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Paper: *Using the SEEA Experimental Ecosystem Accounting framework to advance I-O and CGE integrated environmental-economic modelling*

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Abstract

The data required for input-output (I-O) and computable general equilibrium (CGE) modelling at national and multi-regional levels is sourced primarily from national I-O tables. I-O tables themselves are compiled in line with the statistical standards used to compile the national accounts, i.e. the UN System of National Accounts (SNA).

Recognising the importance of integrating data on environmental stocks and flows with the SNA, over the past 20 years there have been important advances in accounting for natural capital and environmental assets. These are encapsulated in the recent international standard, the UN System of Environmental-Economic Accounting (SEEA) which uses national accounting principles for the organization and integration of environmental and economic data.

In 2013, as part of the SEEA framework, an additional perspective was introduced to apply national accounting principles to the integration of information on ecosystem condition and ecosystem services. This advance is referred to as ecosystem accounting and is described in the SEEA Experimental Ecosystem Accounting.

This paper articulates a conceptual approach by which data on ecosystem services and ecosystem assets can be integrated into standard I-O tables and hence underpin further advances in integrated environmental-economic modelling. The approach ensures that standard accounting identities (e.g. supply and use of products) are maintained and reflects a coherence between measurement boundaries for production and assets. The paper notes a series of conceptual and measurement issues, including those concerning the pricing of ecosystem services that remain to be further explored.

Acknowledgements

The work on this paper builds on the conceptual framework for ecosystem accounting established in the United Nations System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA) published in 2014. The authors recognize the important contributions from the experts from numerous disciplines and countries involved in the ecosystem accounting discussions.

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1. Introduction

In light of the ongoing realities of climate change and the ever increasing demand for resources, understanding the capacity of the environment to support human and economic activity is of upmost concern (MA 2005, TEEB 2010, Roskstrom et al, 2009). An important part of building this understanding is the organization and analysis of information about the link between environmental assets and ecosystems on the one hand, and the production functions that describe the activities of the economic units (including households) that are involved in that activity, on the other. Commonly, joint environmental and economic analysis is not conducted through the use of integrated information sets and this creates a barrier to more, and more extensive analysis, in this area.

Using this broad motivation for the integration of environmental and economic information, an important advance in the field of official statistics has been the development of the System of Environmental-Economic Accounting (SEEA). The development of the SEEA commenced in the early 1990s with the aim of guiding the integration of environmental information into the standard System of National Accounts (SNA) (EC et al, 2009). The SNA underpins the measurement of economic activity including both gross domestic product (GDP) and input-output tables. The UN Statistical Commission adopted the SEEA Central Framework as an international statistical standard in 2012 (UN et al, 2014a).

In this context, the development of environmentally extended input-output tables (EEIOT) to support input-output and computable general equilibrium (CGE) modeling has also been an important and ongoing advance. EEIOT have been developed in relation to a variety of environmental variables including water, energy, greenhouse gas emissions, land use and waste and have supported a wide range of analysis. An extensive summary of this work is provided in Hoekstra (2010). Emphasising the connection between the work on the SEEA and the EEIOT developments, the recent SEEA Applications and Extensions (UN et al, 2014c), devotes one chapter to a description of EEIOT, albeit at only an introductory level.

Recognising the relevance and importance of input-output tables, this paper considers how a new type of SEEA based accounting, ecosystem accounting, (UN et al 2014b) might provide a complementary type of environmental input-output table that integrates information on ecosystem services. This new style of input-output table is labeled the Input-Output Table incorporating Ecosystem Services (IOTES). Its design builds on one of the fundamental aspects of the new ecosystem accounting approach being the extension of the production boundary of the SNA.

This paper describes the IOTES. To provide a clear basis for the design, Section 2 provides an introduction to the SEEA and Section 3 describes key features of ecosystem accounting. Using these descriptions, Section 4 describes the IOTES design, the key conceptual features including the connection to previous work in the input-output space, the basic IOTES design and provides a simple example.

There is quite clearly much further work and discussion that is needed to consider the potential of IOTES in concept and practice. Section 5 highlights four areas in which additional focus will be required. Section 6 concludes.

This paper emerges from a national accounting standpoint. It is hoped that the paper may serve as a basis for more detailed technical discussions with interested input-output experts.

2. Overview of the SEEA framework and its development

Development of the SEEA[1]

The potential and need to better integrate environmental information within the system of national accounts framework emerged through the 1970s and 80s (see Bartelmus, 1987; Ahmad et al., 1989). Consistent with a request from the first United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 (United Nations, 1992), the United Nations Statistical Division led the drafting of the first international document on environmental-economic accounting (United Nations, 1993b). This document, the Handbook for Integrated Environmental and Economic Accounting, became known as the System of Environmental-Economic Accounting or SEEA. It was an interim document prepared by the world's official statistics community to propose ways in which the SNA might be extended to better take environmental data into consideration.

Over the past 20 years there has been an important broadening of focus in SEEA related work. Through the 1980s and early 1990s, the primary focus was on extensions and adjustments to GDP, for example measures of depletion and degradation adjusted GDP, and recording environmental expenditures. Discussion considered the range of ways in which depletion and degradation might be estimated, valued and subsequently incorporated within the structure of the standard national accounts and its various measures of production, income, saving and wealth.

Through the 1990s, the focus started to broaden to consider ways in which accounting approaches and structures may be useful in the organization of physical information on environmental stocks and flows such as those relating to water, energy and waste. This ultimately linked to work on the compilation of material flow accounts and related analysis. This broader application of accounting principles to information

[1] This brief history is taken from Obst (2015a) which summarises the longer description in UN, et. al., 2014a

measured in physical terms confronts the common conception that adoption of accounting approaches necessarily relies on the valuation of the environment in monetary terms. Certainly there are questions that cannot be answered unless valuation is undertaken, for example adjusting measures of GDP, but there are some important advantages of applying accounting principles in the organization of data in physical terms. The compilation and application of environmentally-extended input-output tables is another manifestation of this direction.

The SEEA family

The SEEA 2012 comprises three volumes: (i) the SEEA Central Framework; (ii) SEEA Experimental Ecosystem Accounting (SEEA EEA) (UN et al, 2014b); and (iii) the SEEA 2012 Applications and Extensions (UN et. al., 2014c). In addition, various thematic SEEA publications have been developed including integrated environmental-economic accounting for Forestry (Eurostat, 2002); a SEEA Fisheries (UN and FAO, 2004); and SEEA Water (UN, 2012). Work is also nearing completion on the development of a SEEA Energy and a SEEA for Agriculture, Forestry and Fisheries (SEEA Agriculture) (FAO and UN, 2015).

All of these various publications within the SEEA "family" are connected through their common foundation in the national accounting principles and structures of the international standard for economic accounting – the SNA (EC, et. al., 2009). It is the SNA that defines the measure of gross domestic product (GDP) and many other common economic aggregates that form the basis for much macro-economic assessment and policy. Indeed, the logic driving the development of the SEEA is (i) that the SNA's accounting for the environment is insufficient at best; and (ii) that highlighting the significance of the environment may be best achieved by mainstreaming environmental information via the standard framework for economic measurement. Thus the SEEA is envisioned as a complementary system to the SNA rather than a competing or alternative approach.

The various SEEA publications cover six different aspects of accounting, although to varying degrees within the thematic SEEAs. These six aspects are:

(i) physical flow accounts for substances such as water, energy, solid waste and emissions

(ii) asset accounts for individual environmental assets, such as mineral and energy resources, timber resources, soil resources, water resources and fish stocks

(iii) accounting for stocks and changes in stocks of land and ecosystems and their services

(iv) accounting for environmental transactions (including environmental protection expenditure, the production of environmental goods and services, and flows of environmental taxes and subsidies)

(v) a sequence of accounts and balance sheets including accounting for depletion and degradation and adjusting relevant economic aggregates (e.g. GDP, national saving, net wealth)

(vi) accounting for ecosystem assets and ecosystem services (as described in Section 3).

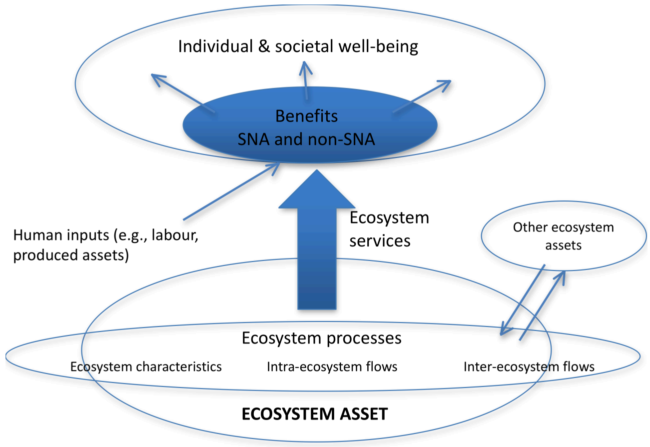
In the wake of the adoption of the SEEA Central Framework and the development of the SEEA EEA, there are now many instances of projects and initiatives that are utilizing the SEEA's accounting framework and approach. Examples include the World Bank's WAVES program (Wealth Accounting and Valuation of Ecosystem Services), the joint UNSD/UNEP/CBD project on Advancing Natural Capital Accounting and nationally led programs of work through Europe, Canada, Australia and Brazil to name a few.

3. The SEEA EEA ecosystem accounting model

The SEEA EEA was developed through 2011 and 2012 to provide an approach to the measurement and integration of environmental degradation within the standard economic accounts. The definition and measurement of degradation has been an area of discussion and contention within national accounting circles for more than 20 years. The work on SEEA EEA was able to take advantage of the more recent developments in the measurement of ecosystem services, such as presented in the Millennium Ecosystem Assessment (MA, 2005) and the original TEEB study (TEEB, 2010). The SEEA EEA represents a synthesis of approaches to the measurement of ecosystems adapted to enable integration with standard national accounting concepts and measurement boundaries.

The full ecosystem accounting model is described at length in SEEA EEA chapter 2 and readers are referred to that document for a detailed description. For the purposes of discussion here Figure 1 provides a depiction of the general model.

Figure 1: General ecosystem accounting model (SEEA EEA Figure 2.2)



Source: UN et al, 2014b

Five key features are noted:

(i) The delineation of spatial areas. Ecosystem accounting is focused on accounting for ecosystem assets, each delineated by a spatial area. By way of example, a relevant spatial area may be a rice farming area or a forest, with the understanding that each spatial area would consist of a similar vegetation type and cover. From a measurement perspective, defining the spatial boundaries is fundamental since without such boundaries it is not possible to consistently measure the condition and changes in condition of the asset or to appropriately attribute flows of ecosystem services.

For the purposes of integrating ecosystem information about the defined spatial areas with standard economic accounting and productivity measurement, it is most useful to consider this asset as a type of quasi-producing unit additional to the standard economic units such as industries and households. From this perspective, the different characteristics that are considered in the delineation of ecosystem assets are largely analogous to the characteristics that are considered in defining different economic units and attributing them to industries.

(ii) Measuring the condition of ecosystem assets. Each ecosystem asset (e.g. a rice farm) has numerous characteristics (climate, soil, vegetation, species diversity, etc.) and performs various ecosystem functions. The integrity and functioning of the asset is measured by its condition. It is the decline in overall condition, in biophysical terms, that underpins the measurement of ecosystem degradation. As yet, there is no standardized view on precisely which characteristics should be monitored for each ecosystem type in order to provide an appropriate assessment of the overall condition (current state) and the change in condition of an ecosystem asset. Accounts for ecosystem condition and ecosystem extent (i.e. the area of the ecosystem asset) are described in SEEA EEA. These accounts are compiled in biophysical terms only.

(iii) Measuring the flow of ecosystem services. Based on both the ecosystem asset's condition and the use made of the ecosystem asset (e.g. for rice production), a basket of various ecosystem services will be supplied. The ecosystem services supplied are matched to users/beneficiaries, i.e. economic units including businesses, households and governments. An ecosystem services supply and use account is developed in ecosystem accounting (see Section 4).

The coverage of ecosystem services includes provisioning services (e.g. food, fibre, water), regulating services (e.g. air filtration, water flow regulation, carbon sequestration) and cultural services (e.g. tourism, spiritual connections).

The focus in SEEA EEA is on final ecosystem services following the approach taken in TEEB (2010) and Banzhaf and Boyd (2012), among others. Consequently, ecosystem services are considered the ecosystems' contributions to the production of benefits, where benefits will include the goods and services recorded within the production boundary of the SNA and some additional services especially those that relate to public benefits from the environment, for example clean air.

In valuation a distinction is drawn between the price of a marketed good such as rice and the value of the contribution of the ecosystem. In this case the contribution would be estimated by deducting growing and harvesting costs (e.g. labour, pesticides, fertilizer, machinery, etc.) from total revenue.

In concept, by estimating the monetary value of all ecosystem services supplied by an ecosystem asset, and then estimating the associated net present value of future flows of this basket of services, the value of the ecosystem asset itself is derived. The value of ecosystem degradation will be related to the change in the value of the ecosystem asset over an accounting period, noting that the value of the asset may change for reasons other than a decline in condition, e.g. through changes in land use; and that a loss in condition may not be due to human activity (e.g. storm damage) and hence would be excluded from ecosystem degradation for accounting purposes.[2]

(iv) Relating ecosystem services to standard measures of economic activity. The supply of all ecosystem services is outside the production boundary of the SNA as they are considered natural processes (see SNA 2008, 6.24). At the same time, many ecosystem services contribute to the production of goods and services that are included in the SNA production boundary, for example the contribution of soil nutrients to rice production. In this case, the net effect on GDP of recording the supply of ecosystem services is zero, since the ecosystem services are considered outputs of the ecosystem asset and inputs to existing production.[3]

The SEEA EEA also goes an additional step by including the supply of ecosystem services that are not inputs to current, SNA recorded, goods and services. For example, the carbon sequestration service of plants. It is this additional output, and associated value added, that directly increases measures of GDP. And it is this expansion of the production boundary that is the fundamental driver of the alternative approach to input-output analysis described in the following section.

[2] In national accounting degradation, like the depreciation of manufactured assets, is considered a cost against income from production and hence only the change in asset value that is attributable to the production activity should be deducted. Other changes in value are recorded in the accounts but not as a deduction from income.

[3] Note that it is by recognizing ecosystem services as both outputs (of ecosystem assets) and inputs (to economic units) that double counting is avoided. The treatment is exactly analogous to the treatment of outputs and inputs through the standard supply chains recorded in the national accounts.

(v) The use of exchange values. The ecosystem accounting model reflects relationships between stocks and flows that exist without regard for the unit of measurement. Thus, in concept, the accounting relationships can be reported in both physical and monetary units. Measurement in monetary terms requires the use of various valuation techniques since prices for ecosystem services and assets are not directly observed in markets as for the standard outputs of products.

Economists have developed many valuation techniques to support analysis of environmental issues including the valuation of ecosystem services. For accounting purposes, some of these techniques are appropriate as they estimate the *exchange value* of an ecosystem service, i.e. the price at which a willing buyer and willing seller would complete a transaction. Exchange values are required for accounting since they allow accounting identities, such as the balance between supply and use, to be maintained in monetary terms. However, a number of valuation techniques measure *welfare values* that reflect the overall value to an individual buyer or seller of undertaking a transaction, including producer and consumer surplus. Such welfare based valuations are not appropriate for accounting purposes although they may be appropriate for various forms of economic analysis. Research is ongoing about the best ways to utilize different valuation techniques for accounting purposes.

4. Input Output Tables incorporating Ecosystem Services (IOTES)

Introduction to the approach

The description of Input-Output Tables incorporating Ecosystem Services (IOTES) builds directly on the extension of the SNA production boundary that is inherent in the way in which ecosystem services are recorded in the SEEA ecosystem accounting model. To recognize the potential that exists, an initial observation is that the scope of the standard national input-output tables compiled by statistical agencies and related bodies is equivalent to the scope of measures of economic activity that are reflected in measures of GDP. Thus the set of goods and services included in a standard IOT and the set of economic units in a standard IOT, classified by industry, is delineated by the SNA production boundary.

The essence of the IOTES is that ecosystem services can be conceptualized as additional outputs, i.e. beyond the standard SNA production of economic units, where the producers of ecosystem services, the ecosystem assets, are considered additional units/industries. Thus, via the incorporation of additional rows and additional columns, an IOTES can be designed.

To visualize the extension implied by an IOTES consider Table 1. Table 1 is an ecosystem services supply and use table developed for the forthcoming SEEA EEA Technical Recommendations (UNSD et al, 2015). Eight blocks of information are included labelled A – H:

- A: No data are recorded in this quadrant as in concept economic units cannot supply ecosystem services.
- B: In this quadrant the supply of ecosystem services by type of ecosystem asset is recorded.
- C: This quadrant is the equivalent of the standard physical supply and use table showing the supply of products by different economic units. This reflects the production of benefits to which the ecosystem services contribute. The scope of products is all goods and services produced in an economy.
- D: No data are recorded here as, in concept, ecosystem assets cannot supply products.
- E: Here the use of ecosystem services by types of economic units is recorded. This includes both the use of ecosystem services as input to further production and the use of ecosystem services as final consumption.
- F: At this stage, it is not anticipated that data would be recorded here as it represents the use of ecosystem services by other ecosystem assets – i.e. intermediate ecosystem services. If these flows were to be recorded then the supply of ecosystem services in quadrant B would need to have an equivalently larger scope.
- G: This quadrant is the equivalent of the standard physical supply and use table showing the use of products by different economic units.
- H: No data are recorded here as, in concept, ecosystem assets cannot use products.

The scope of standard supply and use tables is limited to blocks C and G – i.e. supply and use of products by type of economic unit. The IOTES extensions are reflected in (i) the addition of new rows to record the supply and use of ecosystem services; and (ii) the supply and use by type of ecosystem unit. Since the accounting boundaries for ecosystem assets and services have been defined to facilitate integration of ecosystem information with the national accounts, in concept an IOTES is in fact a simple extension of a standard IOT and hence standard IO techniques should be applicable.

Figure 1: Extended supply and use tables

ECOSYSTEM SERVICES SUPPLY TABLE

	UNITS	Type of economic unit							Type of Ecosystem Unit															TOTAL SUPPLY
		Agriculture, forestry and fisheries	Electricity, gas supply	Water collection, treatment and supply	Other industries	Households	Accumulation	Rest of the world - Imports	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and inter-tidal areas	Sea and marine areas	
									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystem services																								
Provisioning services																								
Regulating services		A							B															
Cultural services																								
Products		C							D															

ECOSYSTEM SERVICES USE TABLE

	UNITS	Type of economic unit							Type of Ecosystem Unit															TOTAL USE
		Agriculture, forestry and fisheries	Electricity, gas supply	Water collection, treatment and supply	Other industries	Households	Accumulation	Rest of the world - Exports	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and inter-tidal areas	Sea and marine areas	
									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystem services																								
Provisioning services																								
Regulating services		E							F															
Cultural services																								
Products		G							H															

Source: UNSD et al, Table 4.4

Distinctions from other environmentally related input-output approaches

There is indeed a rich history of work in the input-output space concerning the links to environmental stocks and flows. A very useful introduction is provided by Lenzen (2006). He identifies key developments in this area. This section considers the links between these developments and the IOTES introduced above.

Research into environmentally related input-output tables started in the late 1960s (e.g. Ayres and Kneese (1969) and Leontief (1970)). The focus was on the integration of externalities, especially pollution, into the IO framework. The work of this time formed the basis for the EEIOT commonly compiled for a wide range of environmental variables. Compared to the IOTES above, the primary difference between an IOTES and an EEIOT is the incorporation of ecosystem assets as additional producing units. Put differently, in an EEIOT there are additional environmental flows that are incorporated (water use, energy use, pollution, etc) but the scope of producing units and the underlying production boundary remains unchanged.

Also in the late 1960s but emerging in large part from the study of regional science, Isard et al (1967) and Daly (1968) sought to provide more complete models that reflected a complete coverage of economic and ecological systems. One of the significant practical challenges here was the need to articulate the “transactions” taking place within ecological systems, i.e. the coverage of these models went beyond exchanges between the environment and the economy. This, of course, remains a significant practical challenge. The IOTES described above incorporates flows form ecosystems to the economy but does not account directly for flows between ecosystems.

Additional work in this area was pioneered by Hannon (Hannon 1973, Hannon 2001) who noted that there was commonly a focus of determining whether input-output type approaches could be applied in analyzing ecosystem behavior as distinct from considering fully integrated systems. Hannon addressed this challenge in his 2001 paper. His solution focused heavily on incorporating the loss of ecosystem assets as distinct from incorporating flows of ecosystem services.[4]

Perhaps the study that most closely emulates the proposed IOTES was a 2011 study by Patterson, McDonald and Smith (Patterson et al, 2011). This study focused on the region of Auckland, New Zealand, used a national accounting based IOT extended to incorporate 16 ecosystem services from 12 ecosystem types. It would appear that the underlying data set would support the design of the IOTES but, as with EEIOT, no extension of the production boundary or the associated set of producing units is envisaged. Nonetheless in both scale and scope the study is very much aligned with the ambition of the IOTES described here.[5]

It is reasonable to conclude that there is in fact quite a limited body of work on the explicit incorporation of ecosystem services into input-output frameworks. An extensive review of economic modeling related to ecosystem services completed in 2014 as part of the UK National Ecosystem Assessment (Anger et al, 2014) highlighted that while there was clearly potential for work linking measures of economic activity and ecosystem services this had been limited to study of only a limited number of services in any given study. One reason may well be the lack of information and comprehensive data on ecosystem services. However, the lack of an integrated framework may also be a contributing factor.

Understanding the conceptual steps underpinning the IOTES

There are three, inter-related conceptual steps underpinning the design of the IOTES. The first is the extension of the production boundary that means ecosystem services are treated as outputs on the same basis as the production of traditionally measured goods and services. In a national accounts and input-output context, the recognition of additional output implies the recording of additional use. Depending on the use, total value added in the system may stay the same (if all ecosystem services are inputs to the production of current goods and services) or may increase (through increases in final demand). Importantly, through the acceptance of an expansion in the production

[4] During research the authors found reference to a paper titled Ecological Input-Output Analysis, Schaffner (2002). This paper may have provided an alternative solution but as the paper could only be found in German this possibility was not investigated further.
[5] A related but not as extensive study can be found in Grêt-Regamey & Kytzia (2007)

boundary, the full range of associated national accounting entries (consumption, exports, imports, income, etc.) can be coherently extended without risk of double counting.

The second conceptual step is that, as a corollary of recognizing additional production, there must also be a source of that production. In the ecosystem accounting framework, the source of ecosystem services are ecosystem assets, i.e. the forests, the waterways, the agricultural land. These are considered producing units and are distinct from the economic units that may own and manage these areas.

At first glance, the treatment of ecosystem assets as producing units may seem at odds with the general expectation that producing units would be those that combine labour and capital to produce outputs. And indeed the extension is unusual. It does however, confer significant advantages and is not without precedent in national accounting.

There are two main advantages. First, since ecosystem assets will commonly supply multiple services to multiple beneficiaries, it is useful to recognize a separate producing unit for these flows, rather than undertaking a forced attribution of additional production to existing units. Second, by bringing ecosystem assets clearly into the system, the costs of using up the associated ecosystem capital (reflected in measures of degradation) can be neatly recorded in the accounting framework – in effect as a partitioning of the value added of the producing unit.

A precedent for this type of recording exists in the current treatment of the supply of housing services from the stock of owner-occupied dwellings. In standard national accounting, the production of housing services by these dwellings does not involve any labour input and is solely reflective of capital inputs. Indeed it is the flow of capital services from the housing stock that is reflected in the measure of imputed rent that is included in total economy output.

Conceptually, one can also see that it would be possible to partition all produced assets as separate producing units and show flows of capital services internal to each business. Indeed, such a step may be of interest in analysing the effects of shifting from the ownership of produced assets to short term leasing and hiring where a flow of capital services is in fact recorded as an explicit transaction in the input-output tables.

The third conceptual step is perhaps the most fundamental and highlights a key difference between the IOTES and earlier approaches to the integration of environmental flows. On the whole, research to integrate environmental information with economic data has focused on the physical reality of environmental flows and the associated natural limits. This is reflected in all of the early and current work on EEIOT, including through the use of concepts such as mass balances. There has been a general acceptance that the challenge is to integrate this physical reality in an extended input-output system.

An alternative conception is possible however and, in fact, it underpins the concept of ecosystem services as interpreted from a national accounting perspective. To explain this, consider the distinction between stock-flow and fund-service relationships as developed in the field of ecological economics (see Daley and Farley, 2011). In their explanation, stock-flow relationships arise when a resource is physically transformed, whereas fund-service relationships when a resource is used but not transformed. The example of a stock of water being used for drinking (stock-flow) or swimming (fund-service) is a neat one.

Reflection on this distinction shows that, in an accounting context, the treatment of all assets, produced or natural, is actually consistent with the notion of fund-service relationships. It is certainly true that some assets will change physically as a result of their use, this is true of both produced and especially non-produced assets, but the accounting treatment in fact treats the flow of associated capital services as quite distinct from this physical change. This has long been accepted in the measurement of produced and human capital, albeit without being aware of the ecological economics distinction.

The point here is that the concept of ecosystem services is an exact analogy for the concept of capital services as applied in the measurement of the productive capital stock. Consequently, ecosystem services as a concept allows accounting for the environment to be considered in a manner consistent with produced assets and in a way that does not require a sole focus on the physical changes in the environment. This approach does not mean that the physical reality of environmental change is not relevant in accounting, indeed in the measurement of asset accounts and balance sheets these physical stocks and flows will be essential. It is however important to make the distinction between the physical changes in the asset and the associated flow of capital services. The IOTES takes full advantage of this conceptual step.[6]

A simple example

The following tables provide a stylized example demonstrating the accounting impact of extending the scope to include ecosystem services. In Table 2a the standard supply and use entries for a wheat farmer are recorded. There is the output of wheat and intermediate inputs of fertilizer and fuel.

Table 2a: Standard recording of supply and use (currency units)

	Wheat farmer	Other industries	Household final consumption	Total
Supply table				
Wheat	800			800
Wheat products		2000		2000
Fertilizer		200		200
Other intermediate inputs		150		150
Total output (1)	800	2350		3150
Use table				
Wheat		800		800
Wheat products			2000	2000
Fertilizer	200			200
Other intermediate inputs	150			150
Total input (2)	350	800	2000	3150
Gross value added (3=1-2)	450	1550	na	2000

In Table 2b, the supply and use table is extended to record the additional outputs of ecosystem services that are produced by the wheat farmland in the form of soil nutrients and the use of these ecosystem services by the wheat farmer. The outcome here is that the value added attributed solely to the wheat farmer in Table 2a is now partitioned across two producing units.

[6] This conceptual step also underpins the potential for a reworking of environmentally extended measurement of multi-factor productivity as explained in Obst (2015b).

Table 2b: Additional IOTES related accounting entries

	Wheat farmer	Other industries	Ecosystem asset: Wheat farm	Household final consumption	Total
Supply table					
Wheat	800				800
Wheat products		2000			2000
Fertilizer		200			200
Other intermediate inputs		150			150
Ecosystem services: Soil nutrients			**200**		200
Total output (1)	800	2350	200		3350
Use table					
Wheat		800			800
Wheat products				2000	2000
Fertilizer	200				200
Other intermediate inputs	150				150
Ecosystem services: Soil nutrients	**200**				200
Total input (2)	550	800	0	2000	3350
Gross value added (3=1-2)	**250**	1550	**200**	na	2000

It is noted that not all environmental flows of interest will be encompassed through the recording of a complete set of ecosystem services. For example, flows of solid waste would be out of scope of an IOTES. However, in this instance, it would appear possible to integrate EEIOT approaches with the IOTES since the classification of economic units would be the same in both cases.

A range of analytical options emerges from the development of IOTES. For example, the IOTES implies the recording of extended production functions and supply chains in which the contribution of ecosystem services to the production of standard goods and services can be tracked. In concept this allows analysis of trade-offs between the use of produced inputs, such as fertilizer, and natural inputs, such as soil nutrients. Input-output experts will no doubt recognize other possibilities.

5. Accounting and measurement challenges

The broad approach of integrating ecosystem accounting and extended input-output tables has considerable potential. An important step in taking any development of IOTES forward will be discussion with IO experts. Aside from discussing the basic conceptual approach described above, the following measurement issues are highlighted as being of particular note.

(a) Measurement of ecosystem service flows

Fundamentally, the compilation of IOTES requires the measurement of ecosystem service flows. Considerable advances have been made in this area over the past 10 years building on the impetus provided by the MA (2005) (see for example the work undertaken within the context of the Ecosystem Services Partnership http://www.fsd.nl/esp). However, there remain many challenges in defining, classifying and measuring ecosystem service flows in physical terms. A particular challenge in an accounting and input-output context is being able to clearly distinguish between (i) final ecosystem services (i.e. flows between ecosystems and economic units including individuals and government on behalf of society); (ii) intermediate ecosystem services (i.e. where ecosystems provide services to each other, for example soil retention services provided by upstream forests within a water catchment); and (iii) benefits representing, in many instances, the combination of final ecosystem services with labour and other human inputs. Many studies on ecosystem services do not distinguish clearly between these different types of flows which may limit the ability to integrate available information into an IOTES.

(ii) Pricing of ecosystem services

The inclusion of ecosystem services within an integrated IO setting requires that the flows are estimated in monetary terms. And, since ecosystem services are not traded in markets, this requires that appropriate prices for ecosystem services are estimated. As for the measurement of ecosystem services in physical terms, there is an increasing number of studies on the pricing of ecosystem services[7]. Examples of ecosystem services pricing in the context of ecosystem accounting include Sumarga

[7] There are a number of databases that hold relevant studies, including the Ecosystem Services Valuation Database (ESVD) that has built on the original work of the TEEB study, the Environmental Valuation Reference Inventory (EVRI) database, and the Ecosystem Valuation Toolkit by Earth Economics. A useful link to these and other valuation databases is on the Ecosystem Services Partnership website (see http://www.fsd.nl/esp/80136/5/0/50).

and Hein (2014), Remme et al (2014) and Schroter et al (2014). Much further work is required however to ensure an appropriate coverage of different ecosystem services supplied by different ecosystems.

A particular challenge is to take advantage of the range of valuation work that has been completed in the context of welfare based assessments of environmental scenarios including the valuation of positive and negative externalities. The extent to which the valuation of externalities generates prices that are consistent with the exchange value concept that underpins accounting is a current area of investigation.

(iii) Incorporating private and public ecosystem services

The conceptual framing of ecosystem accounting incorporates the production of ecosystem services that are inputs to goods and services produced by private businesses and also the ecosystem services that are of broader, societal benefit, such as carbon sequestration. Following standard national accounts approaches, ecosystem services that relate to public goods can be treated as the output and own-consumption of general government and similarly incorporated into IOT.

While conceptually the inclusion of public ecosystem services is possible, measurement of these types of services may be more challenging. In this context, it is noted that an IOTES may be compiled for a sub-set of ecosystem services and a sub-set of ecosystem assets, provided there is alignment between the measurement of ecosystem services and the scope of the ecosystem assets that are incorporated.

(iv) Accounting for ecosystem degradation and ecosystem disservices

Two important aspects of ecosystem measurement have not been discussed to this point – ecosystem degradation and ecosystem disservices. Accounting for ecosystem degradation is, in concept, analogous to accounting for the depreciation of produced assets. In an IOT context this would mean that the cost of using up of ecosystem assets should be recorded against the corresponding producing unit as part of a decomposition of value added. In the formulation above, the cost of ecosystem degradation would be attributed to the relevant ecosystem assets.

While this aspect of accounting for ecosystem degradation is relatively straightforward there are a range of measurement challenges. In the first instance measuring and valuing ecosystem degradation in terms of the change in ecosystem asset condition due to human use will not be directly observable and will require assumptions about the future flows of ecosystem services and the capacity of the ecosystem to sustainably deliver those flows.

Second, since ecosystem assets will usually supply a number of different services to different beneficiaries, the attribution of ecosystem degradation to individual units will not be straightforward. This concern is relevant because while an initial recording of degradation against the type of ecosystem asset is meaningful, more analytical use will arise from an attribution to economic units. The measurement of ecosystem degradation remains an ongoing area of research.

Ecosystem disservices refer to those cases in which people and businesses may be negatively impacted by natural processes – for example, disease resulting from mosquito infestations or losses due to wild animals eating crops. These situations do not reflect transactions between ecosystems and economic units that are mutually agreed and hence it is not possible to directly incorporate them within accounting frameworks as described. There may be alternative formulations of these cases that are amenable to accounting, for example recording the flows in terms of changes in ecosystem condition or in terms of reduced flows of ecosystem services but further discussion of the options is required.

7. Conclusions

This paper builds on the long-standing endeavours of the input-output community to appropriately incorporate environmental stocks and flows into economic analysis. The motivation for this work, recognised from the 1960s, of the inherent and embedded relationship between the economy and the environment, is even more pressing.

In finding solutions, it remains the case that the integration of multiple skills and disciplines is required. The proposals in this paper to design an input-output table that fully incorporates ecosystem services, an IOTES, is reflective of such an integration. The IOTES design builds on the unique accounting approach described in the SEEA

Experimental Ecosystem Accounting which has provided a range of insights into the potential for the more complete integration of ecological and economic measurement.

The development and implementation of ecosystem accounting, and hence the IOTES, is a work in progress and a number of research areas have been identified in the paper. Of highest priority however, is an open dialogue between different communities of expertise. In this regard, it is hoped that this paper can provide another contribution to the discussion within the input-output community on the integration of environmental stocks and flows.

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