Journal of Sustainability Science and Management *ISSN: 1823-8556*
Volume 11 *Number* 1, June 2016: 14-28

ECONOMIC VALUATION OF SOIL CARBON SEQUESTRATION SERVICES IN MALAYSIA'S FOREST SECTOR: A REVIEW OF POSSIBLE APPROACHES

CHAMHURI SIWAR[1*], AHMED ABDULLAHI CHINADE[1,2], SHAHARUDDIN MOHAMAD ISMAIL[1] AND ANIZAN ISAHAK[3]

[1]Institute for Environment and Development, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor. [2]Department of Environmental Management Technology, Abubakar Tafawa Balewa University Bauchi, Nigeria. [3]Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor.

**Corresponding author: csiwar@ukm.edu.my*

Abstract: The carbon in the soil of tropical forest ecosystems, such as Malaysia, is substantial and plays a key role in climate mitigation and enhancing forest health and productivity. The measurement of soil carbon stock and estimation of its economic value is, therefore, essential for accurate reporting of national carbon inventories, conservation and policy making decisions. However, research on the economic valuation of carbon in the Malaysian forest sector concentrate on the carbon in biomass and neglect the contribution of soil carbon, despite the significant amount of carbon held in the soil. A useful approach to economic valuation of soil environmental services is by determining their benefits and costs to the society. Fundamentally, the soil serves as a carbon sink, in the case of sequestration and carbon source, in an event of mineralization or decomposition of organic matter. Another approach is to quantify the services rendered by organic matter (greater percentage of which is organic carbon) in improving soil quality. This paper reviews some economic valuation methods in the literature for the purpose of valuing soil carbon and sequestration services and have categorised them into 'climate mitigation-based methods' and 'soil quality-based methods'. The review identified wide variations in economic values of carbon stock and carbon dioxide emission. The uncertainties associated with estimates obtained by applying most of the existing methods are also highlighted. The soil quality-based methods are specific to the agricultural ecosystem and need to be modified to suit peculiarities of the forest ecosystem. The review has provided opportunity for taking informed choices in selecting appropriate valuation method(s) of valuing soil carbon and sequestration services in the forest ecosystem. This study concludes by recommending the use of market price method as a convenient method for valuing soil carbon sequestrations services in the Malaysian forest sector.

Keywords: Climate change mitigation, soil quality, soil carbon, carbon sequestration, economic valuation, forest ecosystem.

Introduction

Economic valuation of critical ecosystems services such as soil carbon sequestration is necessary for accurate reporting of national carbon inventories by parties to the United Nations Framework for Climate Change (UNFCC). It is also required for carbon trading, conservation and management of the soil resources. Globally, the soil contains 1550 Pg carbon. This figure doubles the amount of carbon found in the atmosphere (760 Pg C) and triples biotic carbon pool (560Pg C) (Lal, 2004). The soil is believed to account for an average of 85% total carbon in boreal forests, 60% in temperate forests and 50% in tropical forests (Dixon *et al.,* 1994). The forest ecosystem makes a significant contribution to the Malaysian economy over the years. However, research on the economic valuation of carbon in the Malaysian forest sector concentrate on the carbon in biomass and neglect the contribution of soil carbon, despite the significant amount of carbon held in the soil (Abdulrashid *et al.,* 2009; Ismariah & Ahmad, 2007, Kumari, 1995; Ismail, 1995; Vincent, 1993).

This paper highlights the importance of economic valuation of soil carbon storage and sequestration services in the forestry sector of Malaysia. It also appraises the various valuation methods and approaches that could be used in valuing the soil carbon sequestration services.

Previous Studies on Economic Valuation of Carbon Sequestration Services in the Malaysian Forest Sector

Few studies were conducted to estimate the economic value of carbon sequestration services in the Malaysian forest ecosystem. Despite an increasing emphasis on adoption of sustainable forestry practices, mitigation of greenhouse gases in the terrestrial sectors and the need for diversification of economic opportunities.

Even among these few studies, none have included the contribution of soil carbon sequestration services despite the enormous quantity of soil carbon in the forest ecosystem (Abdullahi *et al.,* 2015). Some of these studies are reviewed below.

Vincent *et al.* (1993) quantified the forest carbon stock using estimates of physical timber stocks and flows in the timber accounts. The timber quantities were first converted to biomass by using existing conversion factors and then the biomass weights were converted to carbon by dividing by 2 (based on methods described by Brown *et al.,* 1991). They obtained the cost of carbon from estimates of carbon taxes needed to stabilize CO_2 emissions in the United States (US) by the year 2020 (Jorgenson & Wilcoxen 1990); and then discounted it to US$ per ton at 1989 price levels. The carbon taxes used ranged from a high user end scenario of US$60.09 per ton (in 2020), discounted at 4% to a low user cost of US$8.55 per ton (in 2020) at a discount rate of 10%. Based on the above assumptions, they estimated the economic value of forest carbon for Peninsular Malaysia at 500 million (at high user cost scenario) to 800 million (at low user cost scenario) (Vincent *et al.,* 1993).

Kumari (1995) used the damage cost avoided method to value the carbon stored in North Selangor Peat Swamp Forest in Peninsular Malaysia. She determined the value of carbon stock and active sequestration of carbon at the 'study site' under sustainable and unsustainable scenarios using forest inventory data. Firstly, the total physical stock and corresponding carbon stock changes under the different scenarios were determined and then the damage cost avoided approach was used to value the carbon stock afterwards. Results showed that the NPV of carbon under unsustainable option ranges from RM 8,011/ha and RM 7,080/ha under 20% and 50% damage levels; while under the sustainable scenario RM8, 677/ha and RM 8, 049/ha were recorded. The estimation was done using a discount rate of 8%. However, this estimation and valuation were for the carbon in biomass only, and it excludes the carbon in the soil.

Ismail (1995) examined 3 forestry options for their roles in carbon sequestration and concluded that forest plantation sequesters the highest amount carbon per unit area and that natural forests managed for sustainable timber production are the cheapest option for per unit area carbon sequestered. He also recommended that policy for carbon sequestration in forestry should be pursued simultaneously with existing efforts to satisfy the future demand for forestry goods and services, financial resources, technology and human resource development.

In a recent study, Ismariah and Ahmed (2007) used the market price method to value C stock in Ayer Hitam Forest Reserve (AHFR), Peninsular Malaysia. They found that the aboveground and belowground C stock ranged from 104 to 111 t ha^{-1} (estimated by dividing the biomass of 209 to 222 t ha^{-1} by 2). Carbon accumulated in the system at the rate of 4 to 6.5 t ha^{-1} yr^{-1} and the value of C stock ranged from RM 1,654 ha^{-1} to RM 20,800 ha^{-1} (estimated by using the weighted average carbon price ranging from US$ 4.00 t^{-1} to US$ 50 t^{-1}) (Ismariah & Ahmad, 2007). They concluded that the value of C sink at AHFR ranged from

RM2.06 to 25.96 million and that carbon is sequestered at the rate of RM 0.87 to RM 1.45 million per year.

All these studies have failed to recognize or include soil carbon in the valuation process citing difficulties in measurement of the soil carbon stock or assuming the soil carbon stock to be inconsequential.

Malaysia's Forest Sector and Soil Resources

Malaysia has vast forested land that have the potential for sequestering carbon both in biomass and in the soil. The long history of logging activities means that there are degraded areas that could be reforested for carbon sequestration. The total land area of Malaysia is estimated at 32.85 M ha (or 329, 758 km^2). The forested area accounts for 17.77 M ha, and non-forested area constitutes the remaining 15.08 M ha (Ministry of Natural Resources and Environment, 2011). The natural forests occupy about 54% of the total land area. Table 1 shows the distribution of forest areas in Malaysia.

Carbon Stock in Forest Soils

The soil contains two-thirds of the total terrestrial carbon pool estimated at 1500 Gt C at the global level (Lal, 2004). In the forest ecosystem, carbon is stored mainly in biomass and soil. The carbon found in the soil plays a significant role in the global carbon cycle owing to the large expanse of the forest ecosystem estimated to cover 4.1 billion hectares (Dixon & Wisniewski, 1995). Globally, the forest ecosystem contains about 1,240 Pg C (Dixon *et al.,* 1994). Out of this amount, the vegetation provides about 536 Pg C while the soil is believed to contain up to 704 Pg of C. This clearly indicates that there is more carbon in soil than in the vegetation at the global scale.

In Malaysia, Saner *et al.* (2012) reported that the soil contains 23.5% of the carbon in Malua Forest Reserve, Sabah Malaysian

Table 1: Distribution of forest areas in Malaysia

Region	Land Area	Natural Forests			Total Forested Land	% of Total Land Area
		Dry Inland Forest	Swamp Forest	Mangrove Forest		
Pen. M'sia	13.18	4.58	0.24	0.10	5.86	44.4
Sabah	7.37	3.17	0.12	0.32	3.61	49.0
Sarawak	12.30	7.98	1.12	0.14	9.24	75.1
Malaysia	32.85	15.73	1.48	0.56	17.77	54.1

Sources: Forestry Department Penisular Malaysia (2011), Sabah Forestry Department (2011), Forest Department Sarawak (2011)

Table 2: Percentage organic carbon in soil in forest ecosystems as reported by different authors

S/N	Source	Percentage organic carbon in soil of forest ecosystems
1	FAO, 2001	36% (Tropics)
2	Dixon et al., 1994	40% (Global)
3	Jobaggy and Jackson, 2000	43% (Global)
4	FAO, 2006	45.6% (Tropics)
5	Saner *et al.,* 2012	23.5% (Sabah, Malaysia)
6	Neto *et al.,* 2012	52% (Selangor, Malaysia)
	Average	40.625%

Source: Abdullahi *et al.* (2015)

Borneo. Neto *et al.* (2012) also reported that the soil holds 17% (at 30cm depth) to 52% (at 3m depth) of total carbon in Ayer Hitam Forest, Selangor, Peninsular Malaysia. Table 2 demonstrates the percentage organic carbon in soils of forest ecosystems as reported by different authors.

Although found in abundance, soil carbon in natural forests is highly susceptible to depletion due to natural and anthropogenic factors. Naturally, a reduction in biomass (above and below ground) returned to the soil, changes in soil moisture and temperature regimes and degree of decomposability of soil organic matter will markedly deplete soil carbon stock (Post & Kwon, 2001). Also, converting natural forests to agriculture depletes the soil organic carbon by as much as 20-25% (Lal, 2005). Deforestation is reported to emit about 1.6-1.7 Pg C/year (about 20% of anthropogenic emission) (Watson *et al.,* 1995; IPCC 2001).

The Role of Soil Carbon in Forest Ecosystem

Soil carbon plays significant roles in the forest ecosystems by mitigating climate change and enhancing forest health and productivity. The soil sequesters carbon in long-lived pools thereby reducing the amount that is present in the atmosphere (Stockmann *et al.,* 2013; Lal, 2004; Post & Kwon, 2000; Guo & Gifford, 2002; Smith, 2008).

Apart from reducing the concentration of greenhouse gases (GHGs) in the atmosphere, soil carbon sequestration also improves forest health and productivity through the influence of organic matter. The organic matter (>50% made up of organic carbon) improves soil's structural stability, water-holding capacity, nutrients availability and create favourable environment to soil organisms (Lal, 2004).

Soil carbon can be significantly depleted by poor and unsustainable silvicultural practices that may also increase the emission of carbon dioxide to the atmosphere.

Valuation of Soil Environmental Goods and Services

The soil, being an important component of the forest ecosystem, generates a number of ecosystem services. Some of these services include provision and recycling of nutrients vital for plant growth, flood and erosion control, water purification, substrate for soil organisms and carbon sequestration. However, the soil also generates dis-services through natural processes or anthropogenic activities. Some of these dis-services include loss of nutrients, flooding, and carbon emission. The economic benefits of these services (ES) and costs of the dis-services (EDS) are realized or appreciated through economic valuation. The soil generated ES and EDS have different types of economic values and, therefore, different techniques are required to value them.

Previous research on the valuation of soil services were primarily focused on determination of the cost of erosion (Ribaudo *et al.,* 1989; Dragovich, 1990; Whitby & Adgers, 1996). The cost estimates are believed to be an accurate reflection of the values of 'soil quality' (Harris *et al.,* 2006). However, specific valuation of soil EGS (such as nutrient, water and carbon cycling) are few in the literature (Bateman, 2000); although some studies provided hints of values of some soil ecosystem services as part of global ecosystem services (such as Constanza, 1997; Nunen, 2001 in Harris *et al.,* 2006).

Since there is more carbon in the soil than in the atmosphere and terrestrial biomass, globally, there is a compelling need for estimating the value of soil carbon stock and sequestration services for proper management of the soil resource and for policy decisions.

The economic value of soil is determined by its benefits to the society. These benefits can be captured in people's willingness to pay for enjoying the soil's EGS. However, some of these benefits are not traded in formal markets because they do not have market prices. Examples include landscape and biodiversity services. The values of these services are difficult to measure due to the absence of market prices. To get their values, therefore, different types of techniques are used in valuing them depending on the situation (Garrod & Willis, 1999; Pearce *et al.,* 2006; Harris *et al.,* 2006).

Valuation of Carbon Stock and Sequestration in Forest Soil

Carbon dioxide is a major greenhouse gas (GHG) that damages the global environment. Carbon storage and sequestration in soil benefit the society by reducing the quantity of carbon in the air. The economic value of soil carbon, therefore, arises from the carbon storage and sequestration services rendered by the soil resource that lead to a reduction of the amount that could be found in the atmosphere. Conversely, the release of carbon held in the soil through mineralization and decomposition as a result of anthropogenic activities such as deforestation increase the atmospheric carbon dioxide that may exacerbate the consequences of climatic changes. The services rendered by organic matter (greater percentage of which is organic carbon) in improving soil quality can also be quantified to get the value of soil carbon.

In estimating the economic value of soil carbon storage and sequestration, a number of methods have been used in different studies found in the literature. In this paper, we categorize these methods into climate mitigation-based methods and soil quality-based methods. The next section provides a brief overview of some of these methods and reports the findings of some few studies that have attempted to estimate the economic value of carbon, with emphasis on the forestry sector.

Alternative Methods of Valuing Soil Organic Carbon

1. *Climate Mitigation-based Methods*

a. *The Damage Cost Approach*

The economic value of soil carbon can be estimated by using the damage cost approach. This approach is based on the idea that benefits and cost of carbon sequestration or emission, to the society, is tied to the effect of carbon in the soil or the atmosphere. In this approach, the welfare loss resulting from damage caused by climate change is estimated and considered as the economic value of carbon.

Under the damage cost method, the economic value of carbon is determined by estimating the social cost of carbon (SCC). SCC is a measure of the economic benefits of greenhouse gas (GHG) emission reductions (Tol, 2005, 2008; Nordhaus, 2008; Hope, 2006, 2008; Anthoff *et al.,* 2009a, b; Newbold *et al.,* 2011). It is considered as the marginal social damages of an additional unit of carbon dioxide emissions to the environment or society. In view from a welfare perspective, it represents the marginal social benefits of emission reduction. According to Newbold *et al.* (2011), the SCC is the correct 'shadow price' to place on GHG emissions in a benefit-cost or social welfare analysis of climate change policies. Brainard *et al.* (2006) described it as the benefit in savings from damage avoidance and succinctly call it social value per tonne of sequestered carbon (svtC).

SCC is based on the concept of expected utility theory and social welfare function (SWF) (Newbold *et al.,* 2011). The SWF ranks the desirability of market goods and services that may contribute to people's well-being in the society' (Newbold *et al.,* 2011). SCC is the defined as the incremental cost to society of one metric ton increase in carbon emissions (Yohe *et al.,* 2007).

There are two variants of this approach, namely: the enumerative and statistical approach (Mc Nally & Shahwahid, 2003). The enumerative approach (Nordhaus, 1994a; Fankhauser, 1994; Tol, 1995, 2002) uses climate impact models and laboratory experiments to ascertain the physical effects of climate change and then assign prices to these effects. Under the statistical approach, variations in prices and expenditures of environmental goods and services over space and time are measured and used in estimating the effects climatic changes on human welfare (Tol, 2009).

The valuation, under the damage cost approach, is carried out by determining the marginal damage cost; which is defined as the net present value of incremental damage caused by a small increase in CO_2 emission (Tol, 2006). The marginal increases in emission is regarded as equivalent to the damage caused by emission to the environment or society (Jerath, 2012).

The marginal damage cost is calculated by using a family of models jointly referred to as integrated assessment models (IAMs). These include: MERGE (Model for Estimating the Regional and Global Effects of GHG Policies), IMAGE (Integrated Model to Assess the Greenhouse Effect), CASES (Cost Assessment for Sustainable Energy Systems), FUND (Climate Framework for Uncertainty Negotiation and Distribution Model) (Tol, 2002a, b; Anthoff *et al.,* 2009a, b; Tol, 2009) and DICE (Dynamic Integrated Climate Economy Model) (Nordhaus & Boyer, 2000; Nordhaus, 2008; Jerath, 2012). Others include the 'Policy Analysis of the Greenhouse Effect" (PAGE) model (Hope, 2006; 2008) and the "World Induced Technical Change Hybrid"(WITCH) model (Bosetti *et al.,* 2007). These IAMs use socioeconomic and geophysical data to assess the different policy options for controlling climate change (Ding *et al.,* 2010). IAMs have been criticised in some quarters for their lack of influence on policy debates as most of the assumptions driving the models are not clear enough (Kelly & Kolstad, 2000 in Newbold *et al.,* 2011). Some estimated values of marginal damage costs obtained using some of these models are provided in Table 2.

Some Applications of the Damage Cost Method:

Brainard *et al.* (2009) estimated the economic value of carbon storage in British woodlands by developing a model to calculate the rates of (marginal) carbon storage/emission in biomass and soil. They used map databases to determine C gains/losses and monetized C flux with a social value per tonne of carbon (svtC) of $ 10 per of carbon sequestered at a discount rate of 3.5%. The result, expressed as net present value (NPV) in the base year, 2001, was $82 million.

In another study based on the RICE model, Nordhaus *et al.* (2011) estimated the SCC for 2015 at $44 per tonne of carbon (or $12 per tonne of CO_2e) after accounting for uncertainty, risk aversion and assigning equity weighting.

In a meta-analysis study involving 28 publications on SCC, Tol (2005) found 103 different estimates of the SCC ranging from $5-$104/tC demonstrating the large uncertainties in the estimates by different studies. However, he noted that the large estimates are associated with the gray literature and that estimates reported in peer-reviewed studies are more conservative. He also established that the pure rate of time preference or the discount rates are the primary determinants of the SCC values. The lower the discount rate, the higher the estimates and greater the uncertainties (Tol, 2005). Studies using a discount rate of 4-5% reported SCC estimates ranging from $16-$62 per tonne of carbon (Tol, 2005). He concluded that the SCC is not likely to exceed $50/tC.

However, the damage cost method is characterized by uncertainties associated with estimation and forecasting. According to Clarkson and Deyes (2002), these uncertainties can be broadly classified into scientific and economic. Scientific uncertainties refer to uncertainties encountered in estimation and forecasting future CO2 levels, measuring the physical damage caused by climate change. Economic uncertainties, on the other hand, refer to equity weighting and the discount rate used in monetizing future emissions (Nocera & Cavallaro, 2012).

b. The Cost of Damage Avoidance Method

This approach is based on estimating the opportunity cost of preventing adverse impacts of carbon emission on the environment and the society (Dietar & Elasser, 2002). The opportunity cost is the net benefit forgone in order to avoid the negative environmental impact from carbon emission. The cost of damage avoidance is calculated by determining the marginal abatement cost (MAC) which measures welfare benefits derivable from emission trading (Jerath, 2012). Estimates of MAC depend on the type of models, assumptions and stabilization targets used (Kuik *et al.,* 2009).

Several metrics are used in determining the stabilization targets. The standard metrics include radiative forcing ($W m^{-2}$), the concentration of greenhouse gas CO_2 (ppm CO_2) and global mean temperature (^oC) (Kuik *et al.,* 2009).

Some Application of the Damage Cost Avoidance Method:

In a review of several studies on carbon sequestration in the United States, Stavins and Richards (2005) estimated the marginal cost of forest-based carbon sequestration in the United States at $70 per ton of carbon based on 5% discount rate.

Kuik (2008), using a stabilization target of 550 ppmv, estimated an 'idealized global MAC' at €37-€119/tCO_2 in 2020 to €79-226/tCO_2 in 2050 with an average of €204/tCO_2 in 2010. While a range of €69-€241/ tCO_2 in 2020 to €128-€396/ tCO_2 in 2050 was estimated for the 450 ppmv stabilization target.

Another study by Tol (2006) based on FUND 2.9 model, estimated the MAC for CO_2 in 2050 at $ 95.0/tC ($14/tC for 2010) at a stabilization target of 500ppm (Jerath, 2012). Fisher and Nakicenovic *et al.* (2007) reported an estimated MAC at $125/tC (for the year 2010). Additional examples of MAC estimates are provided in Table 2.

c. *Market Price Method:*

Another widely adopted method of valuing carbon is the use of prevailing market price for carbon. Carbon markets exist on demand and supply stimulated by number of regulatory and fiscal measures. The price of a tonne of carbon (or tCO2e) in the markets reflects the willingness to pay by buyers and willingness to accept by sellers of carbon credit (Yee, 2010). Carbon markets are categorized into regulatory (mandatory or compliance) markets and voluntary markets

i. Compliance (Regulatory) Market: Is a carbon market that comprises legally-binding and mandatory emission trading schemes. This market is based on cap-and-trade system established under the auspices of the Kyoto Protocol. Participating countries are assigned with emission targets and allowances in the form of assigned amount units (AAUs).

   Under the Kyoto Protocol of the UNFCC, a cap and trade system is established under which Annex I countries are assigned with emission targets and corresponding number of allowances-called 'assigned amount units (AAUs)'. The cap mandates participating countries to reduce their emissions by 5.2% below their 1990 emission levels between 2008 and 2012. These targets are met under different flexible mechanisms. These mechanisms include:

a. Joint Implementation (JI): Trading between two Annex I countries and the trading units are called 'Emission Reduction Units (ERUs)'.

b. Clean Development Mechanism (CDM): Allows trading between Annex I and non-Annex I country. The trading units are called 'Certified Emission Reduction Units (CERs)'. According to the forest trend report (of ecosystem marketplace), the average price of carbon in 2013 at the CDM/JI compliance market was US$ 6.0/tCO_2e (Peters-Stanley *et al.,* 2014).

c. Land Use, Land-Use Change and Forestry (LULUCF): Facilitates trading of land and forestry-based activities that sequester carbon. The trading units are called 'Removal Units' (RUs).

d. Reducing Emission Deforestation and Forest Degradation (REDD+): Considering the fact that deforestation accounts for 17-20% of greenhouse gas emissions (Van der Werf *et al.,* 2009), the UNFCC Montreal Conference of Parties in 2005 proposed a carbon credit scheme for avoided deforestation called the Reducing Deforestation and Forest Degradation Plus (REDD+) (Jerath *et al.,* 2012). The REDD+ have the additional advantage over the original REDD by including biodiversity conservation and poverty alleviation (Yee, 2010). The REDD+ scheme, gives financial assistance to developing countries in exchange for adoption of a number of activities as follows: slowing down deforestations and measuring the progress of reference levels, reducing emissions from forest degradation, forest conservation through adoption of best management practices, sustainable forest management activities and enhancement of forest carbon stocks (Jerath *et al.,* 2012). The carbon price for REDD+ was $5/tCO2e in the voluntary market in 2010 (Peters-Stanley *et al.,* 2011).

From the foregoing description of the carbon markets, therefore, the value of carbon can be deduced by analysing the trend of carbon prices in compliance and voluntary markets in order to curtail climate change and enhance sustainable development.

ii. Voluntary Market: These markets operate outside the compliance market. It is run by NGOs, businesses, governments and individuals who want to offset their emissions by buying carbon credits (or offsets) that were created through the CDM or within the voluntary market. The trading units on the voluntary market are called 'Verified or Voluntary Emissions Reductions (VERs). The volume of transactions in the voluntary market is small compared with the regulatory market because the demand is created voluntarily and not enforced. The offset prices are also lower compared with that under the compliance markets because less strict verification standards. According to the forest trend report (of ecosystem marketplace), the average price of carbon in 2012 at the voluntary market was US$ 4.8/tCO_2e at the voluntary markets (Peters-Stanley *et al.,* 2014).

The use of market price to estimate the economic value of ecosystem service such as carbon sequestration is criticised for not truly reflecting the value of the ecosystem service in question (Ninan & Inoue, 2013; Jerath, 2012). The value of the ecosystem service estimated using market price may change if the quantity, incomes and prices of carbon changes (Ninan & Inoue, 2013b). In addition, using the high market price of carbon may lead to overestimation of the carbon sequestration services of the forests. It is, therefore, more prudent to use a conservative carbon price in deriving the economic value of C (Ninan & Inoue, 2013b; Pearce, 2001).

Some Application of Market Price Method in Valuation of Soil Carbon:

Ismariah and Ahmed (2007) estimated the economic value of biomass carbon, at Ayer Hitam Forest Reserve Malaysia. They found that the economic value of biomass carbon ranged from RM 1,654 ha^{-1} to RM 20,800 ha^{-1} (by using the weighted average carbon price ranging from US$ 4.00 t^{-1} to US$ 50 t^{-1}) (Ismariah & Ahmad, 2007). Ninan and Inoue (2013a) also used the carbon price and marginal social damage cost to value the carbon sequestration services rendered by Oku Aiza forest reserve in Japan. Using a carbon price range of US$4 to US$20, they estimated the economic value of carbon sequestration in forest soil at US$ 31.24/ha to US$ 156.2/ha respectively.

d. *Stated Preference*

The contingent valuation method was used by Li *et al.* (2004) to estimate the willingness to pay for greenhouse gas emission reduction in the USA. The results of the study revealed that households are willing to pay about $ 15/tC to prevent climate change. In another study, Tsang and Burke (2011) applied the choice modelling method to elicit willingness to pay a premium, by consumers on their water bills, in exchange for climate change improvement. The results revealed that, consumers were willing to pay £135-£333 per tonne of CO_2.

e. *Shadow Price of Carbon:*

Shadow Price of Carbon (SPC) is used in carbon policy appraisal and evaluation by governments. It is based on estimates of the lifetime damage costs associated with greenhouse gas emissions known as the social cost of carbon. The SPC is a reflection of climate change commitment goals set by a country's environmental policy. The SPC helps governments to evaluate the cost-effectiveness of their policies that affect the general welfare of the society (Jerath, 2012; Price *et al.,* 2007). The SPC for United Kingdom in 2007 was set at £25.5/tCO_2 based on Stern Review (2007) (Price *et al.,* 2007). Although now abolished, the Australian government also instituted a carbon tax of $87/tC ($23/tCO_2) based on the SPC in 2012.

2. *Soil Quality-based Methods*

Apart from the role of soil carbon in sequestering carbon and reducing the amount of CO_2 that could be available in the atmosphere, the soil also renders a number of ecosystem services that help in improving soil quality and productivity. A number of methods have been developed to value these services by several studies. This section reviews some of these studies.

a. Fertilizer replacement value: Used fertilizer prices to quantify inorganic N released following mineralization of SOM (Wander & Nissen, 2004).

b. The cost of removing topsoil and replacing it with a different quality top soil (Smith *et al.,* 2000). They found an on-site SOC value ranging from $1-$4 ton/C/ha/yr.

c. The opportunity cost of maintaining soil tilth by reducing tractor fuel consumption. Plots that have manure applied reduce tractor fuel consumption by 13-18% (McLaughlin *et al.,* 2002a).

d. Sperow (2005) estimated the value of carbon from soil sequestration and emission reductions from setting aside highly erodible land. The results show that carbon prices range of $51 to $1,912 (average US$286) per tonne based on land rental rates.

e. The value of carbon sequestered in the soil can also be determined by estimating the value of the marginal change in carbon stock as a result of land use or management change. To arrive at this value, the cost of management change can be divided by the quantity of additional carbon stored as a result of the change (Mark Sperow, pers. comm.).

Conclusion

Difficulties in the measurement of soil carbon and dearth of appropriate economic valuation methods specific to forest soil have led to omissions of soil contribution to forest carbon and sequestration services in most research. This omission is more pervasive in Malaysia as no previous work has attempted to value soil carbon and sequestration services in the forest ecosystem. This paper reviewed some economic valuation methods in the literature (for the purpose of valuing soil carbon and sequestration services in the forest ecosystem) and categorised them into 'climate mitigation-based methods' and 'soil quality-based methods'

From the review, it is found that the economic value of carbon under the damage cost approach ranges from the lower bound of US$1.1, reported by Hope (2008) to US$133/tC reported by Ding *et al.* (2010). The marginal cost of carbon ranges from US$70/tC reported by Richards and Stavins (2005) to US$204/$tCO_2$e reported by Kuik *et al.* (2008). The market prices range from the lower bound of US$4/tC reported by Ismariah and Ahmad (2007) to US$6/$tCO_2$e reported by Peters-Stanley (2014). The economic values of carbon under the soil quality-based approach also show a wide variation from US$1 reported by Smith *et al.* (2000) to US$286/tC reported by Sperow (2005).

The review identified wide variations in economic values of carbon and carbon dioxide. The paper also highlights the huge uncertainties associated with estimates obtained by applying most of the existing methods. The soil quality-based methods are specific to the agricultural ecosystem and need to be modified to suit peculiarities of the forest ecosystem. The review has provided an opportunity for taking informed choices in selecting appropriate valuation method for soil carbon and sequestration services in the forest ecosystem. Considering the complexities involved in application of the IAMs, it would seem that the market price method may be sufficient in valuing the soil carbon in the Malaysian forest ecosystem. The soil quality-based methods may not be convenient and could be quiet expensive under forest ecosystem. This paper therefore recommends the use of market price method as a convenient method for valuing soil carbon sequestrations services in the Malaysian forest sector.

Acknowledgements

The authors wish to acknowledge the support received from National University of Malaysia (UKM) through grant number UKM-AP-2011-24 and also ERGS/1/2013/SS07/UKM/01/1.

References

Abdullahi, A. C., Siwar, C., Shaharuddin, M. I., & Anizan, I. (2015). A Review on Carbon Sequestration in Malaysian Forest Soils. *International Journal of Soil Science,* 10: 17-27. ttp://scialert.net/current.php?issn=1816-4978

Abdul Rashid, A. M., Shamsudin, O., Ismail, P., & Fletcher, S. C. (2009). The Role of FRIM in Addressing Climate Change Issues. *Research Pamphlet No. 128*. Forestry Research Institute of Malaysia.

Anthoff, D., Hepburn, C. J., & Tol, R. S. J. (2009). Equity Weighting and the Marginal Damage Costs of Climate Change. *Ecological Economics*, 68(3): 836-849.

Bateman, I., & Lovett, A. (2000). Estimating and Valuing the Carbon Sequestered in Softwood and Hardwood Trees, Timber Products and Forest Soils in Wales. *Journal of Environmental Management*, 60(4): 301-323. http://linkinghub.elsevier.com/retrieve/pii/S0301479700903888 retrieved on January 2, 2015.

Bosetti, V., Massetti, E., & Tavoni, M. (2007). *The WITCH Model: Structure, Baseline, Solutions*. Climate Change Modelling and Policy working paper. http://www.transust.org/workplan/papers/model_descriptions/WITCH_TechReport.pdf retrieved on March 2015.

Brainard, J., Lovett, A., & Bateman, I. (2006). Sensitivity Analysis in Calculating the Social Value of Carbon Sequestered in British Grown Sitka Spruce. *Journal of Forest Economics*, 12(3): 201-228. http://linkinghub.elsevier.com/retrieve/pii/S1104689906000316 retrieved on January 2, 2015.

Brown, S., Iverson, L., & Lugo, A. (1991). Land-use and Biomass Changes of Forests in Peninsular Malaysia during 1972-1982: Use of GIS Analysis. *Effects of Land-use Change on Atmospheric CO_2 Concentrations. Southeast Asia as a Case Study*. (Ed. V.). Dale: Springer-Verlag.

Chiabai, A., Travisi, C., Ding, H., Markandya, A., & Nunes, P. A. (2009). *EconomicValuation of Forest Ecosystem Services: Methodology and Monetary Estimates*. 11th Annual BIOECON Conference on Economic Instruments to Enhance the Conservation and Sustainable Use of Biodiversity.

Clarkson, R., & Deyes, K. (2002). Estimating the Social Cost of Carbon Emissions. DEFRA. Government Economic Service Working Paper 140. ftp://131.252.97.79/Transfer/ES_Pubs/ESVal/carbon_val/clarkson_02_socialCostCarbon_ukgov140.pdf retrieved on December 2014.

Costanza, R. *et al.* (1997).The Value of the World's Ecosystem Services and Natural Capital. *Nature*, 387: 253-260.

Dieter, M., & Elsasser, P. (2002). Quantification and Monetary Valuation of Carbon Storage in the Forests of Germany in the Framework of National Accounting. (Institute for Economics Working Paper 2002/8). Hamburg, Germany: Federal Research Centre for Forestry and Forest Products, University of Hamburg.

Ding, H., Dias Nunes, P. A., & Teelucksingh, S. S. (2010). *European Forests and Carbon Sequestration Services: An Economic Assessment of Climate Change Impacts*. Rochester.

Dixon, R. K. *et al*. (1994). Carbon Pools and Flux of Global Forest Ecosystems. *Science (New York, N.Y.)*, 263:185-190.

Dixon, R. K., & Wisniewski, J. (1995). Global Forest Systems: An Uncertain Response to Atmospheric Pollutants and Global Climate Change. *Water Air Soil Pollut.,* 85: 101-110.

Dragovich, D. (1990). Does Soil Erosion Matter to People in Metropolitan Sydney? *Australian Journal of Soil and Water Conservation*, 3(1): 29-32.

Fankhauser, S. (1994). *Valuing climate change-the Economics of the Greenhouse*.London: EarthScan.

FAO. (2001a). Production Yearbook. Food & Agric. Organization, Rome, Italy. FAO. (2006). Global Forest Resources Assessment 2005: Progress towards Sustainable Forest Management. Food and Agriculture Organization, Rome, Italy, ISBN-13: 9789251054819, 320.

Fisher, B. S. *et al.* (2007). Issues Related to Mitigation in the Long Term Context. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Garrod, G. D., & Willis, K. G. (1997). The Non-use Benefits of Enhancing Forest Biodiversity: A Contingent Ranking Study. *Ecological Economics*, 21: 45-61.

Guo, L. B. & Gifford, R. M. (2002). Soil Carbon Stocks and Land Use Change. *Global Change Biol.,* 8: 345-360.

Harris, D., John, K., & Paul, N. (2006). *Economic Valuation of Soil Functions Phase 1: Literature Review and Method Development*, No. July. DEFRA Publication. http://www.cjcconsulting.co.uk/pdfs/FINALEcon%20Valuation%20of%20Soil%20Functions%20Rept%20Phase%20I_0806.pdf retrieved on 14th December 2014

Hope, C. W. (2006). The Marginal Impact of CO2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern. *Integrated Assessment Journal,* 6(1): 19-56.

Hope, C. W. (2008). Discount Rates, Equity Weights and the Social Cost of Carbon. *Energy Economics*, 30(3): 1011-1019.

IPCC. (2001). *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., ISBN-13: 9780521807678, 881.

Ismail, R. (1995). An Economic Evaluation of Carbon Emission and Carbon Sequestration for the Forestry Sector in Malaysia. *Biomass and Bioenergy*, 8: 281-292.

Ismariah, A., & Ahmad Fadli, S. (2007). Valuation of Carbon Stock and Carbon Sequestration in Ayer Hitam Forest Reserve, Puchong. *Pertanika Journal of Tropical Agricultural Science*, 30: 109-116.

Jerath, M. (2012). An Economic Analysis of Carbon Sequestration and Storage Service by Mangrove Forests in Everglades National Park, Florida. *FIU Electronic Theses and Dissertations.* Paper 702. http://digitalcommons.fiu.edu/etd/702

Jobbágy, E. G., & Jackson, R. B. (2000). The Vertical Distribution of Soil Organic Carbon and Its Relation to Climate and Vegetation. *Ecological Applications*, 10(2): 423-436.

Jorgenson, D., & Wilcoxen, P. (1990). Reducing U.S Carbon Dioxide Emissions: The Cost of Different Goals. Department of Economics, Harvard University. Unpublished. In: Vincent, J. R., Wan L. F, Chang, Y. T., Nooriha, M., & Davison, G. W. H. (1993). *Malaysian National Conservation Strategy-Towards Sustainable Development*. Volume 4: Natural Resource Accounting. Economic Planning Unit, Prime Minister's Department, Kuala Lumpur.

Kelly, D. L., & Kolstad, C. D. (1998). Integrated Assessment Models for Climate Change Control. In: Folmer, H. & Tietenberg, T. (eds). *International Yearbook of*

Environmental and Resource Economics 1999/2000: A Survey of Current Issues. Cheltenham, U. K.: Edward Elgar. http://www.econ.ucsb.edu/papers/wp31-98.pdf retrieved on November 2014.

Kuik, O., Brander, L., & Tol, R. S. J. (2008). *Marginal Abatement Costs of Carbon-dioxide Emissions: A Meta-analysis*. Economic and Social Research Institute.

Kumari, K. (1995). An Environmental and Economic Assessment of Forest Management Options: A Case Study in Malaysia. *Environmental Economic Series*. Paper No. 26. World Bank Publication. Washington D. C. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/1999/09/14/000178830_98101912360813/Rendered/PDF/multi_page.pdf retrieved on 9th May 2014.

Lal, R. (2004b). Soil Carbon Sequestration to Mitigate Climate Change. *Geoderma*, 123: 1-22.

Lal, R. (2005). Forest Soils and Carbon Sequestration. *Forest Ecology and Management*, 220(1-3): 242-258. http://linkinghub.elsevier.com/retrieve/pii/S0378112705004834 retrieved on July 11, 2014.

Li, H., Berrens, R., Bohara, A., Jenkins-Smith, H. C., Silva, C. L., & Weimer, D. (2004). Would Developing Country Commitments Affect US Households' Support for a Modified Kyoto Protocol? *Ecological Economics*, 48: 32-343.

McNally, R., & Shahwahid, O. H. (2003). *Environmental Economics: A Practical Guide*. WWF-UK and Universiti Putra Malaysia. ISBN 983-41144-0-0.

Neto, V., Ahmad, N. A. M., Wong, Y., & Ting, H. L. (2012). Contributions of Forest Biomass and Organic Matter to above-and below Ground Carbon Contents at Ayer Hitam Forest Reserve, Malaysia. *J. Trop. For. Sci.*, 24: 217-230.

Newbold, S., Griffiths, C., Moore, C., Wolverton, A., & Kopits, E. (2010). The 'Social Cost of Carbon' Made Simple. Environmental Protection Agency National Center for Environmental Economics. Working Paper Series No. 10-07. http://yosemite.epa.gov/EE/epa/eed.nsf/54e92d0d1f202a6885256e46007b104c/b462b207b25df29b852577770061d958/$FILE/2010-07v2.pdf retrieved on January 2015.

Ninan, K. N., & Inoue, M. (2013a). Valuing Forest Ecosystem Services: Case Study of a Forest Reserve in Japan. *Ecosystem Services*, 5: 78–87. http://linkinghub.elsevier.com/retrieve/pii/S2212041613000156 retrieved on January 2, 2015.

Ninan, K. N., & Inoue, M. (2013b). Valuing Forest Ecosystem Services: What We Know and What We Don't. *Ecological Economics*, 93: 137-149. http://linkinghub.elsevier.com/retrieve/pii/S0921800913001638 retrieved on July 11, 2014.

Nocera, S., & Cavallaro, F. (2011). Policy Effectiveness for Containing CO2 Emissions in Transportation. In *Procedia - Social and Behavioral Sciences*, 703-713.

Nordhaus, W. D. (1994a). *Expert Opinion on Climate Change*, American Scientist, Jan-Feb.

Nordhaus, W. D., & Boyer, J. G. (2000). Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol. *The Energy Journal*, 20(1):1-46. http://www.iaee.org/en/publications/ejarticle.aspx?id=1044

Nordhaus, W. D. (2008). *A Question of Balance - Weighing the Options on Global Warming Policies*. New Haven: Yale University Press.

Nordhaus, W. (2011). Estimates of the Social Cost of Carbon: Background and Results from the Rice-2011 Model. *Cowles Foundation Discussion Paper No. 1826*. Yale University.

Nunes, P. A. L. D., & Van den Bergh, J. C. J. M. (2001). Economic Valuation of Biodiversity:

Sense or Nonsense? *Ecological Economics*, 39: 203-222.

Pearce, D. W. (2001). The Economic Value of Forest Ecosystems. *Ecosystem Health*, 7(4): 284-296. http://doi.wiley.com/10.1046/j.1526-0992.2001.01037.x

Pearce, D., Atkinson, G., & Mourato, S. (2006). Cost-benefit Analysis and the Environment. OECD, Paris. http://www.lne.be/themas/beleid/milieueconomie/downloadbare-bestanden/ME11_costbenefit%20analysis%20and%20the%20environment%20oeso.pdf retrieved on March 2015.

Peters-Stanley, M., Gonzalez, G., & Yin, D. (2013). Covering New Ground: State of the Forest Carbon Markets. Forest Trend Report by Ecosystem Marketplace. http://www.forest-trends.org/documents/files/SOFCM-full-report.pdf retrieved on 25th September 2014.

Peters-Stanley, M., Goldstein, A., & Gonzalez, G. (2014). *Turning Over a New Leaf: State of the Forest Carbon Markets 2014*. A report by Forest Trend's Ecosyten Marketplace. Executive Summary. http://www.forest-trends.org/documents/files/doc_4771.pdf retrieved on February 2015

Post, W. M., & Kwon, K. C. (2000). Soil Carbon Sequestration and Land-use Change: Processes and Potential. *Global Change Biol.,* 6: 317-327.

Price, R., Thornton, S., & Nelson, S. (2007). *The Social Cost of Carbon and the Shadow Price of Carbon: What They are, and How to Use Them in Economic Appraisal in the UK*. London, UK.: Economics Group, Department for Environment, Food and Rural Affairs.

Ribaudo, Marc O., & C. Edwin Young. (1989). Estimating the Water Quality Benefits from Soil Erosion Control. *Water Resources Bulletin*, 25(1): 71-78.

Saner, P., Loh, Y. Y., Ong, R. C., & Hector, A. (2012). Carbon Stocks and Fluxes in Tropical Lowland Dipterocarp Rainforests in Sabah, Malaysian Borneo. *PloS one*, 7(1): 29642. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3250468&tool=pmcentrez&rendertype=abstract retrieved on November 25, 2014.

Smith, P. (2008). Land Use Change and Soil Organic Carbon Dynamics. *Nutr. Cycl. Agroecosyst*., 81: 169-178.

Smith, E. G. *et al*. (2000). Soil Quality Attribute Time Paths: Optimal Levels and Values. *Journal of Agricultural and Resource Economics*, 25: 307-324.

Sperow, M. (2005). *Estimating the Economic Value of Temporary and Permanent Carbon Sequestration Activities in Agricultural Land*. Paper presented at Southern Agricultural Economics Association Annual Meetings, Little Rock Arkansas. http://ageconsearch.umn.edu/bitstream/35493/1/sp04sp01.pdf retrieved on January 2014.

Stavins, R., & Richards, K. (2005). The Cost of U.S Forest-based Carbon Sequestration. Pew Center in Global Climate Change. http://www.c2es.org/publications/cost-us-forest-based-carbon-sequestration retrieved on December 2014.

Stockmann, U. *et al.* (2013). The Knowns, Known Unknowns and Unknowns of Sequestration of Soil Organic Carbon. *Agriculture, Ecosystems and Environment,* 164(2013): 80-90.

Tol, R. S. J. (2002). New Estimates of the Damage Costs of Climate Change: Part II. Dynamic Estimates. *Environmental and Resource Economics*, 21(1).

Tol, R. S. J. (2005). The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties. *Energy Policy*, 33(16): 2064-2074. http://linkinghub.elsevier.com/retrieve/pii/S0301421504001028 retrieved on December 29, 2014.

Tol, R. S. J. (2006). *The Costs of Greenhouse Gas Emissions.* Working paper No. 5.4/5.5-RS 1b. Hamburg, Germany: Hamburg, Vrije and Carnegie Mellon Universities.

Tol, R. S. J. (2008). The Social Cost of Carbon: Trends, Outliers and Catastrophes. *Economics,* Vol. 2. 2008-25. www.economics-ejournal.org/economics/journalarticles retrieved on December 2014.

Tol, R. S. J. (2009). The Economic Effects of Climate Change. *The Journal of Economic Perspectives*, 23(2): 29-51. doi:10.1257/jep.23.2.29.

Tsang, F., & Burge, P. (2011). Paying for Carbon Emissions Reduction. (No. OP12). Santa Monica, CA: RAND Corporation. http://www.rand.org/pubs/occasional_papers/OP312. retrieved on December 2014.

Van der Werf, G. R. *et al*. (2009). CO2 Emissions from Forest Loss. *Nature Geoscience*, 2: 737-738.

Vincent, J. R., Wan, L. F, Chang, Y. T., Nooriha, M., & Davison, G. W. H. (1993). *Malaysian National Conservation Strategy-towards Sustainable Development. Volume 4: Natural Resource Accounting*. Economic Planning Unit, Prime Minister's Department, Kuala Lumpur.

Wander, M., & Nissen, T. (2004). Value of Soil Organic Carbon in Agricultural Lands. *Mitigation and Adaptation Strategies for Global Change*, 9(4): 417-431. http://link.springer.com/10.1023/B:MITI.0000038847.30124.77.

Watson, R. T., Noble, I. R., Bolin, B., Ravindranath, N. H., Verardo, D. J., & Dokken, D. J. (2000). *Land Use, Land-use Change and Forestry*. Cambridge, UK: Cambridge University Press. ISBN-13: 9780521800839, 375.

Whitby, M., & Adger, N. (1996). Natural and Reproducible Capital and the Sustainability of Land Use. *Journal of Agricultural Economics*, 47: 50-65.

Yee, S. M. (2010). *REDD and BLUE Carbon: Carbon Payments for Mangrove Conservation*. (MAS Marine Biodiversity and Conservation Capstone Project). San Diego, CA: University of California, San Diego.

Yohe, G. W. *et al.* (2007). *Perspectives on Climate Change and Sustainability. Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge.