to be 218 ± 72 Tg C yr^{-1} using a global area of 160, 000 km^2. Mangroves sequester the atmospheric carbon dioxide into organic compounds in their biomass through the process of primary production. The aboveground pools of biomass consist of leaves, stem and wood while the belowground biomass includes fine and coarse roots. This biomass can be later consumed by local fauna, exported to adjacent ecosystems, remineralized back into the atmosphere or stored in the sediments (Bouillon et al., 2008). As mangroves are present at the interface of land, coasts and watersheds, they produce cumulative benefits of carbon storage, which can be more significant than other ecosystems. With respect to carbon sequestration the two significant pools of carbon are: (a) the net growth of forest biomass which serves as a shorter term carbon sink, and (b) the carbon stored in mangrove soils which is a long-term carbon sink (Bouillon et al. 2009).

Coastal ecosystems like the mangroves have been traditionally overlooked for their contribution as carbon sinks in comparison to terrestrial forests for several reasons. The carbon present in aboveground tree biomass is widely reported but reliable data for belowground biomass and soil carbon is lacking for most mangrove forests. Mangrove soils are rich in organic matter and contain moderate to high carbon concentration. Thus the amount of carbon as reported in most studies lacks information on the total carbon stored within the mangrove ecosystem and represents very conservative estimates (Donato et al. 2011). The methodologies for estimation of carbon sequestration vary considerably (Bouillon et al. 2008, Alongi, 2008). The rates of gross and net primary production are used to determine the sequestration capabilities of mangroves but, here too, large uncertainties exist as more than 50% of the carbon fixed by mangroves is unaccounted for (Bouillon et al. 2008). Such uncertainties make it difficult to categorize a mangrove forest as a sink or source of carbon.

While estimating the economic value of carbon sequestered by mangroves the natural spatial and temporal variability of this ecosystem which results in nonlinear functions and services must be kept in mind. The variability in mangrove production and carbon accumulation through space and time greatly influences the economic valuation of the ecosystem service (Koch et al., 2009). The sequestration abilities of mangroves vary at human and geological timescales making them dynamic, nonlinear and non-equilibrium ecosystems. Small scale studies that use short term measurements are unable to capture the accurate picture of sequestration services provided by mangroves (Alongi, 2011). Thus the valuation of carbon sequestration and storage must be supported by reliable, scientific estimates of the total carbon (aboveground, belowground and soil carbon) within the ecosystem and changes in mangrove production and carbon storage must be regularly documented.

3. Economic Valuation of Carbon Sequestration

The economic value of any resource-environment system lies in the contribution of its ecosystem services and functions to human well-being. Consequently, the economic value of the change in ecosystem service flow can be derived by measurement of the effect on changes in human welfare. Effect on human welfare is measured by people's willingness to pay (WTP) for changes that have a positive welfare impact or the willingness to accept (WTA) compensation to avoid negative impacts. To assess the welfare contribution of ecosystem services economists use environmental valuation methodologies (Freeman 2003). The economic value of private goods in a conventional market is a sum of the producer and consumer surplus as indicated by the supply and demand curves of commonly marketed goods. The total economic value (TEV) of ecosystem services, harder to constrain within the framework designed for private goods, is determined by the sum of their use values and non-use values. However, this valuation can only be done upon the characterization of the changes in ecosystem structure, function and processes that result in the change in ecosystem services. In addition, it is important to understand how the changes in ecosystem structure and function influence the quantity and quality of the flow of an ecosystem service to human beings (Barbier et al., 2011).

The carbon stored within mangrove forest ecosystem has begun to take significant economic value as seen with the emergence of carbon markets. Its economic value arises from the knowledge that CO_2, a major greenhouse gas, is sequestered by forest ecosystems including mangrove forests, thus reducing the effects of global climate change. However, no single valuation method can encompass the value of carbon sequestration service to society and human welfare. Each methodology depends on the context of the study and carbon sequestration project in question, availability of data, and certain theoretical considerations. A detailed analysis of appropriate methodologies is necessary to estimate a suitable price range that would be scientifically justified and socially acceptable. A review of four different approaches is considered appropriate for carbon sequestration: (a) market price analysis, (b) damage cost assessment, (c) damage avoidance method, and (d) stated preference approach.

3.1 The Market Price Method:

A variety of fiscal measures have been developed to create economic incentives that reduce carbon emissions and place a value on carbon (Laffoley & Grimsditch, 2009). Carbon markets, based on the current and future demand and supply of carbon credits, determine the market price and generate payments for storage and sequestration of carbon. The price per ton of carbon represents the price investors are willing to pay to store one ton of carbon (Yee, 2010). Carbon markets can be *regulatory* like the European Union's Emission Trading Scheme (EU ETS) and the Regional Greenhouse Gas Initiative (RGGI) in the U.S or *voluntary* like the European Climate Exchange (ECX) and the now defunct Chicago Climate Exchange (CCX).

3.1.1 Regulatory carbon markets

Carbon markets have been in the process of evolution since the beginning of the EU ETS. Regulatory markets like the EU ETS are a classic cap-and-trade system as (a) an absolute quantity limit (cap) on CO_2 emissions is set on the installations and factories; (b) tradable allowances (called EUAs or European Union Allowances in EU ETS) equal to the cap are given to these installations; and (c) the installations have to measure and report the CO_2 emissions every year and then surrender allowances to cover the emissions. A company that has more emissions than allowances will have to purchase additional allowances and a company that has surplus allowances can sell them. In such a regulatory or compliance market, parties and installations are required to meet an emission reduction commitment which raises the demand for credits. Along with the higher demand, strict standards for verification of validity of emission reductions result in a higher price per metric ton of CO_2 emissions. Emission trading occurs among the 30 countries with binding targets under the Kyoto Protocol. The targets for each country with the commitment are the "allowed emissions" and are divided into "assigned amount units" (AAUs). Countries with excess emission units to spare can sell them to countries that are over their targets so they can meet their commitments. In addition to AAUs, other units that can be traded are (a) Certified emission reductions or CERs generated from Clean Development Mechanism (CDM) projects; (b) Emission reduction units or ERUs generated from Joint Implementation (JI) projects; and (c) Removal units on the basis of land use, land use change and forestry (LULUCF) activities. All these are equal to one ton of CO_2.

The Regional Greenhouse Gas Initiative (RGGI) is the first market based regulatory program for greenhouse gas emissions in the United States in which ten Northeastern and Mid-Atlantic States aim to reduce their emissions by 10% from the power sector by 2018. Emission allowances are sold through quarterly auctions in the primary market and the revenues are invested in clean energy technologies, energy efficiency and renewable energy programs. CO_2 emission allowances are distributed in the market through auctions, and 319 million CO_2 allowances have been sold for $777 million since the inception of the program in January 2009 through December 2010. The allowances can also be traded any time in a secondary market in between auctions. This allows protection to firms against potential volatility of future auction clearing prices and also provides price signals to affected firms that help in making investment decisions in markets (RGGI annual report, 2010).

In 2010, the international carbon markets transacted 6,692 $MtCO_2e$ and were valued at $124 billion. The EU ETS dominated the market with a value at $106 billion (Peters-Stanley et al. 2011). The RGGI had seen promising growth in its first year but problems of over-allocation coupled with the failure of a federal US climate legislation dampened the momentum of the United States' first carbon market. The average trading price of a metric ton of CO_2e is $18-23 in the EU ETS and $9-16 in the Clean Development Mechanism (CDM) market (Yee, 2010). For December 2011, the closing price of European Union Allowances (EUAs) was predicted from the average values as € 10.78 or $15.37 as reported by Point Carbon (http://www.pointcarbon.com/, date of last access August 5, 2011). The price assessment for secondary CERs was € 7.60 or $10.83 (http://www.pointcarbon.com/, date of last access August 5, 2011). In December 2010, the CO_2 allowance prices in the RGGI market fell to $1.87 from $2.24 in January 2010 (RGGI annual report, 2010).

3.1.2 Voluntary carbon markets

Voluntary carbon markets (VCM) are not guided by regulatory obligations. The volume of credits transacted in this sector is small and formed 0.1% of the global carbon markets share in 2010 (Peters-Stanley et al., 2011). The demand for offsets is low and the standards for verification of credits are less strict, resulting in lower price range of CO_2 emissions from $5-10 (Yee, 2010). Transactions are driven by individuals and companies that take responsibility for offsetting their own emissions or by pre-compliance buyers. Pre-compliance buyers are those that purchase offsets at a lower price as they anticipate a future regulatory system. ECX is a formal exchange, a cap and trade system that is legally binding for members that sign up for it voluntarily. A formal, public exchange offers a straight forward method of trading, eliminating risks of default by counter parties due to the monitoring facilities offered by the exchange (RGGI annual report, 2010). Most voluntary offset transactions take place in the decentralized over-the-counter (OTC) market where buyers and sellers engage directly, allowing them to create contracts that suit their purpose and needs. The credits generated through OTC markets are referred to as Verified or Voluntary Emissions Reductions (VERs) or carbon offsets. Investors in OTC can also purchase and retire allowances from compliance markets like RGGI or CDM. Voluntary markets guide and inform regulatory markets through innovative experiments in project finance, monitoring and methodologies (Peters-Stanley et al., 2011).

Reducing Emissions from Deforestation and Forest Degradation-Plus (REDD+)

The carbon related to land use projects traded in voluntary markets provides the best indication of the potential value for carbon stored in ecosystems (Campbell et al., 2008). In 1997, the Kyoto Protocol only allowed project based incentives for afforestation and deforestation. The current carbon market therefore uses credits from afforestation and reforestation projects. Comprehensive greenhouse gas reductions can only be achieved by including avoided deforestation efforts that protect existing carbon sinks along with reforestation and afforestation projects. The 2005 UNFCCC Montreal Conference of Parties (COP) proposed a carbon credit system for avoided deforestation and transformed the original Reducing Emissions from Deforestation and Forest Degradation (REDD) mechanism to Reducing Emissions from Deforestation and Forest Degradation-Plus (REDD+). The goals of REDD+ include the added benefits of biodiversity conservation and poverty alleviation (Yee, 2010).

The market share of REDD grew last year due to the formal international recognition in the 2010 UNFCCC Cancun COP for REDD and REDD+ as significant tools for climate change mitigation. REDD+ has also been recognized by California's upcoming cap-and-trade program in 2012. The COP 16 decision at Cancun recognized the significance of tropical forests in mitigating global climate change. Developing countries not covered by the global emissions commitment can now receive financial incentives through the following REDD+ activities by: (a) reducing emissions from deforestation by slowing the process and measuring against reference levels; (b) reducing emissions from forest degradation; (c) conservation through continued practice of good management techniques; (d) sustainable management of forests by lowering impacts through sustainable harvestation methods; (e) enhancement of carbon stocks in forests. These reductions are subject to verification and validation based on conditions of additionality, permanence of credits and spatial leakage. Credits for REDD+ will require protection of rights and participation of indigenous people and local communities (Linacre et al., 2011).

The average credit price for REDD and avoided conversion projects rose to \$5/tCO_2e and these projects contributed 29% of credits transacted in the voluntary market in 2010 (Peters-Stanley et al., 2011). This increase was attributed to private sector finance injected into forest conservation and sustainable development projects in developing countries. REDD+ projects have gained further standing in the voluntary market following the approval of project methodologies by Verified Carbon Standard (VCS) which is a greenhouse gas accounting program used by projects to verify and issue carbon credits in voluntary markets.

In sum, the 2010 voluntary carbon markets transacted 131 MtCO_2e, higher than the previous year by 34%. This rise is mostly attributed to the single bilateral OTC transaction of allowances called Carbon Financial Instruments (CFIs) worth 59 MtCO_2e following the demise of Chicago Climate Exchange. Despite this statistical outlier, the volume of OTC transaction was higher than previous years. The volume-weighted average price of credits transacted in the voluntary OTC market fell from \$6.5/tCO_2e in 2009 to \$6/tCO_2e in 2010. The value of the voluntary carbon markets for 2010 is estimated to be \$424 million (Peters-Stanley et al., 2011).

The carbon price from all operating markets can be analyzed for long term trends and for alternative regulatory and voluntary policy scenarios to arrive at a suitable and conservative price estimate for valuation of the carbon stored by mangroves forests. A strong economic price of carbon can be envisaged within a robust international carbon market. To build one, it will be important for more global regions to be represented through national and sub-national markets that are linked together in a strong network. A strong and long-term price signal will inject more finance into the markets, lead to innovations in low carbon technologies and promote the spread of comprehensive climate policies across the globe.

3.2 The Cost of Damage Avoidance approach

Any project that lowers greenhouse gas emissions and avoids attendant environmental damage by investing in less carbon-intensive technology or sequestration measures entails certain opportunity costs. These costs are the benefits forgone when scarce resources are used to avoid the chances of negative impacts of emissions instead of being used in alternative activities. Estimation of such opportunity costs is referred to as damage avoidance approach (Dieter and Elsasser, 2002). More specifically, opportunity cost is the net benefit sacrificed in order to prevent or reduce the chances of a negative environmental impact. Marginal avoidance costs increase with increased amounts of reduction, and inter-sectoral and emissions trading lowers them as trading leads to growth in technology. These costs encompass all explicit and implicit costs and are not a mere reflection of monetary accounting (Stavins & Richards, 2005). Forest-based sequestration has emerged as a powerful concept in mitigating the effects of climate change as forests being highly productive ecosystems, can sequester CO_2 from the atmosphere and become long-term carbon sinks. Based on this, Stavins and Richards (2005) analyzed eleven previous studies that have estimated the likely costs of large scale, hypothetical forest carbon sequestration programs based on modified management of existing forests or conversion of agricultural land to forests or agroforestry in the U.S. The costs for carbon sequestration in these eleven studies were mainly derived from “engineering” cost methods and some studies relied on the revealed preference approach. Stavins and Richards (2005) analyzed these previous studies for opportunity costs of using vast amounts of land in the United States for sequestration and the factors that influence the economics of a long-term sequestration project. As noted by the authors, the cost of forest carbon sequestration is influenced by several factors: (a) forest management practices, the species of trees used, related rates of carbon uptake over time and geographic location of the area selected; (b) disposition of the biomass through burning, harvesting, and forest product sinks; (c) opportunity costs of the land; (d) anticipated changes in forest and agricultural product prices over time; (e) the analytical methods used to account for carbon flows over time; (f) the discount rate applied; and (g) the policy instruments used to achieve a given carbon sequestration target. Upon normalization of results from relevant studies, the marginal cost of supplying 500 million tons of forest-based carbon sequestration in the United States was found to be $70 per ton of carbon (using a discount rate of 5%).

Marginal abatement costs (MAC) are the costs of eliminating an additional unit of carbon emissions and a MAC curve can be constructed by plotting CO_2 prices against a corresponding reduction amount for a specific time and region (Ellerman and Decaux, 1998). MACs are used to demonstrate the benefits of emissions trading. Computer based economic models are developed to calculate MACs with respect to long-term policy targets. Varying estimates are produced depending on the models used which differ in the assumptions and specifications provided and the stabilization targets used. Most models equalize MACs across all sources and MACs of different GHGs are also equalized with respect to their warming potentials and lifetimes in the atmosphere. A meta-analysis of MAC estimates was carried out by Kuik et al. (2008) by synthesizing the results from multiple sources using statistical techniques. The MACs from these studies were based on the level of stabilization target, the baseline of emissions used, intertemporal optimization, the choice of control variable and assumptions on future technological options. Normalization of results was done using the consumer price index from OECD to convert all prices to a common year of 2005, market exchange rates from OECD were used to arrive at a common currency (euros) and molecular weights were used to convert all physical dimensions to that of CO_2 (Kuik et al. 2008). The resulting MAC from this meta-analysis is labeled an "idealized global MAC" as it strives to equate MAC across all sources of emissions at each point in time and is designed to result in an optimal trajectory of MAC over time (Kuik et al. 2008). The range of values of the globalized MAC is €13 – €119/tCO_2 for the year 2025 and €34 – 212/tCO_2 for the year 2050. This estimation is calculated for a target range of 550-350 ppmv. It can be considered as the carbon permit price in an idealized global emissions trading system (Kuik et al. 2008).

Tol (2006) estimated the avoidance costs for CO_2 and other GHGs with the 2.9 version of the model, Climate Framework for Uncertainty, Negotiation and Distribution (FUND). Marginal abatement costs in this study were considered equal between regions and gases although differential global warming potentials have been taken into account. The marginal abatement cost for CO_2 in 2050 was estimated to $ 95.2/tC for a target of 500ppm.

3.3 Damage Cost approach

Several authors have estimated the economic costs of climate change in terms of reduction in welfare below its reference levels. Cost estimates for doubling of CO_2 concentration in the atmosphere roughly lie in the range of 1 to 2% of the GDP of the world in many studies (Nordhaus1994a; Fankhauser, 1995; Tol 1995; Nordhaus and Yang, 1996) but there exist estimates as low as 0.1 % and as high as 4.8% (Maddison, 2003; Nordhaus, 1994b). In contrast, Tol (2002) and Hope (2006) have estimated that the net effects of global warming could be positive. These studies show that the aggregate benefit for the doubling of CO_2 in the atmosphere could be as high as 2.3%. The studies indicate initial benefits derived from small increases in temperature followed by losses with larger increases (Tol, 2009).

Two basic approaches are used to carry out these studies. The *enumerative method* used by Nordhaus (1994a), Fankhauser (1995) and Tol (1995, 2002) uses the physical effects of climate change based on climate and impact models and laboratory experiments and data. The physical impacts are then allocated a suitable price. For example, the cost of building levees for coastal protection and the value of the loss of land with rise in sea level can be estimated through scientific and economic data. All such effects of climate change are then added up to arrive at final cost estimates. Valuation of nonmarket goods and services may require the benefit transfer approach to attach economic values to effects of climate change by using research in epidemiology of effects on health and environment. There is a fair degree of extrapolation used in the enumerative approach in terms of time scale, level of development, geographic scope and transfer of values from one area to another. On the other hand *the statistical approach* uses direct estimates of welfare impacts based on observed variations in price and expenditures over space and time in order to quantify effects of climate change (Tol, 2009).

Marginal damage costs are the net present value of the incremental damage caused by a small increase in emissions (Tol, 2006). The damage cost associated with the marginal increase in the atmospheric content of carbon equals the damage inflicted by that carbon emission on the environment and society. Marginal damage cost of carbon is also referred to as the social cost of carbon (SCC) which is defined as the incremental cost to society of a one-metric-ton increase in carbon emissions (Yohe et al. 2007). Marginal damage cost may be considered equal to the Pigouvian tax on carbon for policy purposes in order to make for an efficient market by internalizing the externalities (Tol, 2009).

To offset the uncertainties in the calculation of damage costs a sizeable amount of research has been carried out on the economic modeling for the estimation of socio-economic damage costs of climate change. These models like MERGE, IMAGE, FUND and DICE are called Integrated Assessment Models (IAMs). They combine the socio-economic aspects of global economic growth with the scientific aspects of geophysical climate dynamics and aim to set a dynamic approach for assessing policy options for climate change control (Ding et al. 2010).

Ding et al. (2010) have used the values of SCC derived from the Cost Assessment for Sustainable Energy Systems (CASES) project which is a worldwide study funded by the European Union. The estimated cost of GHG emissions by CASES is based on IAMs. The central estimate range for the SCC was \$119.86/tC in 2000 to \$ 213.70/tC in 2030. A survey of Tol (2005) of the literature's SCC estimates reports a mean estimate of \$50/tC. Nordhaus (2007) estimated the SCC with no emission limitations, using the Dynamic Integrated model of Climate and the Economy (DICE), to be about \$28 per metric ton of carbon in 2005. Another study by Chiabai et al. (2009) has used the lower marginal damage costs estimates, \$9/tC for the year 2007 and \$32.4/tC for the year 2050. The values are taken from CASES assuming a 30%

reduction in emissions in 2020. This study has provided conservative estimates for carbon sequestration of the world's biomes using lower bound values in terms of annual per hectare values.

Tol (2009) carried out a meta-analysis 232 published estimates of SCC measured in 1995 dollars per metric ton of carbon. A probability density function was constructed in which the modes of all of the estimates are used to construct a distribution. Using the discount rate of 3 per cent the range of values for SCC would be the modal value at $25/tC and the mean value at $50/tC.

3.4 Stated valuation approach

In July 2009, the United Kingdom's Department of Energy and Climate Change changed course and shifted to using the cost of mitigating emissions to value carbon rather than estimates of damages associated with climate change. The approach based on valuing carbon through damage costs was rooted in the suggestions of the Stern Review and was also referred to as the Social Cost of Carbon. Tsang and Burge (2011) in a report titled "Paying for carbon emissions reductions" based their research on people's willingness to pay using four stated choice studies in the water sector in order to apply the resulting values for climate change policy. The study found that households were willing to pay £1.45 to £2.97 per year on their water bill in exchange for climate change related improvement. This premium translates to a willingness to pay of £135- £333 per ton of CO_2 with a potential saving of 0.01 ton of CO_2 per household per year. The studies carried out on behalf of four water companies quantified the WTP of customers through service improvements like availability of water meters, frequency of hosepipe bans and leakage in water mains along with the environmental attributes.

In comparison, the official SCC value in UK was £64/tCO_2 in 2006 (2007 prices) based on lifetime damage costs of GHG emissions. In 2007, the shadow price of carbon was derived from SCC but with a different stabilization goal was found to be £25t/CO_2 (2007 prices). Meanwhile in July 2009 the traded price of carbon in EU ETS was £22/tCO_2.

The study notes that payments in voluntary carbon offset markets (£12.10 to £15.23/tCO_2 in UK is much lower than the stated WTP. This raises doubts whether people are willing to pay at all for carbon emission reduction. The authors of the study note that the lack of commitment in the stated WTP studies may be an important cause. At the same time, many contextual factors influence individual decision making that raise the WTP for stated preference. In the stated preference studies, respondents are aware of the fact that the premium is shared by all households which appeals to their perception of fairness and hence raised the acceptability of a carbon tax. Society tends to place trust in government and public utilities like water companies for climate change information but not in business and industry to the same extent. Another reason cited by this study is mental accounting, a psychological phenomenon, which explains why people's WTP and acceptability for an essential expenditure like the water bill rather than non-essential spending which voluntary carbon offsets entail. The high public stated WTP in this study suggests a socially acceptable carbon tax and an opportunity for a large consumer surplus. In the case of mandatory contributions, when benefits are perceived to be high and environmental improvements are considered, stated WTP tends to be higher (Tsang and Burge, 2011).

4. Discussion

A review of the valuation methodologies indicates that there is no single carbon price (Table 1). The prices and costs of carbon sequestration vary with valuation methodologies and methods of carbon sequestration. Carbon prices also vary across countries and markets with several technological, regulatory, economic, and social factors influencing them.

There is a variation in the carbon price within each valuation methodology as discussed in section 3. Under ideal conditions carbon prices based on different methodologies should be the same but are not so in the real world. The variation in carbon prices across different methodologies used is because some valuation techniques reflect the maximum WTP of consumers while other techniques represent the marginal costs of supplying carbon sequestration service. On the demand side, the consumer price (WTP) for carbon is estimated by the market price method, stated preference approach and damage costs studies (marginal damage costs or SCC). The market prices for carbon range from $6.86/tC (RGGI) to $75.24/tC (EU ETS). The social cost of carbon ranges from $ 9/tC to $50/tC. On the supply side, the producers' cost is estimated by damage avoidance approach which generates marginal abatement costs. Marginal abatement costs vary from $70/tC to $616.17/tC. A comparison of prices across the valuation methodologies shows that the price estimates based on the two demand-side methodologies, marginal damage costs and the revealed market methods, especially based on the European markets, are in the same ballpark. The US market prices are relatively low. However, the prices based on the supply-side of the market or the damage avoidance costs are much higher than the demand-side market prices. This indicates that the consumers participating in the carbon market are probably not in the position or not willing to pay a full price for carbon as yet.

Social costs of carbon and marginal abatement costs estimate carbon prices in the context of climate change effects on ecosystems, often using Integrated Assessment Models. These models use economic tools and mathematical modeling to combine scientific knowledge on climate change and socio-economic aspects of economic growth under possible climate change scenarios. The presence of uncertainties regarding key parameters of climate change models and the kind of model used to estimate carbon prices contribute vastly to the conundrum. In addition, the complexity and non-linearity of ecosystem services and functions make it difficult to arrive at stable estimates for carbon price. Uncertainties about climate change will reduce over time as we learn more about the precise nature of benefits and costs involved. Dietz and Fankhauser (2009) recommend the use of marginal abatement costs of carbon over social costs of carbon because of the higher range of uncertainty observed in estimates for the latter.

The logical question that arises is why prices for carbon are relatively low in the current fledgling carbon markets. The formation of an extensive global network of stable carbon markets alone can reflect the true demand for carbon sequestration and storage among the public. However, the underlying fact is that this regulating service provided by mangroves is a public good which is non-rival and non-excludable. Public goods governed by property rights fit into conventional markets less than perfectly, which not unsurprisingly, are unable to convey the real price for carbon. The evolution of carbon markets that gives rise to a strong and stable price for carbon will decidedly take longer but in the meanwhile the present values are extremely helpful for effective management. In addition, the market price for carbon is representative of few players in society. As knowledge and significance of carbon sequestration and storage grows among the general public, so will its value. The uncertainties associated with climate change gives rise to variable perceptions about the impacts of global warming among societies which is reflected in the value they attach to carbon. These perceptions are likely to undergo gradual transformation with increasing evidence of climate change and manifest themselves in the form of evolving carbon markets and stable carbon prices. In other words, people's willingness to pay will correspondingly increase with their conviction that carbon sequestration by mangrove forests will give them significant and tangible benefits.

Note that the actual market price for carbon varies substantially between markets, especially between European markets, US markets and other voluntary markets such as REDD. The European market prices are perhaps higher due to the mandatory nature of the market. The EU ETS qualifying carbon emission reduction or carbon sequestration projects are more regulated and are subject to stringent verification requirements. However, the carbon credits generated out of the voluntary market may not have similar verification requirements.

Consequently the decision on what carbon price should be adopted by environment policy depends on the stage of the policy cycle. The expected progression of price setting as indicated by economic analysis evolves from the use of social costs of carbon to marginal abatement costs and then to the use of shadow prices in a nation's environmental policy (Dietz & Fankhauser, 2009). In the long term, stable and robust prices from evolving carbon markets become reliable indicators of carbon price that can be adopted by policymakers. Countries that have no set policy for greenhouse gas emissions reduction measures in place rely on social costs of carbon which enable the setting of environment protection targets. On the basis of the targets thus set, abatement costs can be calculated. In order to establish carbon markets several regulatory, institutional and technological factors come into play without which an efficient carbon market is not possible. In the meanwhile, stated valuation methods can be very useful to guide decisions on carbon price as they reveal the au courant value that people attach to carbon. A significant number of well-designed regional surveys based on stated valuation approach in communities influenced by presence of mangroves can reveal preferences of relevant stakeholders and aid in estimation of an appropriate carbon price.

Factors influencing the pricing mechanism for mangroves

In addition to the regulatory and economic reasons for carbon price variance discussed above, there are several biological reasons that might influence the carbon price. When setting the price for carbon sequestered and stored in mangroves, it will also be appropriate to pay attention to (a) The geological age of the forest: a mature, intact mangrove forest has more interconnectivity, functional redundancy and offers a variety of ecosystem services in comparison to younger, single species plantations. An older forest has a higher monetary value (Nickelson, 1999 as cited in Alongi, 2011) and hence should be valued using relevant methodology. In the case of mangrove plantations, carbon payments are made using net sequestration rates within the framework for REDD+ or payments for ecosystem services (PES). In the case of mature, older forests, payments made for sequestration rates as well as the geological carbon stored may be appropriate. (b) The sequestration abilities of mangroves are non-linear and vary with time and space as discussed in section 2. Carbon payments have to take into account the variable nature of this dynamic ecosystem. (c) Status of the forest as a protected area: protected areas are designated for the main purpose of conservation of biodiversity but they also regulate climate through carbon storage (Campbell et al., 2008). As a result of limited or no extractive uses, forests in protected areas become significant sinks of carbon. Accounting for carbon stocks in a nation's protected areas is recommended for payment for these existing sinks of carbon based on opportunity costs. The valuation of carbon sequestration and storage services in protected areas depends on the magnitude of carbon stored, the level of management and enforcement of a protected mangrove forest, amount of resource use permitted, the governance and land use change pressures determine the capability of the system to store carbon (Campbell et al., 2008). For instance, the mangrove forests in Everglades National Park, Florida have not been subjected to extractive uses for a long period of time. The magnitude of carbon stored in these forests is expected to be significant in comparison to mangrove forests in developing countries that face constant pressures of human activities despite being designated as protected. Protected areas that lie in more restrictive IUCN management category (e.g. categories I-II) are more effective in reducing deforestation although more research is required to state whether such areas store more carbon (Clarke et al. 2008). However, it must be noted that protected areas too face the problem of leakage wherein deforestation within their boundaries is avoided but pressures of deforestation are displaced elsewhere. Mangroves in protected areas can be significant sinks of carbon, but they require being economically valued so that they can be effectively managed. The recent economic downturn has affected the amount of funding allocated towards management of protected areas and hence sources of sustainable financing are required.

5. Conclusion

In conclusion, there are there are a number of factors why various valuation methodologies result in different price estimates for forest-sequestered carbon in general and mangroves-sequestered carbon in particular. There are considerable differences in what is being valued by each valuation methodology. While some techniques focus on what benefits consumers might derive from sequestering carbon, others provide estimates of the costs of supply of carbon sequestration. The consumers' willingness to pay estimates may rely on the actual revealed market prices or damage costs. We find that prices based on these two methodologies provide more robust estimates, although prices remain weak in markets not well regulated or voluntary in nature. Carbon prices based on the marginal costs of supply are too large indicating that existing markets may not have fully developed to adequately pay a full cost for carbon sequestration. Extrapolating the existing prices to mangroves require additional considerations such as biology, age, ecology and geographic factors.

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Appendix

Table 1: Carbon prices based on different valuation methodologies.

Valuation Method	Type	Source	Original costs	\$/tC	Year		Average price \$/tC
Market Price							
	Regulatory	EU ETS	\$18-\$23/tCO_2	66.06-84.41			75.24
		EUAs	\$15.37/tCO_2	56.40			56.40
		CDM	\$9-\$16/tCO_2	33.03-58.72			45.88
		Secondary CERs	\$10.83/tCO_2	39.75			39.75
		RGGI	\$1.87/ tCO_2	6.86	2010		6.86
	Voluntary	VERs	\$6/ tCO_2	22.02	2010		22.02
		REDD	\$5/ tCO_2	18.35	2010		18.35
Damage avoidance							
	MAC	Tol 2006		95.2	2050 (projection)	For target CO_2 concentration of 500ppm	95.2
		Kuik et al. 2008	€13-€119/tCO_2	65-596	2025 (projection)		330.5
			€34- €212/ tCO_2	170.32-1062.02	2050 (projection)	Globalized MAC	616.17
		Stavins & Richards 2005		70	1997	(500 mill. ton/year) Forest based sequestration	70
Damage costs							
	SCC	Tol 2005		50	2100 (projection)		50
		Nordhaus 2007		28		DICE-2007	28
		Chiabai, 2007		9	2007	Assuming 30% reduction in emissions by 2050	9
		CASES		32.4	2050		32.4
		Tol 2009		\$25 Modal value \$50 Mean value	1995 dollars	Meta-analytical study	25
Stated Valuation							
		Tsang & Burke, 2011	£135-£333/tCO_2	\$789.32-\$1946.98	2011		1368.30