Carbon stock accounts

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A. Introduction

1. The draft System of Environmental-Economic Accounting (SEEA) Central Framework states that the SEEA Experimental Ecosystem Accounts will discuss a complete articulation of carbon accounting (UN Statistics Division 2011, para 5.390). It also noted that the underlying asset and physical flow accounting models are sufficiently well developed for carbon accounting purposes (para 5.390). Of particular importance for carbon accounting are the Central Framework's attention to mapping processes and technologies linked to discrete land area units (para 5.239); proposed land use and land cover classifications which also includes marine environments (para 5.243); comprehensive coverage irrespective of whether land is 'used' or not (para 5.250); forest classifications underpinned by ecosystem function (paras 5.277 – 5.279); physical asset accounts (para 5.282) and tracking carbon in timber resources (para 5.387). To advance the carbon accounts discussion, the Road Map (p. 16) sets tasks relating to data requirements, availability and gaps for compiling stock and flow carbon accounts globally. The Road Map (p. 13) also sought illumination on the need and policy application of ecosystem accounts, of which carbon accounts are one component.

2. This paper presents an articulation of carbon accounting from an ecosystem science perspective. It focuses on the stock account as a compliment to the flows inventories produced under the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol. The paper draws heavily on Blakers M[2]., Keith H[3]., Ajani J[3]., Mackey B.M[3]. and King H[3]. (in prep), A proposal for a comprehensive carbon accounting framework. Issues for consideration are presented at the end of the paper.

B. Carbon Accounting Today

B1. UNFCCC and Kyoto Protocol

3. The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to limit atmospheric stocks of GHG and achieve '*... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*' (Article 2, United Nations, 1992). Article 3 states that policies and measures to deal with climate change should be '*comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors*'. The UNFCCC is implemented through the Kyoto Protocol for ratified Parties (United Nations, 1998).

4. Through Reducing Emissions from Deforestation and forest Degradation (REDD+), the UN also encourages developing countries, which may not be party to the Kyoto Protocol, to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. Incentives are based around the financial value of the carbon stored in forests.

5. Under the UNFCCC and Kyoto Protocol, countries submit national GHG inventories (NGGI) to the Climate Change Secretariat (UNFCCC, n.d., a). For countries that have ratified the Kyoto Protocol, they are the basis for assessing compliance with emission reduction targets. NGGI for the UNFCCC and the Kyoto Protocol can differ for a country depending on whether optional Articles in the Kyoto Protocol have been elected. NGGI use standard methodologies for the '*estimation and reporting of greenhouse gas emissions and removals*' (IPCC 2003, IPCC 2006): inventories present flow information. NGGI reports use sectors and categories based on the human activities giving rise to emissions and removals. Net emissions are converted to a common unit of tonnes of CO_2 equivalent calculated on the basis of the gases' global warming potential.

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6. In UNFCCC inventories, the land sector is divided into six categories: Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land (marine ecosystems are not included). Land can remain within a category or be converted from one category to another through land use change. Parties are required to report net emissions from managed lands, considered to be due to anthropogenic activities, while emissions and removals for unmanaged lands are omitted. In the Kyoto Protocol, the land sector is divided between two Articles on the basis of activities rather than areas. Under Article 3.3, it is mandatory to report emissions from land use change and direct human activities in the form of reforestation, afforestation and deforestation. Management of forest, crop and grazing land and revegetation are elective under Article 3.4.

7. The frameworks, concepts, definitions and standards for NGGI are the domain of the IPCC, an intergovernmental body whose membership is open to all UN and World Meteorological Organization member countries.

B2. Other organisations

8. Organisations other than the UNFCCC collect data on GHG emissions (UNFCCC, n.d., b). The Global Carbon Project (2003, 2011) aims to develop a complete budget of the global carbon cycle, including geographical and temporal variations in the major pools and fluxes. It uses data from measurements and modelling of atmospheric CO_2 concentrations, ocean sinks and land sinks, combined with emission estimates from fossil fuel combustion and land use change, to prepare an annual global carbon budget. This presents a variety of global, regional and sectoral data including CO_2 flux changes, changes in atmospheric CO_2 concentrations, and the extent of human perturbation of the global carbon cycle. The World Resources Institute's Climate Analysis Indicators Tool (CAIT) is a set of climate-related data products (World Resources Institute, n.d.). It includes a comprehensive database of annual and cumulative GHG emissions, using information from unofficial sources, and a complementary CAIT-UNFCCC database using only data from official national submissions to the UNFCCC. Consistent with UNFCCC reporting, both these global GHG and carbon accounts emphasise annual emission rates and categorise data according to the economic activities that produce the emissions.

C. The Need for Carbon Stock Accounts

C1. Land sector brings new accounting challenges

9. Reducing fossil fuel emissions was the first main challenge addressed by the UNFCCC. For this, a flows (for fossil fuels, effectively a one way emission) focussed policy target and accounting framework was appropriate. Emissions reduction targets were set before deciding the accounting framework and rules for Land Use, Land Use Change and Forestry (LULUCF). The focus on flow accounts for LULUCF is derived from the fossil fuel sector where this is the obvious quantity to measure. It has been transferred to all sectors of the global carbon cycle.

10. For the land sector, however, it is the total stock in each reservoir[4] (where stocks of GHG precursors are stored) that determines the condition of the system rather than net flows. The carbon dynamics associated with the biosphere differ in fundamental ways from fossil fuel emissions in terms of their reversibility, long-term controllability and variability. Carbon dynamics are influenced by complex interactions of human activities, natural disturbances and climate variability that are difficult to separate. The current state of carbon dynamics through the terrestrial biosphere is highly dependent on previous land use history. Carbon emissions and removals due to human land use activities can occur over many years, whereas most emissions from fossil fuels occur immediately (Höhne *et al*., 2007). Measurements of carbon flows have a much greater uncertainty in the land sector. The

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[4] Defined by the IPCC (http://www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf) as a component of the climate system, other than the atmosphere, which has the capacity to store, accumulate, or release a substance of concern (e.g., carbon). Oceans, soils and forests are examples of reservoirs of carbon. The absolute quantity of substance of concern, held within a reservoir at a specified time, is called the stock.

UNFCCC designed separate rules under the Kyoto Protocol in recognition of the differences in the accounting needs of the energy, industrial processes, agriculture and waste sectors, compared with LULUCF (IPCC 2003, UNFCCC 2005).

C2. Policy requirements

11. NGGI report each country's net annual emissions. The over-arching goal, however, of the UNFCCC is defined in stock terms (GHG concentrations in the atmosphere). It is the magnitude of the carbon stock in each reservoir that influences processes such as climate, ocean chemistry or the amount of vegetation. Research suggests that the relationship between cumulative CO_2 emissions and peak warming is 'remarkably insensitive' to the timing of emissions or peak emission rates (Allen *et al*., 2009). The distinction between stocks and flows has particular relevance in the land sector. From the perspective of the carbon cycle, it is the total amount stored in the land sector that determines the carbon stock in the atmosphere (under equivalent rates of fossil fuel emissions). For example, a fast-growing plantation provides a high annual rate of removal of CO_2 but the average carbon stored in a plantation system that is periodically harvested and regrown is much less than the carbon stored in a primary (or old-growth) forest or a secondary forest that is allowed to regrow undisturbed (Diochon *et al*., 2009, Brown *et al*., 1997, Costa and Wilson, 2000, Thornley and Cannell, 2000).

12. The strongest qualitative differences amongst carbon reservoirs are between geocarbon and biocarbon (Table 1). Consequently, accounting data for geocarbon and biocarbon are derived using different methods with varying statistical accuracy. When such data are combined and converted to a CO_2-equivalent quantity, substantial underlying differences in the reliability of estimates may be masked.

Table 1 Qualitative difference – geocarbon and biocarbon

Attribute	Geocarbon	Biocarbon
Coverage	Specific to deposit location	Entire landscape
Stock stability and maintenance cost	Inert and zero cost to maintain	Ongoing ecosystem management is needed
Competition with other land uses	*in situ*, nil	Competes with alternative uses of land and water including food production
Cause of stock change	Almost entirely anthropogenic	Stocks vary temporally and spatially to such an extent that statistically reliable estimation is difficult. Distinguishing anthropogenic from non-anthropogenic stock changes is complicated
Number of entities and transaction points	As carbon-containing products move through the economy, the number of entities and possible transaction points increases	The number of entities is large both for stocks *in situ* and for anthropogenic stocks

13. Separate accounting and reporting of geocarbon and biocarbon stocks enables transparent attribution of carbon stock changes and also keeps track of the qualitative differences between geocarbon and biocarbon. It may be argued that mitigation policies should exclude removal of carbon by land sinks because the imperative to reduce fossil fuel emissions is diminished. Alternatively, rather than excluding or limiting biocarbon stocks in mitigation policies, geocarbon and biocarbon could be separated with specific policies and targets set for each.

14. Comprehensive accounts covering both stocks and flows of geocarbon and biocarbon should reduce the risk of unintended policy outcomes and missed policy opportunities that could result from the current limited view of accounting for emissions, and mostly emissions from burning of fossil

fuels. Specifically, under the Kyoto Protocol, not all fluxes, activities and land areas are accounted in the rules, definitions and modalities for LULUCF (IPCC, 2000). Partial accounting of land areas may misguide policy development and facilitate unintended consequences for biodiversity, land use and atmospheric CO_2. For example, afforestation projects are included in compliance and voluntary carbon offset markets, but protecting existing natural forests to avoid emissions from harvesting is not, unless Article 3.4 of the Kyoto Protocol is elected. Electing Article 3.4 demands higher inventory reporting: in this example, net emissions in the Kyoto Protocol commitment period resulting from acting to protect and restore natural forests under threat. If natural ecosystems are not threatened by degradation or deforestation, there is no ‘avoided’ emissions and therefore inventory reporting. Carbon stock accounts could fill this gap and assist policies and measures aimed at supporting the protection and restoration of natural ecosystems independent of whether they are currently threatened by degradation or deforestation. Current carbon stocks could also be managed to maximise carbon storage.

15. Time is crucial in the climate change challenge. Stock accounts can be constructed to make transparent the relationship between time (stock longevity) and the ecosystem characteristics that contribute to natural biocarbon stock stability. This can be done by defining and ranking carbon reservoirs such that permanent or long-lived emissions and removals can be distinguished from temporary ones. Alternatively temporary emissions could be weighted according to the time CO_2 is anticipated to remain in the atmosphere before the carbon density of the originating reservoir is restored, but this would be a more complex and contested way of addressing the issue.

16. A carbon account that recognises carbon reservoir quality differences will provide policy makers with information about activities that result in permanent removal of carbon from the atmosphere compared with activities that result in transfer of carbon between biosphere stocks. This will help avoid policy outcomes that result in a long term increase in atmospheric GHG concentrations (e.g. Searchinger *et al*., 2009) mostly because the time factor (stock longevity) and the ecosystem characteristics that contribute to natural biocarbon stock stability have not been considered.

17. The CO_2 stock in the atmosphere is determined by cumulative emissions, not annual emissions. Carbon sinks in the land sector, derived by net uptake of CO_2 by plants, depend on both the trajectory of net uptake over time and the asymptote or maximum carbon stock of the system. It is necessary to know the maximum carbon stock to predict the sink capacity of a system. The carbon sequestration potential of vegetation and soil as a means of climate change mitigation is finite with stocks limited by land area and maximum carbon densities (Powlson *et al*., 2011). In reality, maximum carbon density is about ‘carbon carrying capacity’ (CCC), a dynamic equilibrium concept. The CCC of an ecosystem is defined as the mass of biocarbon able to be stored under prevailing environmental conditions and natural disturbance regimes, but excluding anthropogenic disturbance (Gupta and Rao, 1994). The difference between the CCC and current biocarbon stocks of a landscape ecosystem reflects land use history and is an estimate of sequestration potential of that land (Keith *et al*., 2009). Carbon stock accounts readily accommodate CCC measures: the issue is one of defining the base which ideally, from the perspective of land sector policy makers, is pre industrial revolution.

18. Carbon accounting frameworks that incorporate stocks, with provision for carbon carrying capacities to be incorporated, is highly policy relevant given the increasing demands on a finite land asset. Grounded in science based understandings, carbon stock information would illuminate the following (for example) for policy makers: (i) converting natural ecosystems to other land uses depletes biocarbon stocks, (ii) prioritising land for restoration of biocarbon stocks through reforestation, afforestation, revegetation, restoration or improved land management may compromise food and fibre production and to differing degrees, and (iii) some land uses result in only temporary carbon sequestration and storage which achieve little for climate mitigation (Powlson *et al*., 2011, Kirschbaum, 2006).

19. The flow based approach to accounting has encouraged policies that assume the mitigation value of carbon in different reservoirs is equal. By design, a stock-based approach can recognise that the mitigation value of carbon depends on the qualities of the reservoir in which it is embodied, namely longevity, reversibility of carbon loss and carbon density. Such stock accounts will facilitate the development and monitoring of policies that protect and where possible restore primary carbon stocks. This broadens policy choice which under a flows based inventory steers the focus to activities aimed at reducing emissions and increasing removals.

20. Increasing removals of CO_2 from the atmosphere by terrestrial sinks through, for example, reforestation or soil carbon restoration, are valuable mitigation activities that can be achieved reasonably rapidly. In emissions trading schemes, they are widely considered as an ‘offset’ for fossil fuel emissions. The concept of ‘offsets’ is based on the equivalence of GHG emissions and removals with respect to the atmosphere. This ignores the attributes of their original reservoirs, including their history. For example, offsetting fossil carbon emissions by reforestation or revegetation has three effects: depletion of a high-ranked stock (fossil carbon); creation of a lower-ranked stock (usually trees, often in plantations); and the ‘opportunity cost’ of depleting the restoration capacity of the landscape. Offsets such as afforestation and reforestation are widely used, for example in the UNFCCC’s Clean Development Mechanism (although there are not many certified projects), the European cap-and-trade system, the Regional Greenhouse Gas Initiative of the US north-eastern states, the European Emissions Trading Scheme, the Chicago Climate Exchange, and the US Climate Security Act of 2009 (Conant, 2011).

21. In aiming to return land to its full carbon carrying capacity by reforestation, afforestation or soil carbon restoration, there is an upper limit to CO_2 removals that can be achieved due to the environmental conditions for plant growth and the need for land to produce food and fibre. This limit has been simulated in dynamic global vegetation models that model growth processes in relation to environmental conditions, with predictions that the land carbon sink will level off in the second half of this century (Cramer *et al*., 2001, Friedlingstein *et al*., 2006). Additionally, climate change may reduce the potential size of the land carbon stock due to increased frequency of droughts and disturbances such as fire and insect outbreaks, and rates of soil respiration. Well informed and designed stock accounts can illuminate the implications of these trade-off challenges for government.

22. Comprehensive stocks and flows-based accounting provides a rigorous analytical framework to evaluate climate change mitigation choices with time frames made explicit. For example, in the energy market, analyses could compare the energy intensity of different stocks and the emissions committed over defined periods through existing and approved developments. Wood products provides another example where a time frame is defined for constructing carbon balance sheets for wood products and their substitutes incorporating all relevant stocks and exchanges between them, including the stock of sequestered carbon foregone through forest harvesting.

C3. UNFCCC NGGI limitations

23. UNFCCC methodologies are designed to report net annual GHG emissions rather than emissions and removals separately. Reporting net emissions, especially in the land-use sector, loses information about the unidirectional flows and hence the processes driving them and the nature of their original stocks. Thus, stable stocks can be depleted and the emissions subsequently sequestered into temporary stocks that are balanced in the short-term but cause an increase in atmospheric CO_2 concentrations in the longer term. Combining net flows from different types of carbon stocks allows large fluxes to go undetected and obscures important information about estimation reliability.

24. For the land sector, separately reporting emissions and removals for each land unit is problematic because of concurrent photosynthesis, respiration and decomposition processes. Netting is inevitable and the accounting challenge is to do so without loss of information integrity for research and policy.

25. For Kyoto Protocol inventories, two netting rules are applied and these work to shape the modelling and the information generated. Gross-net accounting rules are used for Article 3.3 activities of afforestation, reforestation and deforestation and Article 3.4 forest management activities. Here the net annual change is calculated for the commitment period 2008 to 2012. Net-net accounting rules are used for Article 3.4 activities of cropland and grazing land management and revegetation whereby the net annual change during the commitment period is compared with a baseline of the net change in 1990. Debate over these different accounting rules, and the difficulty in factoring out natural and indirect effects, results from the use of annual fluxes and the restricted timeframe over which they are compared. This was the reason for applying the cap on credits from forest management under Article 3.4 (Schlamadinger *et al*., 2007). Issues due to baselines could be resolved by accounting for total stocks in each land use sector in terms of their accumulation or reduction continuously over time.

26. The approach taken in SEEA Central Framework of specifying land units is a potential way forward. Each unit could be tagged with a land use history; baseline carbon stock measures; and annual net emissions. For land units experiencing human activities during the year (for example, timber harvesting), emissions will dominate net emissions whilst in non harvest years, generally removals will dominate net emissions. This approach provides a more informative data set for aggregation.

D. Classification and Ranking of Carbon Reservoirs

D1. Classification of carbon reservoirs

27. Different carbon reservoirs vary qualitatively including in their inherent stability and susceptibility to human perturbation. A reservoir classification system is required. Following the UNFCCC, carbon reservoirs are defined as components of the climate system where a GHG or its precursor is stored. Stocks are the quantity of carbon in a given reservoir. In this proposed framework, three main carbon reservoirs are identified: primary, anthropogenic and atmosphere/ocean, each with subsets of reservoir types (Table 2).

Primary reservoirs

28. These are carbon reservoirs in the geosphere (geocarbon) and biosphere (biocarbon) whose destruction and degradation are the primary source of increased carbon emissions into the atmosphere and subsequently into ocean water. Geocarbon reservoirs can be divided into: ‘sediments’ where carbon is stored in sedimentary rocks and deep ocean sediments, and ‘fossil carbon’ in deposits of coal, oil, gas and methane clathrates. Biocarbon reservoirs are embodied in terrestrial, aquatic and marine ecosystems. These include peat and marine vegetated ecosystems such as mangroves, saltmarshes and seagrass beds (CO_2 dissolved in the ocean is excluded).[5]

Anthropogenic reservoirs

29. These are human-created carbon reservoirs. They include stockpiles of carbon-containing materials (mined or extracted materials held until the next accounting time period for processing or use), products in use such as wood and bitumen, and waste reservoirs (including geosequestered GHGs).[6]

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[5] Marine ecosystems are excluded from NGGI but are important carbon sinks and reservoirs (Nelleman *et al*, 2009). A large part of the net ecosystem exchange is stored in shallow sediments where it can remain for millennia. ‘Marine vegetated ecosystems’ should be identified as a distinct biocarbon reservoir.

[6] Geosequestration would result in emissions from the depletion of fossil carbon stocks being stored in geological formations (at generally lower density and higher risk). This is a form of ‘waste disposal’; it does not reverse fossil carbon stock losses.

Atmosphere and Ocean

30. The atmosphere and ocean are the receiving environments for carbon released from primary reservoirs. Ocean water can be conveniently split into shallow and deep ocean reservoirs, with the deep ocean being the largest reservoir of carbon in the global cycle. In this framework, these reservoirs are not considered further as exchange of carbon between them and the atmosphere predominantly involves natural processes operating independently of human activities.

Table 2 Definition of carbon reservoirs based on their role in the global carbon cycle and their physical and ecological attributes

Carbon reservoirs	Carbon cycle component	Description
Primary Contain carbon stocks that are or can be mobilised in the carbon cycle and whose depletion is the main source of increased concentrations of GHGs in the atmosphere and oceans.	**Geocarbon** Carbon reservoirs in the geosphere	**Sediments** Carbon reservoirs in sedimentary rocks and deep ocean sediments
		Fossil carbon deposits Carbon reservoirs in coal, oil and gas including methane clathrates and shale oil and gas
	Biocarbon Carbon reservoirs in the biosphere	**Ecosystems** Carbon reservoirs in terrestrial and marine ecosystems. Includes peat; excludes CO_2 in the oceans
Anthropogenic Contain carbon stocks created by human activity	**Stockpiles** Carbon in stockpiles of materials from primary reservoirs	
	Processed Carbon and other materials transformed by human activities	**Products** Carbon in products in use, e.g. wood, cement, plastics, bitumen
		Waste Carbon in waste created by human activity. Includes solid, liquid and gaseous wastes, the latter including geosequestered CO_2
Atmosphere and Ocean water Contain stocks of CO_2 and other GHGs whose increasing concentration is interfering with the global climate system.	**Atmosphere** CO_2, CH_4 and other carbon-based gases in the atmosphere	
	Ocean water Dissolved CO_2 and carbonic acid	Shallow water Deep water

D2. Ranking of carbon reservoirs

31. The life-time of the airborne fraction of a pulse of CO_2 is very long in the atmosphere (Prentice *et al.*, 2007). This underpins interest in protecting existing stocks of carbon in primary reservoirs; recognising that global carbon storage capacity is limited; and appreciating that reservoirs have different characteristics. Primary carbon reservoirs differ fundamentally in the amount, form and longevity of carbon stored, and the degree to which they naturally exchange carbon with the atmosphere and thus influence the climate (Prentice *et al.*, 2007). These physical realities mean that different types of primary carbon reservoirs differ in their priority for protection when considering climate change mitigation policies. For this purpose, reservoirs can be ranked using the following

criteria: (i) inherent temporal stability and hence longevity; (ii) the reversibility of carbon losses over time; and (iii) current or potential carbon density (Table 3). Reservoir types are evaluated against these criteria below.

Table 3 Ranking system for primary carbon reservoirs according to their priority for protection

Reservoir		**Stability**	**Restoration time**	**Carbon density**	**Rank**
Geocarbon		High	Geological	High	A. High
Biocarbon	Natural ecosystems	High – moderate	Decades to millennia	High	A. High
	Semi-natural ecosystems	Moderate	Years to centuries	Potentially high	B. Moderate
	Agricultural systems	Low	Annual to decades	Low - moderate	C. Low - moderate

Geocarbon reservoirs

32. Geocarbon reservoirs are generally stable and inert in the absence of human intervention (fugitive emissions from gas deposits are an exception). Stock losses from geocarbon reservoirs are effectively irreversible over time scales relevant to climate change and human society.

Biocarbon reservoirs

33. The stability of biocarbon reservoirs depends on the interaction of environmental, biological and anthropogenic factors. The size and longevity of biocarbon stocks in an ecosystem fundamentally reflects an environmentally regulated balance between gross primary productivity and ecosystem respiration (Keith *et al*., 2009). Natural processes such as fire regimes and insect attacks are also important depending on ecosystem type (Mackey *et al*., 2002). Biodiversity in natural ecosystems supports the stability of biocarbon stocks by conferring resilience, and the capacity for adaptation and self-regeneration. The biocarbon stocks of natural ecosystems are therefore relatively stable over long time periods (centuries to millennia). Semi-modified and highly modified land systems are likely to be less resilient and less stable (Thompson *et al*., 2009). On the criterion of reversibility, biocarbon stock losses are in principle recoverable to the extent permitted by land management and prevailing environmental conditions. However, losses from mature natural ecosystems may only be recoverable over centuries to millennia (Righelato and Spracklen, 2007) and in some cases are not completely recoverable (Lindenmayer *et al*., 2011). On the criterion of carbon density, the current biocarbon stock is influenced by the degree of disturbance as well as vegetation and soil condition compared with the carrying capacity or potential carbon stock that is based on the environmental conditions. Natural ecosystems have larger carbon stocks per unit area than agricultural systems and forests managed for products.

34. Within an ecosystem, carbon pools are classified as above ground biomass, below ground biomass, dead standing trees, coarse woody debris, litter and soil (Keith *et al*., 2009). These also vary in temporal stability and reversibility of carbon losses. Stock losses from short-lived pools such as leaves and litter are quickly reversible and of less significance from a climate perspective than an equivalent amount of carbon lost from long-lived pools such as wood.

Anthropogenic reservoirs

35. The stability of anthropogenic reservoirs varies depending on their susceptibility to decay and to risks such as fire. Anthropogenic carbon may pass through a sequence of reservoirs. For example, some of the carbon in harvested wood may be accounted for successively in a stockpile, a wood product and waste before reaching the atmosphere. Effectively, anthropogenic carbon stocks are deferred emissions and the final emissions are irreversible.

Significance of ranking reservoirs

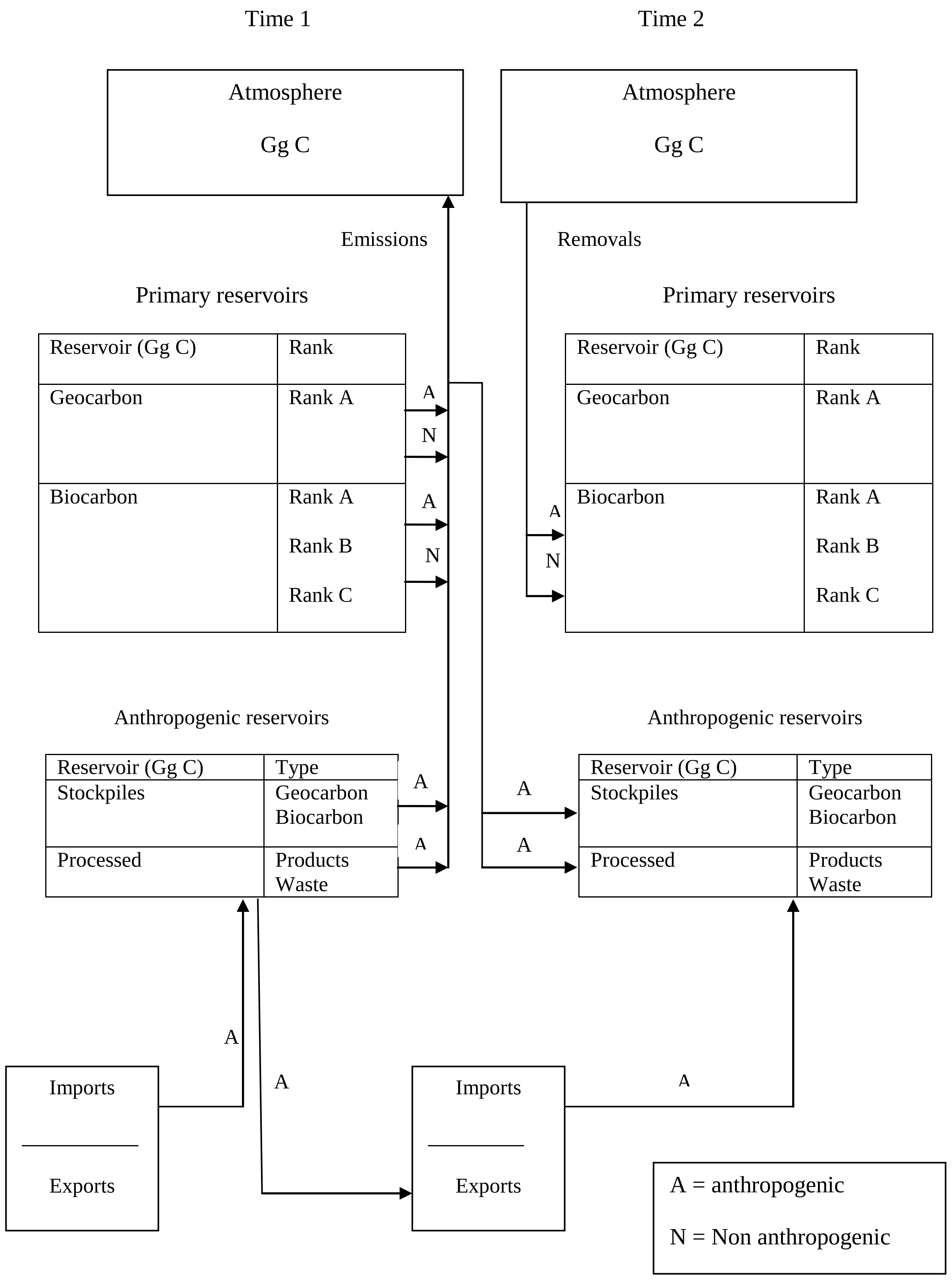
36. The earth's carbon storage capacity is limited. In formulating carbon budgets, the stability of stocks and the reversibility of stock losses – whether the stock can be restored and over what time period (restoration time) – are therefore important. Reservoirs have higher priority for protection if they are stable in the absence of human activity, if carbon stock losses caused by human action are irreversible or only reversible over a long time period, if carbon stock gains are likely to be permanent, and if they store carbon at high density. Geocarbon reservoirs have high priority for protection because they are inert and stock losses are irreversible except in geological time. Mature or near-mature natural ecosystems similarly have high priority for protection because they are stable under appropriate management, store carbon at high density relative to their environment, and if degraded the carbon stock restoration time is decades to millennia.

37. For analysis and policy, reservoirs can be further subdivided and ranked according to characteristics that influence their stability and longevity. For example, remnant natural vegetation in a largely cleared landscape could be considered more at risk from land use impacts and ranked lower than a comparable area embedded within an intact natural landscape.

E. A Proposed Framework for Carbon Accounting

38. The development of systematic and internationally comparable NGGI to support the UNFCCC and Kyoto Protocol is a major achievement of international climate change negotiations. The carbon accounting framework proposed here complements NGGI by incorporating both stocks and flows, effectively introducing a double-entry bookkeeping system. Under the framework, carbon stocks, carbon stock changes, emissions and removals would be estimated for each reservoir. Emissions would be disaggregated from removals. Direct human-induced (anthropogenic) emissions and removals would be distinguished from non-anthropogenic to the extent possible. Data would be reported primarily by reservoir. Figure 1 illustrates the framework schematically.

Figure 1 Schematic carbon balance sheet for a country or region at two time periods, showing stocks and flows between them



E1 Carbon Stock Account Development Issues

39. Building a carbon stock account could compliment the UNFCCC flows based NGGI. Structurally, the carbon accounting framework presented in this paper aligns with the System of National Accounts (SNA) framework (Table 4). Both aim to generate a complete and consistent account of stocks and flows in their respective domains. Conceptually and in implementation,

however, there are important differences. The SNA measures the monetary value placed on goods and services by people; underlying physical changes do not appear in the accounts: a matter being addressed through SEEA. Carbon accounts, on the other hand, report physical quantities of carbon in different parts of the environment. Attaching ‘value’ – environmental, economic or social – to specific carbon stocks and stock changes would be a separate exercise. Table 4 compares NGGI and SNA with the framework presented in this paper.

Table 4 Comparison of some features of SNA, NGGI and comprehensive carbon accounts

	System of National Accounts (European Commission *et al*., 2009)	**National Greenhouse Gas Inventories (IPCC, 2006)**	**Comprehensive stocks and flows carbon accounts**
Jurisdiction	UN Statistical Commission	Intergovernmental Panel on Climate Change	Policy-independent institution
Structure	Stocks and flows	Flows	Stocks and flows
Data	Economic activity	Net CO_2e emissions	Carbon stocks and stock changes
Place where activity is recorded	Resident nationality of the institutional unit	National territory where emissions and removals occur (with exceptions, e.g. emissions from road fuel use are reported in the country where the fuel is sold)	National territory where stocks are held
Geographic coverage	Complete (all institutional units have a resident nationality)	Incomplete (emissions from international transport fuel are reported as a memo item)	Potentially complete (treatment of stocks in international waters needs consideration)
Activity coverage	All economic activities	UNFCCC inventories: net anthropogenic GHG emissions except for ‘unmanaged land’ Kyoto inventories: net anthropogenic GHG emissions for elected lands and activities	All carbon stocks and stock changes
Sectors and categories	Industry (International Standard Industrial Classification of All Economic Activities)	Activity (groupings of related processes, sources and sinks: energy; industrial processes and product use; agriculture, forestry and other land-use; waste; other)	Reservoir (geocarbon, biocarbon, anthropogenic reservoirs)

F. Data Availability

40. The key data set for comprehensive carbon stock and flow accounts is the land unit, each separately identified and tagged with information: land use history; carbon stocks at determined baselines; annual emissions and removals. NGGI flows data diminish in value as model building and data requirements are constrained to meet the negotiated netting accounting rules under the UNFCCC and Kyoto Protocol. Geocarbon stock data could be derived from environmental accounts as they develop (UN, 2003). For biocarbon on land that was forest before the onset of large scale intensive agriculture and the industrial revolution, a first approximation could be obtained from land cover data assembled by the IPCC (Forster *et al*., 2007). Very few data are available pertaining to non-forest land (see for example, Houghton (2003, 2008) for estimates of soil carbon loss resulting from cultivation of new lands in the 1990s).

41. Distinguishing direct human-induced changes from indirect changes and natural variability presents similar issues for both stocks and flows based inventories (IPCC, 2010). NGGI use 'managed' land as a proxy assuming all carbon stock changes on such land are human-induced. Carbon stock accounts could take the same approach but smooth the variability by aggregating carbon stock changes over longer time periods. Alternatively, anthropogenic stock changes could be defined as those caused by an agreed set of human activities. These could include, for example, fossil fuel production and conversion from a high ranked natural forest to a lower ranked plantation reservoir; conversion from a high density to a lower density land use such as from plantations to annual crops; reducing the carbon density of a reservoir for example through forest harvesting or soil disturbance.

G. Questions for discussion

1. What form should a carbon account take, keeping in mind likely data sources, the needs of policy and maintaining accounts integrity?
2. What is the potential for integrating a carbon account with SEEA land, water, energy and environment protection expenditure accounts and possibly biodiversity account?
3. What is the priority for establishing ecologically meaningful land units tagged with land use history, and carbon stock and flow information covering an entire region or country?
4. How can carbon stocks in the oceans be included?

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