



Supplementary Materials for **Progress in natural capital accounting for ecosystems**

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Published 31 January 2020, *Science* **367**, 514 (2020)
DOI: [10.1126/science.aaz8901](https://doi.org/10.1126/science.aaz8901)

This PDF file includes:

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Supplementary material #1

The state of ecosystem accounting by country

The table was prepared based on a review of the literature and websites of statistical offices world-wide, and also draws upon the experience of the authors, who have all been involved in the preparation of SEEA EEA accounts in their respective countries or regions, and as advisors to the compilation of SEEA EEA accounts in other countries. It reflects current knowledge as of December 2019.

Note 1: Land and water accounts are part of both the SEEA Central Framework and SEEA EEA. Accounts count as publications under SEEA EEA if they are explicit in their reports that accounts are produced under SEEA EEA and follow SEEA EEA conventions (implying a spatial approach to analyzing ecosystem assets). Several countries, such as Botswana and Brazil, have published a water account following the Central Framework, i.e., without spatial analysis or reference to the SEEA EEA. In these cases, these accounts have not been included in the table below.

Note 2: The European Union has published extent, monetary and physical ecosystem services, land, water and biodiversity accounts for the whole of the EU , and the European Environment Agency, the Joint Research Centre and Eurostat are continuously enhancing and expanding the SEEA EEA accounts. The table below presents national-scale efforts only.

Note 3: Several EU countries started preparation of SEEA EEA accounts in early 2019, in the context of the EU Horizon2020 'MAIA: project (Mapping and Assessment for Integrated ecosystem Accounting; <http://www.ecosystemaccounts.org/home/maia.jsp>). These include Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Greece, Norway, the Netherlands and Spain. Of these, the Finland, the Netherlands, Norway and Spain have published SEEA EEA accounts already and are included in the table. In the remaining countries, SEEA EEA work has started with the selection of accounts to be compiled (as per December 2019). These countries are not included in the table below.

Note 4: Nepal and Myanmar recently started the compilation of forest accounts, and China, Malaysia, Samoa, Thailand and Vietnam have started compiling ocean accounts following the SEEA EEA. These activities were also started recently and are not yet included in the table below.

Table S1. The state of ecosystem accounting by country

Key: 1 = national, 2 = sub-national, a=published, b=compiled but not yet published

Country	Main institutions involved	Extent account	Condition account	Biophysical ecosystem services account	Monetary ecosystem services account	Ecosystem asset account	Carbon account	Land account	Water account	Biodiversity account	References
Australia	Australian Bureau of Statistics, State government agencies, Australian National University	2a	2a	2a	2a		1a	2a	1a	2a	<p>Ajani J. and Comisari P. Towards a comprehensive and fully integrated stock and flow framework for carbon accounting in Australia', Australian National University, Canberra (2014)</p> <p>Australian Bureau of Statistics. Experimental Environmental-Economic Accounts for the Great Barrier Reef (2017)</p> <p>Department of Sustainability and Environment. Victorian Experimental Ecosystem Accounts. (2013)</p> <p>https://unstats.un.org/unsd/envaccounting/londongroup/meeting19/LG19_16_5.pdf</p> <p>Keith H, Vardon M, Stein JA, Stein JL, Lindenmayer D. Ecosystem accounts define explicit and spatial trade-offs for managing natural resources. Nat Ecol Evol 1: 1683–1692. (2017)</p> <p>Parks Victoria. Valuing Victoria's Parks (2015)</p> <p>https://www.worldurbanparks.org/images/Documents/Valuing-Victorias-Parks-Report-Accounting-for-ecosystems.pdf</p> <p>Wentworth Group of Concerned Scientists. Accounting for nature (2016)</p> <p>https://wentworthgroup.org/2016/12/accounting-for-nature-2016/2016/</p>

Canada	Statistics Canada	1a						1a	1a	<p>Statistics Canada. The changing landscape of census metropolitan areas. Human Activity and the Environment, Catalogue no. 16- 201-X, (2016)</p> <p>https://www150.statcan.gc.ca/n1/pub/16-201-x/16-201-x2016000-eng.htm</p> <p>Statistics Canada. Freshwater in Canada. Human Activity and the Environment, Catalogue no. 16-201-X, (2017).</p> <p>https://www150.statcan.gc.ca/n1/pub/16-201-x/16-201-x2017000-eng.pdf</p> <p>Statistics Canada. Forests in Canada,” Human Activity and the Environment, Catalogue no. 16-201-X (2018)</p>
China	National Bureau of Statistics, regional government, Chinese Academy of Sciences	2b	2b	2b	2b					<p>National Bureau of Statistics, China. Natural Capital Accounting and Valuation of Ecosystem Services (2019).</p> <p>https://seea.un.org/content/natural-capital-accounting-and-valuation-ecosystem-services-china</p>
Colombia	Institute of Hydrology, Meteorology and Environmental Studies; The Department of National Planning			2a	2a			1a	1a	<p>World Bank. Natural Capital Accounting and Policy Colombia, Policy brief, WAVES (2017)</p> <p>https://www.wavespartnership.org/en/knowledge-center/natural-capital-accounting-and-policy-colombia</p>
Costa Rica	Central Bank	1a		1a					1a	<p>Banco Central de Costa Rica. Cuentas Ambientales de Costa Rica (2018)</p> <p>https://seea.un.org/sites/seea.un.org/files/costa_rica_cuentas_ecosistemas.pdf</p> <p>http://www.inec.go.cr/medio-ambiente/indicadores-ambientales</p>

Croatia	Energy Research Institute, Agency for Environment and Nature	1a		2a						Energy Research Institute. Final report about the assessment of the selected ecosystem service with detailed methodology explanation. Energy Research Institute, Zagreb (2018) https://biodiversity.europa.eu/maes/maes_countries/croatia
Denmark	Statistics Denmark			1a				1a		Vind, I, 2018. Developing Ecosystem Services Accounts from Land Accounts. Final report Statistics Denmark (2018)
Finland	Finnish Environment Institute – SYKE	1b		2a	2b					Lai et al. Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland. Ecological Modelling 377:51-65 (2018) Project information: https://www.syke.fi/projects/estat-eea
Guatemala	Central Bank, Institute of Research on Environment (a.o.)	1a	2a	2a	2a			2a		World Bank. Toward Natural Capital Accounting in Guatemala – Synthesis Report (2019) https://www.wavespartnership.org/sites/waves/files/kc/WAVES_Towards-Natural-Capital-Accounting-in-Guatemala-Synthesis-Report.pdf
India	National Statistical Office		1a		1a			1a		EnviStats India. Volume II – Environment Accounts, Ministry Of Statistics and Programme Implementation, National Statistics Division (2019) EnViStats Supplement on Environmental Accounts (2018)

Indonesia	Central Statistical Office (BPS), National Development Planning Agency	2a	2a	2a	2a			1b			Government of Indonesia, Badang Pusat statistics, in press. Land and extent account for Indonesia, Pilot peat ecosystem account. http://documents.worldbank.org/curated/en/280931564033874140/pdf/Pilot-ecosystem-account-for-Indonesian-peatlands-Sumatra-and-Kalimantan-islands.pdf
Italy	National Capital Committee comprising representatives of (a.o.) 10 ministries	1a	1a	1a							Second Report on the State of Natural Capital in Italy, The Natural Capital Committee. https://www.minambiente.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/II_Rapporto_Stato_CN_2018_3.pdf
Japan	Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries; Kobe University			1b				1b			Hayashi, T. and M. Sako. Ecosystem service valuation and ecosystem asset account in Japan (2019) https://seea.un.org/sites/seea.un.org/files/lg23_ecosystem_service_valuation_asset_accounts_japan.pdf
Liberia	Conservation International	1a		2a				1a		2a	Neugarten, R. M. Alam, M. Honzák, D. Juhn Natural Capital Mapping and Accounting in Liberia: Understanding the contribution of biodiversity and ecosystem services to Liberia's sustainable development. Technical Report Conservation International (2017)

Madagascar	Ministry of Economy and Industry			2a					1a		World Bank. Madagascar valuing ecosystem services in the CAZ forestry corridor. World Bank, Washington, DC, USA. (2012) https://www.wavespartnership.org/sites/waves/files/kc/A4-60pages-eau-9-PRINT%281%29.pdf
Mauritius	Indian Ocean Commission, Statistics Mauritius	1a	1a					1a	1a	1a	Weber, JL, 2014. Experimental ecosystems natural capital accounts; Mauritius case study. Indian Report Ocean Commission, Mauritius
Mexico	National Institute of Statistics and Geography (INEGI)	1b	1b	1b	1b			1a	1a	1a	INEGI website on environmental accounts: https://www.inegi.org.mx/temas/ee/default.html#Informacion_general , https://www.inegi.org.mx/app/mapas/ https://seea.un.org/sites/seea.un.org/files/documents/Forum_2018/s13_mexico.pdf INEGI. Technical note water accounts (2018) https://seea.un.org/sites/seea.un.org/files/8_9.pdf Schipper A., M. Tillmanns, P. Giesen, S van der Esch, 2017 Compiling biodiversity accounts with the GLOBIO model. A case study of Mexico Technical Note PBL, the Hague, the Netherlands (2017).
Netherlands	Statistics Netherlands, Wageningen University	1a	1a	1a	1a	1a	1a		1a	1b	Statistics Netherlands, 2017, 2018, 2019. SEEA EEA accounts for the Netherlands. https://www.cbs.nl/en-gb/society/nature-and-environment/natural-capital

Norway	Statistics Norway, Norwegian Institute for Nature Research	2a		2a	2b	2b				2a	NINA. Urban ecosystem accounts for Oslo municipality (2019) http://urban.nina.no/
Peru	Regional Government of San Martin; Conservation International	2a	2a	2a	2a			2a		2a	Reporte técnico Gobierno Regional San Martín and Conservation International. Cuentas experimentales de los ecosistemas en San Martín, Perú (2016).
Philippines	Philippines Statistics Authority, Palawan Council for Sustainable Development, Laguna Lake Development Authority		2a	2a	2a		2a				Government of the Philippines, 2017. Pilot Ecosystem Account for Laguna de Bey; https://www.wavespartnership.org/sites/waves/files/kc/LdeBay%20FINAL%20LowRes%20Dec15%202016.pdf Government of the Philippines, 2017. Pilot Ecosystem account for Palawan. https://www.wavespartnership.org/sites/waves/files/kc/WB_Southern%20Palawan%20Tech%20Report_FINAL_Nov%202016.pdf
Rwanda	Ministry of Natural Resources, Ministry of Finance and Economic Planning, National Institute of Statistics	1a		1b			1b	1a	1a		Government of Rwanda. Rwanda Natural Capital Accounts – Land (2018) Government of Rwanda. Rwanda Water Accounting Report 2012-2015 (2019) Mukarubibi, F. Rwanda Natural Capital Accounting. Ministry of Natural Resources, Rwanda (2015)

South Africa	South African National Biodiversity Institute, Statistics South Africa	2a,1b	1b	2b	2b			2a	1a	1b	Nel, J.L., A. Driver. National River Ecosystem Accounts for South Africa. Discussion document for Advancing SEEA Experimental Ecosystem Accounting Project. South African National Biodiversity Institute, Pretoria (2015) Statistics South Africa. Natural resource accounts: water accounts for nineteen water management areas. Government of South Africa (2000).
Spain	Spanish National Research Council, Regional Government of Andalusia	2a, 1b		2a	2a	2a			2a		Campos P. et al. Bridging the Gap Between National and Ecosystem Accounting Application in Andalusian Forests, Spain. Ecological Economics, 218-236 (2019). Caparrós, A., Oviedo, J.L., Álvarez, A. and Campos, P. Simulated Exchange Values and Ecosystem Accounting: Theory and Application to Free Access Recreation. Ecological Economics 139: 140–149 (2017). Gutiérrez-Martín, C., M.M. Borrego-Marín., and J. Berbel. The Economic Analysis of Water Use in the Water Framework Directive Based on the System of Environmental-Economic Accounting for Water: A Case Study of the Guadalquivir River Basin. Water 9:180 (2017) Pedro-Monzonis, M., A. Solera, J. Ferrer, J. Andreu, and T. Estrela. Water accounting for stressed river basins based on water resources management models. Science of the Total Environment 565:181-190 (2016)

Uganda	UNEP-WCMC									1a	UNEP-WCMC & IDEEA Technical report Experimental Ecosystem Accounts for Uganda. UN Environment World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK (2017).
United Kingdom	Office of National Statistics, Department for Food, Environment and Rural Affairs	1a		Office for National Statistics and Department for Environment, Food and Rural Affairs. UK Natural capital accounts (2019) https://www.ons.gov.uk/economy/environmentalaccounts							
United States	U.S. Geological Survey, Bureau of Economic Analysis	1b	2b	1b	1b		2b	1b	1b		Warnell, K., et al. In press. Testing ecosystem accounting in the United States: A case study for the Southeast. Forthcoming in: Ecosystem Services

Supplementary Material #2. Biophysical accounts, mapping and modeling

SEEA EEA's relevance is underlain by both its detailed spatial biophysical information and monetary value indicators. This section presents a brief overview of (i) how spatial variability is captured in the SEEA EEA; (ii) modeling and mapping approaches that have been applied to date, and (iii) next-generation data and modeling approaches that can support SEEA EEA.

Spatial variability in SEEA EEA. Spatial variability - the distance at which spatial variations in ecosystems become relevant to understanding their functioning and use - is captured in the SEEA EEA framework in two ways (6). First, through the extent account, a country is divided into specific ecosystem types. These ecosystem types are relatively homogenous units in terms of key ecological characteristics such as climate, vegetation, soils and hydrology (though ecosystem types can be further subdivided). Second, maps of ecosystem condition and ecosystem services supply show variation both between and within ecosystem types. Within ecosystem types, there is usually spatial variability in for example slope, groundwater depth, vegetation composition and ecosystem use. This is expressed in the condition and services supply accounts, which show how relevant indicators vary across the landscape. Spatial variability is also captured in the thematic accounts. Biodiversity and carbon stocks and flows, for example, are mapped as well as represented in accounting tables. Usually, accounts are produced based on annual accounting periods. However, indicators can be added to quantify variations in ecosystems within a year (e.g., mean or maximum NDVI over the duration of the growing season within a condition account).

Spatial variability can differ substantially between ecosystem types, reflecting geography and past and present land use. Boreal forests are more homogenous than western European agricultural landscapes, for instance. This can influence the resolution needed for ecosystem accounts produced following the SEEA EEA (16). In the Netherlands, for example, a resolution of a few meters is required to capture landscape elements such as hedgerows that are important for ecosystem functioning and biodiversity (17). However, ecosystem condition and services in Siberian boreal forests might be accurately represented using maps with a resolution of e.g., 100 meters or more. The largest challenge, clearly, is in mapping for large yet diverse countries. Doing so requires considerable data, sophisticated biophysical models that are customized for varying geographic contexts and substantial computing power.

Biophysical models are used in SEEA EEA to compile continuous, national-scale ecosystem extent maps, ecosystem condition maps that indicate the state of ecosystems and biophysical ecosystem service supply and use maps, which indicate ecosystem service use (6). Land use, biodiversity, carbon stocks and flows and water may be mapped in four thematic accounts. Mapping and spatial modeling for SEEA EEA builds upon an extensive literature (e.g., 16-21)). Mapping of ecosystem condition and services poses several challenges that are specific to SEEA EEA, which we briefly describe below.

Mapping ecosystem condition. Ecosystem condition accounts reflect the state and functioning of ecosystems, including key ecosystem components and processes (22). For example, condition indicators may provide information on nutrient and hydrological cycles, species composition and productivity and may include specific indicators reflecting ecosystem degradation. As best as possible given data availability, condition indicators should reflect key ecosystem properties that are relevant for the supply of ecosystem services. Examples include the presence and density of commercial timber species in a forest, or water quality indicators in ecosystems used for fish production and subject to pollution.

Mapping ecosystem services. In SEEA EEA, by definition, the quantity of ecosystem services supplied by an ecosystem equals the quantity of their use in the economy. Three types of services are distinguished (6): provisioning, regulating and cultural services. These reflect, respectively, the harvest and extraction of ecosystem goods (e.g., timber, fisheries), the regulation of ecological process beneficial to people (e.g., air filtration, flood regulation), and non-material uses of the ecosystems (e.g., recreation). The mapping of provisioning services is generally relatively straightforward, requiring the downscaling of statistical data, for instance on timber harvests (e.g., 23). The SEEA EEA records how the ecosystem contributes to economic activity, for instance by supplying standing stocks of timber. The harvested timber is recorded in the SNA, the supply of timber for harvesting is the ecosystem service. The monetary value of the service, in this case, reflects the value of the harvested timber minus the costs of harvesting. Regulating and most cultural services, however, cannot be directly related to an economic activity that is included in the SNA. These services need to be mapped and modeled, requiring substantial data on ecosystem properties, processes and uses. This is often computationally challenging. For example, modeling the regulation by ecosystems of water flows (in terms of volume, timing and quality) requires analyzing how ecosystems moderate water flows in the landscape. This requires spatially and temporally explicit data on rainfall, temperature, soils, slope, stream flow and water use. Obtaining data and model development is often challenging, particularly in developing countries (24).

Modeling and mapping approaches applied in SEEA EEA. A broad range of modeling and mapping techniques have been applied in the various SEEA EEA accounts published to date. Broadly, two types of models have been used – models that: (i) downscale statistical information as a function of ecosystem characteristics and (ii) simulate ecological processes based on ecosystem properties to analyze ecosystem services supply. Downscaling models have been used, for instance, to downscale timber production data from the Netherlands' national forest inventory to nationwide maps of the ecosystem service timber supply (18). The forest inventory provides data on timber harvest by administrative unit and tree species. These data were combined with detailed ecosystem extent maps to allocate timber supply by forest type across the country. Downscaling models were similarly used for SEEA EEA accounts in the EU, specifically for crop provision, timber provision, and carbon sequestration (25).

The second type of spatial models are often used to model regulating services and occasionally cultural services. These models assess the specific processes underlying ecosystem services, such as the deposition of particulates onto vegetation (filtering the air) or the action of plant roots in holding soil in place by ecosystems. Various models are used, ranging from simple (e.g., lookup tables) to more complex (e.g., geostatistical interpolation or process-based models). Examples include models of flood control, crop pollination, and recreation in the EU (25) and those for air and water filtration, crop pollination, carbon storage and avian biodiversity in the US (26). Model inputs are frequently generated from remote sensing products (27).

Several SEEA EEA accounts have used toolkits that address multiple ecosystem services using common interfaces and modeling frameworks (28). Examples include the Ecosystem Services Mapping Tool (ESTIMAP, 29), applied to EU accounts (25) and Integrated Valuation of Ecosystem Services Tradeoffs model (InVEST, 30) applied to SEEA EEA in Rwanda (31). An advantage of such toolkits is their ability to model multiple ecosystem services using a common framework (vs. e.g., multiple models with different interfaces or written in different programming languages), and comparability between accounts generated using the same modeling approach.

Importantly, all models are simplifications of reality – in this case complex linked ecological- socioeconomic systems – so tradeoffs exist when choosing between the many types of models that can be used to build accounts (32). Generally, modelers must consider different models' fit to the

decision context, the level of data and expertise available, and the transparency and trust that different models may have with users of the accounts.

An example of a map produced with SEEA EEA is provided in Figure A2.1 below (33). The maps show carbon emissions from peat oxidation in the Netherlands, expressed in tons of carbon (C) emitted per hectare per year (as recorded in the SEEA EEA Carbon account). Emissions are assessed based on soil type, drainage levels and density of drainage canals. National emissions from peat amount to around 2 Mton C per year. In the deepest drained areas, emissions are as high as 12.5 tons of C (or 45 tons of CO₂) per hectare per year (equivalent to emissions from nine Dutch households). The carbon account shows high-priority areas for restoration. The ecosystem services supply account shows that the large majority of drained peatlands support dairy farming. That industry's per-hectare profits are roughly equal to CO₂ emissions costs (in deep drained areas), when these are valued at 48 euro per ton CO₂ (34). Costs of pumping and restoring infrastructure damage due to soil subsidence amount to an additional cost of 1000-1500 euro per hectare per year. Information from the Netherlands carbon accounts has been used to inform the policy and public debate on peatland uses (35); peatland restoration is part of the recent national climate action plan (36).

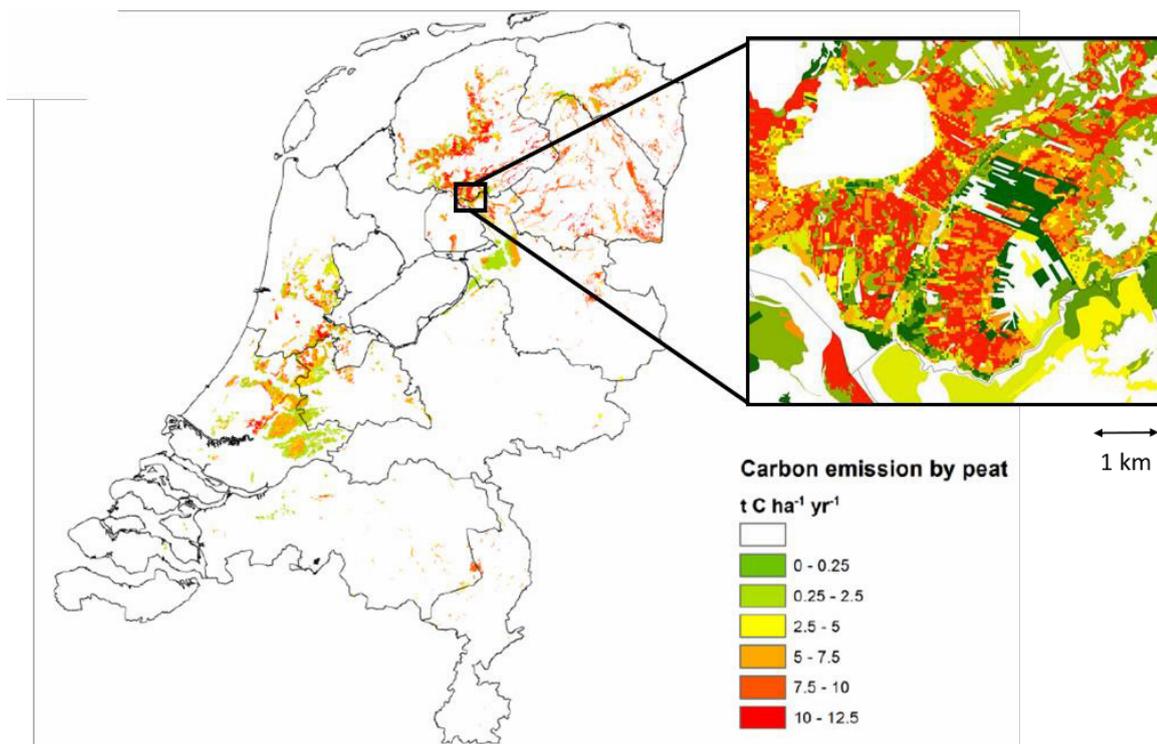


Figure A2.1. Carbon account map for the Netherlands, showing carbon emissions from peatland drainage (32).

Next-generation modeling to support SEEA EEA. Characteristic of the era of “big data,” a variety of new technical approaches are emerging that may make SEEA EEA modeling faster, more transparent, and higher quality, while improving the accessibility of SEEA EEA results and their application to decision making. We briefly describe five novel approaches below that could better inform future SEEA EEA applications. First, several global models of ecosystem services exist (37) and might be incorporated into SEEA EEA accounts. The benefits of their international consistency and comparability must be weighed against the increased trust and gains in accuracy that models typically gain when populated with local data (16). Second, the diversity and quality of remote sensing data has grown rapidly in recent years, offering many paths to improve the quality,

consistency, and accuracy of ecosystem accounts (27). Third, social media and citizen science offer ways to “crowdsource” information that may be amenable for use with SEEA EEA, particularly about cultural ecosystem services (e.g., 38,39). Fourth, machine learning algorithms offer new approaches to modeling that yield improved predictive power at the cost of the theoretical grounding characteristic of traditional process models (40). Emerging approaches like process-guided machine learning may offer the “best of both worlds,” combining the strengths of both process and machine learning models (41). Finally, the FAIR Principles, which suggest that scientific data should be Findable, Accessible, Interoperable, and Reusable by both human users and computers (42), are part of the larger open science movement. The Artificial Intelligence for Ecosystem Services (ARIES) project, which makes data and models accessible and interoperable on the web, is one such approach to making SEEA EEA data and models more FAIR (43). These approaches could make the application of biophysical models in support of SEEA EEA more feasible particularly in countries where data and technical capacity are limited.

Supplementary material #3. Monetary valuation in the SNA and SEEA-EEA

This Annex briefly explains the relationships between the valuation principles guiding SNA and SEEA- EEA and between those principles and measures of welfare in economic terms.

Valuation principles. The general rules on valuation in the 2008 version of the SNA state that “the power of the SNA as an analytical tool stems largely from its ability to link numerous, very varied economic phenomena by expressing them in a single accounting unit. The SNA does not attempt to determine the utility of the flows and stocks that come within its scope. Rather, it measures the current *exchange value* [italics added] of the entries in the accounts in money terms, that is, the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash (currency or transferable deposits).” (3, paragraph 3.118). Note that the SNA concept of ‘exchange value’ refers to the price at which goods and services are or could be exchanged. In the main text of our Policy Brief we therefore use the term ‘exchange prices’ instead of ‘exchange values’.

The section “The SNA and measures of welfare” (3, paragraph 1.75) states that “GDP is often taken as a measure of welfare, but the SNA makes no claim that this is so and indeed there are several conventions in the SNA that argue against the welfare interpretation.” An example of such a convention is the exclusion of unpaid services from the production boundary (the limits of goods, services, and assets included and valued in accounts) used to define GDP. Note, however, that although excluded by convention these values can, in principle, be part of the national accounts.

Welfare versus exchange values. The focus on exchange values in SEEA EEA implies that the monetary values shown in the national accounts are not equivalent to a correct measure of welfare from an economic point of view¹. In particular, the exchange values recorded in the transaction- based nature of the system² exclude consumer surplus while including producer surplus and production costs.

However, the literature has pointed out that by using index number theory³, it is possible to approximate a correct measure of welfare *change* from national accounts data using the prices and quantities pertaining to two periods of time (45). The literature has also shown that, as long as changes are marginal and a set of additional conditions are met; changes in societal welfare are approximated sufficiently well by changes in Net Domestic Product (NDP), which is calculated by subtracting depreciation from Gross Domestic Product (GDP). More precisely, in a dynamic model Weitzman (46) showed that marginal variations in NDP equal variations in welfare under a set of restrictive assumptions, which have been partially relaxed in subsequent studies (see (44) for a previous and similar result and (47) for a survey of this literature and a discussion about the assumptions needed).

The key point for the discussion at hand is that for this result to hold one needs to assume that all consumption services and capital stocks (assets) that are relevant to human wellbeing are correctly priced and included in the accounts. Thus, for this to hold all relevant natural capital and ecosystem services need to be included in the accounts to obtain an indicator that approximates welfare changes. By the same token, the (accounting) prices discussed in this literature are not focused

¹ In a partial equilibrium context and ignoring wealth effects, economists measure changes in welfare estimating changes in the consumer and the producer surplus (the consumer surplus is the maximum amount that consumers would have been willing to pay in excess to what they actually paid for a good, and the producer surplus is the amount that producers obtained from selling a good, in addition to their costs). Hicksian variations are considered to be more precise measures of welfare, as they take into account general equilibrium and wealth effects. For details, see (44).

² The SNA uses a quadruple entry bookkeeping system that ensures consistency in recording transactions between multiple entities.

³ An index number is the measure of change in a variable, or group of variables, over time. The literature has proposed different indexes to measure welfare changes (see (45)).

exclusively on those observed in current market transactions. Indeed, this is also true in principle for the national accounts since the SNA states that “when non-financial resources are provided without a quid pro quo, such resources should be valued at the market prices that would have been received if the resources had been sold in the market” (3, paragraph 3.130). Nonetheless, while measurement of these services and asset prices may be appropriate in principle, their inclusion is not standard SNA practice.

Valuation in the SEEA EEA. The objective of the SEEA-EEA (5) is to incorporate natural capital and ecosystem services into economic decision making by describing how the economy depends on the environment, as well as its impacts on it. The SEEA-EEA approaches its objective by extending the general principles of the SNA to environmental goods and services that are not included or not separately identified in the SNA. This allows compilation of integrated monetary accounts that capture the flow of ecosystem services and stocks of ecosystem assets, including measures of income and wealth adjusted for ecosystem degradation. To achieve this integration, it is necessary to maintain consistency with the SNA valuation principles. This consistency allows the inclusion of environmental goods and services in measures of economic activity and, using index number theory as discussed above, enables derivation of correct measures of welfare *change*.

The nature of this extension is consistent with the motivation, as discussed in (1), that future developments of the national accounts should be guided by the principles underlying national accounts rather than by current conventions (see (48) for a discussion about the integration of pollution in the national accounts). At the same time, as noted by (49, 1) and (2), while the national accounts should tackle the difficult task of measuring welfare and well-being, this work should be undertaken without forgetting the importance of current measures of economic activity, such as GDP, which also need ongoing refinement to adapt to new economic phenomenon (e.g., the digital economy).

To ensure a consistent extension to the SNA, ecosystem services and assets are thus valued in the SEEA EEA using prices based on the SNA exchange value concept, i.e., the prices at which goods, services or assets are, or could be, exchanged for cash (note that the SNA exchange price concept is, in principle, identical to the price as a marginal value concept used in economics). When traded in regular markets, exchange values are observable. However, following the SNA, “when market prices for transactions are not observable, valuation according to market-price-equivalents provides an approximation to market prices. In such cases, market prices of the same or similar items when such prices exist will provide a good basis for applying the principle of market prices. ... If there is no appropriate market in which a particular good or service is currently traded, the valuation of a transaction involving that good or service may be derived from the market prices of similar goods and services by making adjustments for quality and other differences.” (3, paragraph 3.123).

While this approach can be applied in a range of instances, for some ecosystem services, such as open-access, nature-based recreation or air filtration, there are often no markets where the same or similar items are currently traded in sufficient numbers and in similar circumstances. The Technical Recommendations document of the SEEA EEA (6: p. 97) therefore proposes to apply the concept of exchange values to include “those values that reflect the price at which ecosystem services and ecosystem assets would be exchanged between buyer and seller if a market existed.” In this framing, valuation approaches that are compatible with the principles of the SEEA EEA include, for instance, avoided damage costs methods and hedonic pricing. These methods do not generally provide a measure of welfare, i.e., including producer and consumer surplus (50). An innovative alternative solution, the Simulated Exchange Value (SEV) method, is to simulate the price and quantity that would have been observed if a similar good would have been traded in a market (51).

Further research. Although there is broad alignment on the principles and methodologies for valuing ecosystem services in the context of the SEEA EEA, further refinements are still being pursued. These include for instance (i) better defining the applicability of various valuation methods under different ecosystem management regimes; (ii) specification of the discount rate(s) and other assumptions to use in the valuation of ecosystem assets; and (iii) further exploring how to value cultural ecosystem services, where the appreciation of ecosystems often depends upon multiple types

of interactions between people and ecosystems (52, 53). These and other topics are being pursued in the SEEA EEA revision process currently underway.

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