Advancing connected values of ecosystem services: Integrating socio-ecological context and economic dependency

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32nd UN London Group on Environmental Economic Accounting, 2026

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Contents

Questions to the London Group

We invite members of the UN London Group on Environmental Economic accounting to comment on how this work could inform future SEEA EA development.

How could SEEA EA further characterize the link between ecosystem condition and ecosystem capacity, including through a more explicit treatment of condition-service relationships?

How could SEEA EA operationalize the assessment of economy-wide dependence on ecosystem services beyond direct users, including dependencies embodied in supply chains, final demand and international trade?

How could SEEA EA better build upon the recognition of multiple connected values that reflect different stages of the pathways from socio-ecological conditions to realised service flows and societal benefits?

Abstract

The integration of ecosystem services into economic analysis remains one of the central challenges in implementing SEEA EA. While recent collaborative work by Statistics Estonia, Statistics Netherlands (CBS), and Italian National Institute of Statistics (Istat) has advanced the measurement and interpretation of the monetary values associated to ecosystem services through the Connected Values approach, two important questions remain open: how to ground these values in social and ecological framework conditions, and how to trace the propagation of ecosystems' contributions to economic benefits through economic systems.

This paper presents the further development of the Connected Values approach into a broader framework by introducing two complementary analytical dimensions and methodological developments that address these questions. The first is the Socio-Ecological Context structured analysis, a standardized per-service profile that characterizes the ecological and social conditions underpinning ecosystem service provision, identifies critical dependencies, thresholds and irreversibility constraints, and explicitly characterizes the relationship between ecosystem condition and service supply. The second is a double-headed approach to analysing economic dependency on ecosystem services through input-output analysis, enabling the tracing of how the values connected to ecosystem services and their potential loss propagate through supply chains to economic sectors' value added and to final demand. Together, these dimensions support the interpretation and policy relevance of Connected Values and improve the understanding of how ecosystem services contribute to economic activity and societal well-being.

Both developments are illustrated through selected ecosystem services. Results from the Socio-Ecological Context structured analysis across seven services reveal substantial variation in the relationship between ecosystem condition and service capacity, including strong positive, non-linear, threshold-dependent and currently uncertain relationships, with direct implications for the interpretation of both physical and monetary ecosystem-service indicators. Preliminary economic dependency analysis further shows that ecosystem-service dependency extends well beyond direct users. Using complementary Leontief-based final-demand and Ghosh-based supply-side perspectives, the analysis demonstrates how ecosystem-service benefits and dependencies propagate through production systems, value chains and international trade. Together, the results illustrate how socio-ecological characterization and economy-wide dependency analysis can complement the Connected Values framework, supporting a more comprehensive interpretation of ecosystem-service importance, vulnerability and economic relevance. The work is ongoing; further development is planned through 2026–2027 in collaboration with Istat and Statistics Netherlands and supported by Eurostat grant funding (Eurostat grant 101262404 2025-EE-SUSTAINABILITY).

We would like to thank Eurostat for providing the grant to develop this work and everyone contributing and consulting us on the topic. Keywords: SEEA EA; connected monetary values; socio-ecological characterization; ecosystem condition; economic dependency; input-output analysis;

1 Introduction

The System of Environmental-Economic Accounting Ecosystem Accounts (SEEA EA) requires that ecosystem services be measured and valued in a way that supports both national accounting and environmental policy (United Nations et al., 2021). For national statistical offices implementing these accounts, three challenges are particularly persistent. The first is interpretive: a single ecosystem service can attract a wide range of monetary estimates from observable market values to hypothetical stock-based calculations that differ by orders of magnitude and must not be conflated. The second concerns the socio-ecological context of ecosystem services' flows: the ecosystem's ability to provide the services needs to be assessed, its enabling conditions exposed and the nature of the link between ecosystem's conditions and ecosystem services' demand and supply better understood. The third is structural: standard ecosystem accounts identify who directly uses a service, but do not capture the whole range of economic implications of having (or losing) that service, i.e. how the dependency upon it propagates through supply chains to indirect beneficiaries.

Prior work by Istat, Statistics Estonia and Statistics Netherlands on the application of Connected Values framework has addressed the first challenge at the level of monetary value typology, distinguishing between actual, hypothetical, and risk-based values and mapping them across several analytical stages (Femia, 2022; Oras et al., 2025). Empirical applications on Estonian and Dutch data have demonstrated the relevance of this distinction for seven ecosystem services and identified the two remaining gaps: the absence of an ecological grounding for choosing among values, and the absence of a method for tracing economic dependency beyond the direct beneficiary.

This paper presents the methodological developments that address these gaps. Section 2 provides a brief overview of the Connected Values framework and prior empirical results, which form the foundation for both developments. Section 3 presents the Socio-Ecological Context Assessment, the social and ecological grounding of ecosystem services component. Section 4 presents two approaches to the analysis of economic dependency based on input-output analysis. Section 5 reports preliminary results for both directions. Section 6 discusses implications and planned next steps.

This paper presents two new parallel methodological contributions. They are conceptually linked, the context assessment establishes what socioecological reality underpins a service, while the input-output analysis traces how that service's economic value propagates through the economy.

2 Foundation: the connected values approach

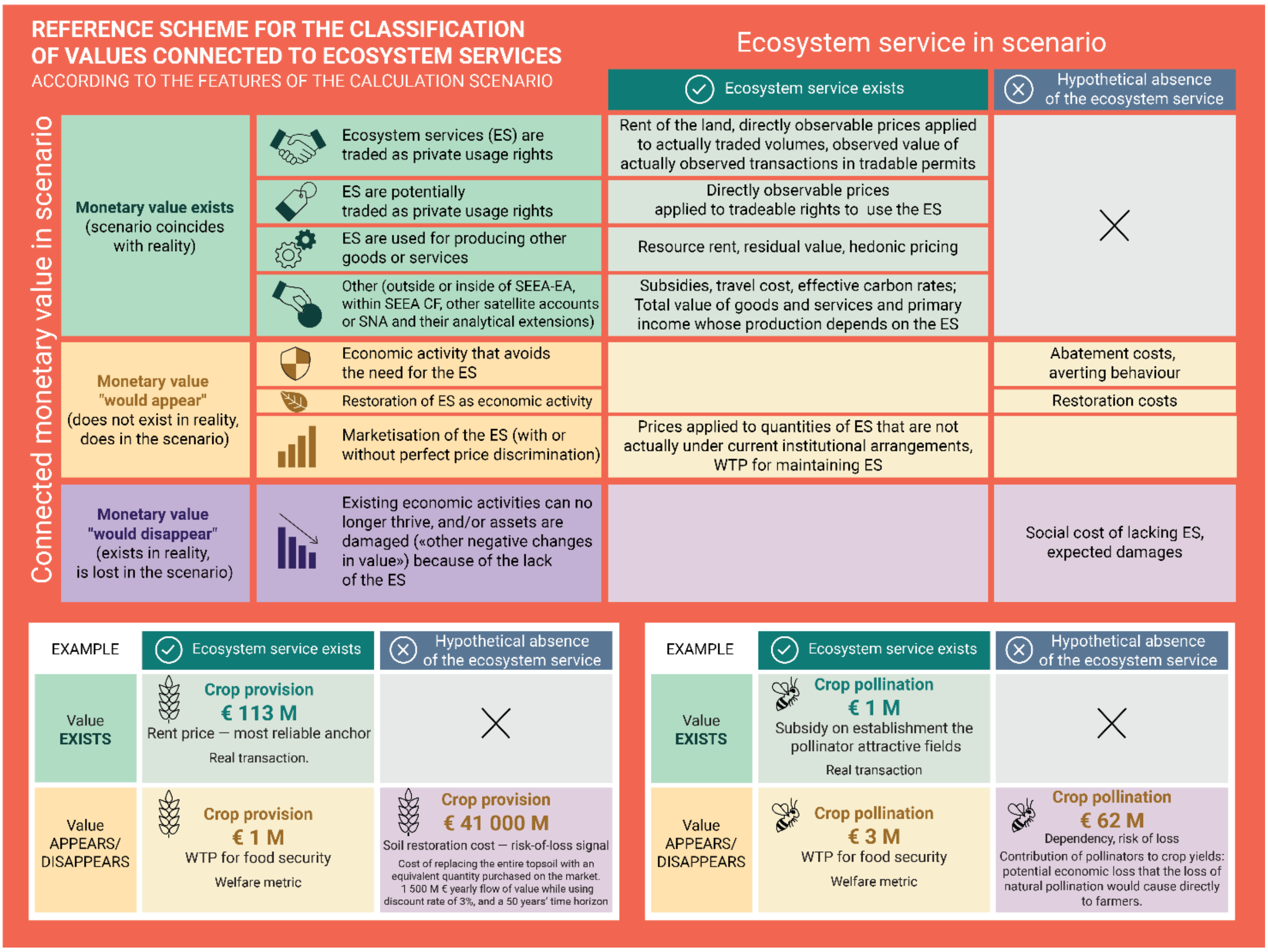
2.1 Overview

The Connected Monetary Values approach to the economic importance of ecosystem services provides a unifying perspective on the wide range of methods, proposed in the relevant literature for the valuation ecosystem services in monetary terms (most of which are discussed in SEEA EA Chapter 9)[1] . It organizes the monetary values associated with an ecosystem service based on what they actually represent: (1) exchange values directly captured by/embodied in market transactions or reflected in produced assets' value, (2) "equivalent" products' values (potential substitutes or replacements), (3) societal welfare value estimated through stated preference or social costs methods, and (4) hypothetical and risk-based values representing the potential social costs of service loss. These different perspectives on values associated with ecosystem services do not generate alternative estimates of the same quantity; they answer different policy questions and are appropriate for meeting different user groups information needs. The scheme, developed in previous work - which is reproduced below including a couple of minor adjustments with respect to previous versions – does not encompass the economic values indirectly involved, which can be traced through inter-industry dependency relationships. One of the two extensions of the analysis presented

[1] Connected values can ideally also be non-monetary and related to ecosystem assets as well as to ecosystem services. We concentrate on monetary values but from a perspective that helps other values emerge from the connections between ecological and human facts conceptualised as ecosystem services.

in this paper concerns the calculation of some of these indirectly dependent values, which may be computed starting from the values included in the scheme.

Figure 1. Reference scheme for the classification of values connected to ecosystem services with two stylized examples for crop provision and crop pollination ecosystem services



Source: Adapted from" Femia et al., Treatment of multiple economic values connected to ecosystems – theoretical aspects" (UN London Group, 2025)

The framework was tested collaboratively by Statistics Estonia, CBS, and Istat and applied empirically to seven ecosystem services in Estonia and Netherlands using 2022–2024 data. The application demonstrated that the range of values within a single service can span orders of magnitude (notably for global climate regulation, where values range from €249 million using an ETS-price-equivalent valuation to magnitudes exceeding 57 times GDP under social cost of carbon assumptions), and that this variation reflects the structure of the accounting rather than methodological inconsistency.

2.2 Summary of prior empirical results

Table 1 summarizes some of the most interesting monetary values established in the prior phase and the main finding or limitation identified for each value, by ecosystem service. These findings directly motivate the two methodological developments presented in this paper.

Table 1. Summary of connected monetary values for seven Estonian ecosystem services established in prior work (2022–2024 data). Values in € million unless otherwise stated.

Service	Key monetary values established		Main finding / limitation identified
	Estonia	**Netherlands**	
Crop provision	€113 M (rent price)* €15 M (resource rent, arable farming) €174M agricultural subsidies attributable to crop production €300M (gross value of crops product) €41300M total soil asset value, replacement of soil, €1500 M (replacement of soil, NPV 3% DR, 50 years, if stock replacement value is €41 300 M). €1 M (WTP for maintaining supply of agricultural production)	€590 M (rent price) €959 M (resource rent, arable farming) €4 769M (gross value of crops product)	*Reliable market anchor; does not capture soil services separately from the effects of other market conditions providing competitive edge
Crop pollination	€1 M (policy given value; subsidy for pollinator-attractive fields) €62 M (dependency / avoided damage) €3 M (WTP for pollination)	€134 M (dependency / avoided damage)	Low market subsidy ≠ low ecological importance; dependency value is more policy-relevant
Wood provision	€20 639 M (market value of timber stock) €3 900 M (land value); €86 M (land value, annuity, rent on land only); €171 M (resource rent, NACE A02 equivalent) €762 M (harvest at stumpage prices); €565 M (increment) €2 M (reforestation subsidy)	€20 M (resource rent, NACE A02 equivalent) €99 M (harvest)	NL forestry sector structurally minor relative to EE.
Global climate regulation	€249 M (ETS-price-equivalent); €1 259 000 M (stock); >57× GDP/ €154 M sequestration (SCC); € 1 700 000 M (C stock abatement cost); €2 500 000 M (social cost of having carbon in atmosphere); €13 M (WTP for maintaining sequestration)	€184 M (effective carbon price, averting behaviour) €36–186 M (social cost of carbon, sequestration)	Values span several orders of magnitude; communication of range requires interpretive framework
Local climate regulation	€1.67 M (CVM)	-	WTP framing; hedonic pricing effect (3–10% higher real-estate prices) identified but not monetised in either country
Air filtration	€1.3 M (avoided health cost, benefit transfer) €5 M (WTP)	€167 M (avoided health cost)	PM2.5 model requires update; monetary value is risk-of-loss, not market transaction. NL figure ~130× EE, consistent with NL's far higher PM2.5 adsorption (15,408 t vs 552 t).
Nature-based tourism	€576 M (tourism-related expenditure, 2022) €157 M (opportunity cost of time, 2022) €25 M (WTP for recreation infrastructure, 2022)	€3 390 M (travel costs, accommodation costs, other costs), of which €1 150 M (travel cost)	Observable market value reliable; condition–service link is weak and perception-mediated

Source: Oras et al., "Empirical insights into the multiple economic values of ecosystems: applications and reflections" (UN London Group, 2025)

Three findings from Table 1 are particularly important as motivation for the new work. First, the limitation identified for most services is interpretive rather than computational: several values associated with ecosystem services coexist and their different ecological, economic and political meaning needs to be explicated, rather than put in competition with one another as for which one is “the true value”. Second, actual observable prices and rents, as well as residual values, are compatible with the SNA, but only capture economic agents ability, given the current institutional arrangements and market structure, – to take advantage of their privileged access to or control of ecosystems and their services (by getting a property income or by adding some extra margin in their products’ price for allowing or facilitating others to use its services, or – in the case of the General Government - by imposing taxes or tariffs). These mostly are faint representations of the importance of ecosystem services for the economy, as they do not fully reflect the underlying economic fundamental dependence upon ecosystems, and do not reflect the costs that non-action in preserving ecosystems would impose on society. Third, for services that are not the immediate object of market transactions (local climate regulation, air filtration), the only available values are substitution-based, welfare-based or risk-based, requiring careful framing that the current guidance does not provide[2]. By considering these findings, we concluded that it is necessary to specify, on a case-by-case basis, the specific socio-ecological framework conditions that provide depth in meaning and use opportunities to the different connected values, and with this aim we developed and tested, for all seven services included in the EU Regulation 691/2011, the socio-ecological context-assessment presented below.

Furthermore, till now for any service the economic dependency had not been traced beyond the first user, a gap that limits the use of these accounts for industrial policy and trade strategy. The dependency analysis we carried out currently focuses on provisioning services, which can be straightforwardly assigned to specific industries as their direct users. For the same kind of analysis to be extended to other ecosystem services, it will be necessary, when relevant and meaningful, to assign the connected values to industries, e.g. as first users of the ecosystem service or as recipients of demand for produced goods and services that directly depends on the ecosystem service.

3 Direction 1: Socio-Ecological Context Assessment

This section addresses the context characterization gap: how can monetary values for ecosystem services be grounded in the ecological and social conditions of service generation?

3.1 Motivation and conceptual basis

The monetary values summarized in Table 1 share a common limitation: they are produced without a systematic characterization of the conditions under which each service is generated, the ecological constraints and thresholds that may limit its provision, the relationship between ecosystem condition and service supply, and the socio-economic circumstances that shape its use and associated benefits. This creates two risks. First, values may be applied to policy contexts for which they are not ecologically appropriate. For example, by interpreting a replacement-cost estimate as evidence that a service can be readily restored by human action when ecological degradation may be impossible, difficult or slow to reverse, e.g. just because nature needs time to recover. Second, although SEEA EA conceptually distinguishes ecosystem condition from ecosystem service supply, this distinction is not yet systematically reflected in the interpretation and communication of ecosystem-service values in practical accounting applications.

The concept of the Socio-Ecological Context Assessment developed in this work draws on the IPBES Conceptual Framework, its concept of nature’s contributions to people, and the IPBES Assessment of the diverse values and valuation of nature (Diaz et al. 2015, 2018; Pascual et al., 2022). IPBES understands nature’s contributions as arising within coupled social–ecological systems that connect nature and its processes, anthropogenic assets, institutions and governance systems, and people’s quality of life. From this perspective, monetary values alone do not reveal how an ecosystem service is generated or delivered, while ecological processes alone do not explain its eventual use or societal significance. The translation of ecological capacity into service flows and societal benefits may depend on interactions between ecosystem structures and functions, human knowledge, labour, technology and infrastructure, as well as on the institutions that shape access, use and the distribution of resulting benefits.

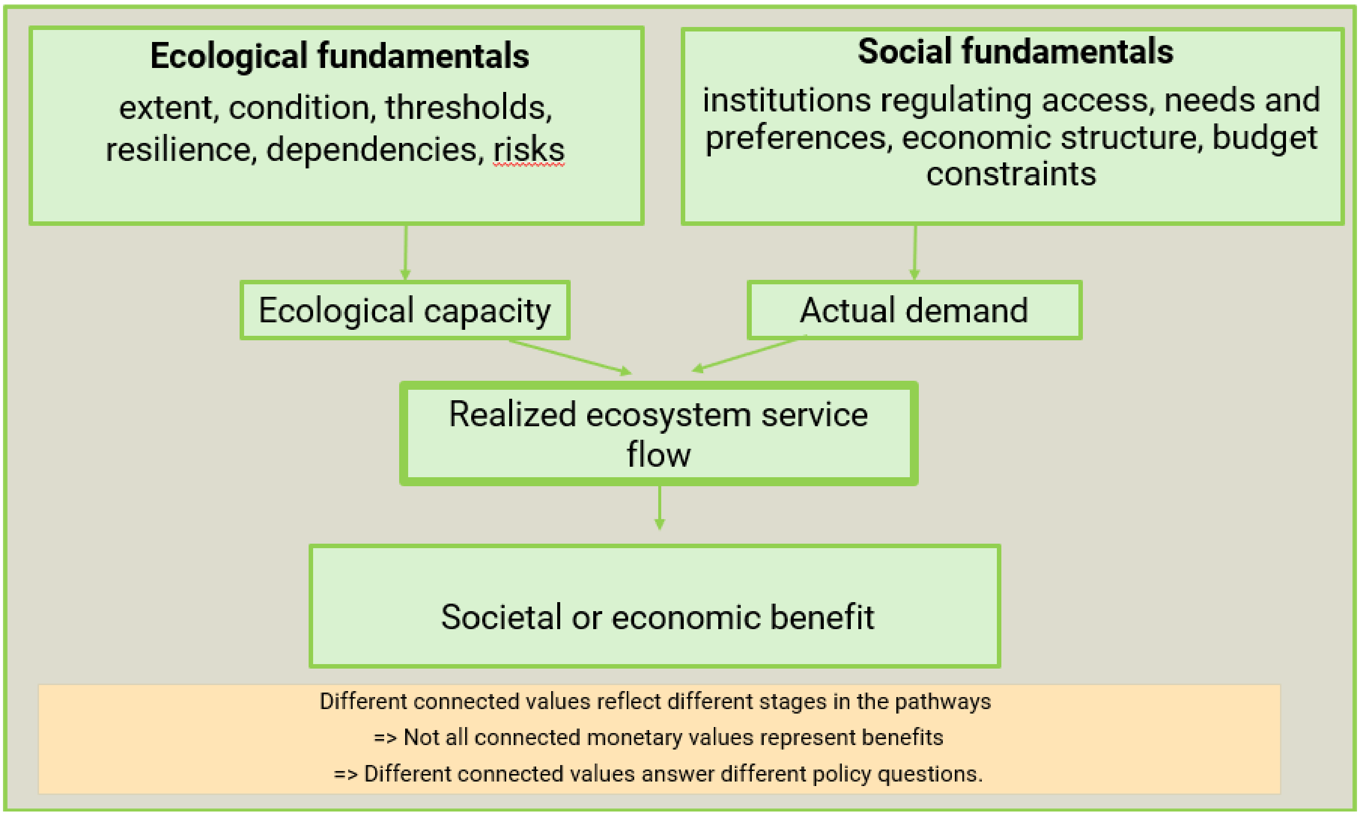
These relationships are also culturally and contextually mediated. Different social groups may recognize, use and value the same ecological contribution in different ways. The IPBES Values Assessment emphasizes that the values of nature are diverse and plural and that their expression in decision-making is influenced by worldviews, institutions, power relations and the valuation methods applied. Available physical and monetary indicators may therefore

[2] We did not compute hedonic values, which would however provide the same kind of information as resource rents

represent some instrumental, relational or intrinsic values while overlooking others, including place-based values, cultural identity, stewardship responsibilities, distributional concerns and the interests of groups whose values are not readily expressed through markets or formal decision-making processes (Pascual et al 2022).

Characterizing the pathways from ecological capacity and social context (including the institutions governing the access to ecosystem services and the distribution of their benefits), is therefore necessary for determining which physical and monetary values are ecologically meaningful, socially relevant and appropriate for a particular policy question (Díaz et al., 2015, 2018). The following scheme (Figure 2. Socio-ecological pathways to ecosystem services) provides an overview of these pathways, which converge in the realised ecosystem services and their benefits.

Figure 2. Socio-ecological pathways to ecosystem services



For analytical purposes, on the ecological side, we distinguish four linked but non-equivalent stages: **ecosystem extent and condition → ecological capacity → realized service flow → societal benefit and value. Ecosystem extent and condition describe the state and integrity of the ecosystem and its components and processes.** They shape the **ecological capacity** of the ecosystem to generate a service. The translation of this capacity into a **realized service flow** depends on human and institutional factors, including management, technology, accessibility and the spatial and temporal configuration of service demand. The realized flow in turn **generates societal benefits. Monetary and non-monetary values are associated to different stages in these pathways**. The magnitude and distribution of these benefits depend further on location and characteristics of beneficiaries, exposure, institutions, preferences and economic structures. A change at one stage therefore does not necessarily produce an immediate or proportional change at the next.

The relative importance of these mediating factors differs among ecosystem services. For co-produced provisioning services such as crop and wood provision, human inputs, management and infrastructure are integral to realized output and may partly compensate for declining ecological capacity, at least temporarily. For regulating services, ecological processes and related service flows may not require specific human acts of punctual demand (as the demand often is given by the very existence of humans and man-made capital), while the magnitude and distribution of realized societal benefits depend on where and when regulation occurs relative to beneficiaries. For example, the cooling capacity of urban vegetation does not translate automatically into an equivalent reduction in human heat exposure, which also depends on urban form, weather, spatial configuration and the location of exposed populations. Cultural services may be mediated still more strongly by accessibility, infrastructure, institutions and user preferences. Distinguishing these pathways is necessary for understanding what physical and monetary indicators actually represent.

A particular gap in existing guidance concerns the ecological part of this chain and precisely the relationship between ecosystem condition and ecological service capacity. For some services this relationship may be relatively direct and positive; for others it is non-linear or threshold-dependent, so that changes in condition (for a given extent) may produce disproportionate changes in service capacity. In still other cases, the ecological mechanism is well established but the available evidence is insufficient to quantify the strength or functional form of the condition–capacity relationship. Ignoring these differences can create a false impression of smooth and reversible change and may lead to monetary indicators being interpreted without regard to the ecological processes, recovery times and constraints that underpin them (Driver, 2026).

The same distinction is important when interpreting connected monetary values. Monetary indicators may attach to different stages of the socio-ecological pathway and therefore need not represent the same underlying quantity. Market output and resource rents may primarily reflect realized economic use under current production and institutional conditions; restoration or replacement costs describe potential interventions or substitutes; dependency estimates indicate economic activity or production associated with reliance on the service, whereas risk-based estimates describe potential consequences under possible service loss scenarios; and welfare measures reflect societal preferences or avoided damages under particular valuation assumptions. These values should therefore not be treated as interchangeable measures of a single "ecosystem value". Their interpretation requires explicit consideration of the ecological capacity underlying the service, the factors mediating its realized flow, and the societal processes through which benefits and values arise.

The proposed Socio-Ecological Context Assessment developed here operationalizes these distinctions in a standardized per-service format[3]. It characterizes the ecological processes and dependencies underpinning service capacity, resilience and recovery potential, critical risks and thresholds, socio-cultural and institutional context, accessibility and co-production, and the relationship between ecosystem condition and service provision. It then links this information explicitly to the interpretation of connected values. The aim is not to replace ecosystem condition accounts or quantitative ecosystem-service modelling, but to provide an interpretive layer that makes the ecological and socio-institutional assumptions underlying ecosystem-service indicators and monetary values more transparent.

The Socio-Ecological Context Assessment can be viewed as an extension of the ecosystem-service logic-chain perspective reflected in SEEA EA Appendix A6.1. For each ecosystem service, the SEEA EA logic chains identify common ecosystem types, factors affecting supply and use, potential physical metrics, associated benefits, and the main users and beneficiaries. The proposed assessment builds on this structure by providing a more explicit characterisation of socio-ecological dependencies, resilience, governance context, condition-capacity relationships and the interpretation of connected values.

[3] For ecosystem services that may be provided by several ecosystem types, it could be necessary to carry out the analysis per-ecosystem-type, given the service. Depending on the differences between socio-institutional context, the characterisation may also differ between ecosystem accounting area.

3.2 The standardized Socio Ecological Context Assessment

The Socio-Ecological Context Assessment is a standardized per-service profile structured around eight fields. It is completed by domain experts based on existing knowledge, data and literature, and accompanies the connected monetary values as an interpretive anchor. Table 2 describes the eight fields.

Table 2. Structure of the Standardized Socio-Ecological Context Assessment.

Dimension	Field	Purpose
Ecological perspective	**1. Ecosystem dependencies and processes**	Identifies the ecosystems, ecological characteristics and biophysical processes required for service provision. Describes the ecological foundations of the service and distinguishes them from human-produced inputs.
	2. Resilience and recovery potential	Assesses the capacity of ecosystem and the associated service to resist, adapt to and recover from disturbance. Considers vulnerability, reversibility of degradation, ecological restorability and expected recovery times.
	3. Critical thresholds and risks	Identifies ecological limits, short- and long-term constraints on service supply capacity, potential saturation and tipping points and other risks that may affect long-term service provision.
Socio-institutional perspective	**4. Socio-cultural context, diverse values and user dependence**	Describes how different social groups use, depend on, perceive and value the ecosystem and service. Considers place-based, cultural and societal values; differences among users, beneficiaries and rights-holders; and the availability of alternatives for groups dependent on the service.
	5. Institutional and governance context	Identifies formal and informal institutions that influence service provision, access and use, including property and access rights, rationing mechanisms (price- or permit-based restrictions of access), policies, management systems, regulations and governance arrangements.
	6. Accessibility, co-production, substitution and other factors ("Technological context")	Describes the accessibility, infrastructure, markets, technology and other human inputs that enable or constrain the service use. Where relevant, assesses whether the loss or reduced supply of the service can be compensated for by ecological, technological, spatial or behavioural alternatives and whether these substitutes are accessible and functionally equivalent.
Interface between ecological status and society benefits	**7. Condition–service relationship**	Characterises how ecosystem condition affects potential service capacity, given ecosystems' extent. It also identifies the principal factors that mediate the translation of ecological capacity into realised service flows, while distinguishing these from subsequent societal benefits and monetary values.
Interpretation of values	**8. Interpretation of connected values**	Explains what the various monetary and non-monetary value indicators, associated with the ecosystem service, capture and what they do not capture in ecological, social and institutional terms.

Cross-cutting evidence assessment: For each field, the evidence basis, confidence level and principal uncertainties should be recorded. The evidence basis may include observations, modelling, literature transfer and expert assessment.

Field 7, characterizing the condition–service relationship, requires domain experts to select one of five categories: strong positive, positive but non-linear, threshold-dependent, weak, or unclear, and to provide a brief explanation with a confidence level. This field responds to the observation that ecosystem condition and ecosystem service supply are conceptually distinct and that in an official statistics measurement context the nature of their relationship should be assessed rather than assumed. In other words, even though some indicators used for ecosystem service modelling may coincide, in general conditions should not be used as predictors for realised ecosystem services, as the latter depends on the socio-economic side (ecosystem service demand), and probably also not for establishing maximum ecosystem service supply potential, especially when human inputs play important roles in enabling the generation/use of the service. Conditions are understood here in general terms, and the expert assessment conducted without reference to any specific indicator (this may be a further refinement of the analysis in the future).

The context assessment is not intended to replace condition accounts or provide a basis for ecosystem services modelling; it does not require new data collection nor a quantitative assessment of ecosystem condition. Rather, it codifies existing scientific knowledge about the socioecological requirements of service delivery in a form that can be linked to the connected monetary values framework.

3.3 Expert review process

Context assessments for all seven Estonian services were drafted based on the earlier work on the development of the ecosystem accounts (Statistics Estonia., 2025) and submitted to two domain experts for review. Prof. Aveliina Helm (University of Tartu, restoration and landscape ecology) reviewed the assessments for crop pollination, crop provision, wood provision, global climate regulation, and local climate regulation. Prof. Kalev Sepp (Estonian University of Life Sciences, landscape planning and green infrastructure) reviewed the assessments for air filtration and nature-based tourism. Final expert review is planned for completion by December 2026.

Both experts received a pre-filled document containing all fields in editable form, with instructions to review, correct, and expand each field. For field 7, experts were asked to select the most appropriate relationship category and provide a justification with a confidence assessment. For field 8, experts were asked to review and expand the pre-drafted valuation implications.

3.4 Preliminary results on socio-ecological context

Table 3 summarizes the socioecological context relationship characterizations for all seven services, based on the current draft of expert assessment. These are preliminary results subject to revision following expert review.

Table 3. Preliminary characterization of seven Estonian ecosystem services. Based on draft expert assessment (Helm and Sepp, in progress, 2026). Results subject to revision following expert review completion.

	Ecological dependencies, vulnerability and recovery potential	Socio-cultural importance and user dependence	Institutional and governance dependence	Ecosystems condition–service relationship	Implications for interpreting connected monetary values
Crop provision	Depends on soil structure, organic matter and biota, nutrient cycling, water regulation, pollination and natural pest regulation. These processes are vulnerable to compaction, erosion, organic-matter loss, waterlogging or drainage failure, drought and intensive management; severe soil degradation may take decades to reverse.	Supports food and feed supply, farm income, rural livelihoods, domestic processing and food security. Benefits and risks are distributed among farmers, landowners, workers, processors, consumers and future generations.	Shaped by the CAP, land tenure, drainage and water management, plant-protection and fertiliser rules, advisory services, infrastructure, markets and risk-management instruments. Coordination is required where water flows, drainage systems, pests and supporting habitats cross property boundaries.	**Positive but non-linear, with threshold-dependent risks.** Ecosystem condition affects productive capacity through soil structure, biological functioning and water regulation, but realised crop output is strongly co-produced with human inputs. External inputs may therefore temporarily mask declining ecological capacity.	Land rent, resource rent and gross output overlap. Contributions from soil processes, pollination and natural pest regulation may be overlooked or embedded within these values and therefore require explicit treatment to avoid double counting.
Wood provision	Depends on tree growth and regeneration, species and structural diversity, soil and fungal processes, hydrology, nutrient cycling and disturbance regulation. Vulnerability increases where drought, storms, pests and disease interact; biomass may recover within decades, while mature forest structures and soil communities	Supports forest-owner income, rural employment, wood processing, construction, energy use and exports. Timber production may create trade-offs with biodiversity, recreation, cultural landscape, water-regulation and climate values.	Determined by ownership and harvesting rights, regeneration requirements, protected-area and Natura 2000 rules, state-forest management, private-forest support, certification and markets. Protection and management status determine whether biological increment can become realised wood supply.	**Positive but non-linear.** Ecosystem condition affects timber-production capacity through regeneration, soils, hydrology and stand development, while realised wood supply is additionally mediated by management, accessibility, markets and harvesting restrictions.	Standing timber and forest land are asset values, whereas increment and removals are flow-related values. Timber-based estimates overlap with resource rent and land annuity and capture only part of the wider carbon, biodiversity, water and cultural values associated with forests.

	recover much more slowly.				
Crop pollination	Depends on viable and functionally diverse pollinator communities, continuous floral resources, nesting sites, landscape connectivity and a temporal match with flowering crops. Habitat loss, fragmentation, pesticides and forage gaps can cause non-linear declines, and recovery may be slow where source populations have disappeared.	Supports pollinator-dependent crops, fruit and berry production, food diversity and supply stability. It also contributes to wild-plant reproduction, berry gathering, beekeeping, cultural practices and the intrinsic value of pollinator diversity.	Influenced by agricultural support, pesticide and fertiliser regulation, habitat management, spatial planning and nature conservation. Because pollinators move across property boundaries, effective governance requires landscape-scale coordination among farmers, landowners, municipalities and environmental authorities.	**Strong positive.** Habitat quality, connectivity and pollinator-community condition strongly shape pollination capacity. Realised crop-pollination flow additionally depends on the presence and timing of pollinator-dependent crops, weather and farm management. Habitat loss may produce non-linear or threshold-like declines, although no universal national habitat threshold has been established.	Dependency values, policy expenditure, restoration costs and willingness to pay represent different valuation perspectives and should not be added. Pollination values may overlap with crop-provision estimates and often omit wild-plant pollination, resilience and cultural or intrinsic values.
Global climate regulation	Depends on vegetation growth, decomposition, soil and peat formation, intact hydrology and the retention of carbon in biomass and soils. Drainage, harvesting, fire and drought can release accumulated carbon; restoration can reduce losses, but rebuilding large stocks may take decades to centuries.	Benefits current and future generations through reduced climate risks, while protection and restoration costs are often borne by landowners and local communities. It also carries stewardship, intergenerational and biodiversity-related values.	Governed through international climate commitments, EU LULUCF rules, national greenhouse-gas accounting, forestry and agricultural policy, drainage and peat-extraction regulation, and ecosystem-restoration programmes. Effective governance must address permanence, additionality, leakage and the distribution of protection and restoration costs.	**Threshold-dependent, with non-linear responses.** Ecosystem condition strongly affects carbon retention and annual net fluxes, but accumulated carbon stock, annual sequestration flow and the resulting societal climate benefit represent different stages and should not be conflated.	Carbon-stock, annual-flow, social-cost, avoided-abatement and willingness-to-pay estimates answer different questions and should not be combined. ETS-based values are price equivalents rather than ecosystem-carbon market transactions, while very large stock values are risk indicators rather than sale values or public liabilities.
Local climate regulation	Depends on shading, evapotranspiration, reduced heat storage and air-flow modification provided by healthy vegetation, permeable soils and water availability. Canopy loss, drought, soil sealing and restricted rooting space reduce cooling, while replacing mature	Supports thermal comfort, health, productivity and the liveability of public space. Benefits are spatially uneven and particularly important for elderly people, children, outdoor workers and residents of densely built or poorly shaded neighbourhoods.	Shaped by municipal land-use planning, development permissions, tree-protection rules, stormwater management, street and park maintenance, and climate-adaptation and public-health policies. Governance determines whether mature canopy, permeable soils and cooling access are retained	**Unclear / insufficient evidence.** Vegetation and green–blue infrastructure clearly generate cooling capacity, but current Estonian evidence does not adequately quantify how changes in ecosystem condition affect air temperature or human heat exposure. Urban	The available willingness-to-pay estimate combines urban microclimate regulation with carbon sequestration and cannot be attributed wholly to cooling. Avoided health costs, energy savings, property-price effects and restoration costs measure different benefits or inputs and may overlap.

	canopy generally takes decades.		in heat-vulnerable neighbourhoods.	form, weather, water availability and spatial configuration strongly mediate realised cooling.	
Air filtration	PM2.5 removal depends on vegetation structure, canopy cover and ecosystem condition.	Reduces mortality and morbidity; improves public health and urban liveability.	Influenced by urban planning, green infrastructure and vegetation management.	Positive; non-linear.	Avoided health damages best reflect societal value; replacement cost and property premiums should be interpreted cautiously; avoid double counting.
Nature-based tourism	Depends on biodiversity, ecological integrity, scenic quality and landscape character.	Supports recreation, well-being, local economies, cultural identity and environmental awareness.	Depends on protected area management, RMK infrastructure, Environmental Board, accessibility and tourism services.	**Moderate to strong positive but non-linear, context dependant.** Ecosystem condition shapes capacity, while realised use is mediated by accessibility, infrastructure and visitor preferences.	Visitor expenditure reflects ecosystem-supported economic activity rather than total welfare; combine with non-market valuation (e.g. WTP); avoid double counting with other ecosystem services.

Across the seven services assessed here, differences arise not only in the strength and form of the relationship between ecosystem condition and service provision, but also in where along the pathways from socio-ecological conditions to societal benefit the strongest human mediation occurs. Crop provision and wood provision are strongly co-produced services: ecosystem condition (for any given extent) shapes underlying productive capacity, while realised output is additionally mediated by management, technology, infrastructure, markets and, for wood provision, institutional restrictions on harvesting. Crop pollination has a comparatively direct ecological basis, as habitat quality, connectivity and pollinator-community condition strongly influence pollination capacity, although realised crop-pollination flows also depend on crop distribution, weather and farm management. Global climate regulation is characterised by threshold-dependent changes in carbon retention and fluxes, requiring a distinction between accumulated carbon stocks, annual sequestration or emissions, and resulting societal climate benefits. Air filtration also has a relatively direct ecological basis, with vegetation structure, canopy cover and condition influencing pollutant-removal capacity, while realised health benefits additionally depend on pollution concentrations and population exposure. For local climate regulation, vegetation clearly generates cooling capacity, but the pathway from ecosystem extent and condition through realised cooling to human heat-exposure benefits is strongly mediated by urban form, weather, spatial configuration and population location and is not yet adequately quantified in the Estonian evidence. Nature-based tourism represents the most strongly socially mediated case: biodiversity, ecological integrity and landscape character underpin the capacity to provide nature-based experiences, while realised use and associated benefits depend additionally on accessibility, infrastructure, governance and visitor preferences.

These differences show why ecosystem condition, ecological capacity, realised service flow, societal benefit and monetary value should not be treated as interchangeable. High realised output or economic value does not necessarily indicate good ecosystem condition, because human inputs may temporarily compensate for declining ecological capacity, institutional arrangements may constrain or enable realised supply, and ecological degradation may remain partly invisible until non-linear responses or thresholds are reached. Conversely, a weak or uncertain observed relationship between ecosystem condition and a final benefit does not necessarily imply weak ecological dependence where strong spatial, institutional or socio-economic mediation occurs. Connected monetary indicators therefore need to be interpreted according to the stage and perspective they represent: market output and rents reflect realised economic activity and returns under current conditions; dependency estimates indicate economic activity associated with reliance on a service; restoration and replacement costs concern interventions or substitutes; risk-based estimates describe consequences under specified loss scenarios; and welfare-related measures reflect preferences or avoided damages. These values are neither generally additive nor alternative estimates of a single ecosystem value.

Figure 3 illustrates these distinctions for crop provision, a strongly co-produced service in which ecosystem processes, human inputs and governance jointly shape realised output. The example shows how the Socio-Ecological Context Assessment can connect ecological dependencies and risks with the condition–service relationship and the interpretation of connected monetary values.

The following two subsections illustrate further the cases of crop and timber provisioning, in order to better connect these analyses with the economic dependency analysis carried out in section 4.

3.4.1 Preliminary results on socio-ecological context for crop production

Crop provision is a strongly co-produced ecosystem service in which ecosystem processes and human inputs jointly determine realized agricultural output. As illustrated in Figure 3, crop production depends on healthy soils, water regulation, pollination, nutrient cycling and natural pest control, while capital, labour, technology and management practices influence how this ecological capacity is translated into actual production. The socio-ecological assessment therefore highlights that crop output should not be interpreted as the direct result of ecosystem condition alone but as the outcome of interactions between ecological and human systems. The assessment identifies soil erosion, nutrient depletion, biodiversity loss, climate extremes and unsustainable land-use practices as key risks affecting long-term service provision. While the relationship between ecosystem condition and service supply is assessed as positive but non-linear (for any given extent), the effects of declining ecosystem condition may remain only partially visible in production statistics because agricultural systems can temporarily compensate through increased human inputs. This creates a risk that deterioration in ecological capacity remains hidden until ecological thresholds are approached or exceeded, after which declines in service provision may become disproportionately large.

The resilience profile further indicates that recovery of agricultural ecosystems can be slow, particularly where soil degradation, biodiversity loss or simplified monoculture systems reduce ecological functioning. As a result, ecosystem restoration may require substantially longer time horizons than those typically considered in annual production or market assessments. Current economic performance may therefore provide an incomplete signal of long-term ecosystem viability.

The governance context is equally important. Agricultural policies, agri-environmental schemes, land and water management regulations and farm-level management decisions all influence whether ecological capacity is maintained, degraded or restored over time. Consequently, the sustainability of crop provision depends not only on ecosystem condition itself but also on the institutional arrangements that shape land-use decisions (as these affect the extent of cropland) and agricultural practices.

These characteristics have important implications for the interpretation of connected values. Rent values, production values, subsidies, restoration costs and willingness-to-pay estimates represent different points along the pathway from ecosystem extent and condition to societal benefit. Market-based indicators principally capture realized economic benefits under current production conditions, while restoration costs and dependency-related values provide information about risks associated with declining ecological capacity. The coexistence of these values therefore reflects different aspects of society's dependence on ecosystem functioning rather than competing estimates of a single "true" value.

From an integrated perspective, crop provision combines substantial economic dependency with ecological vulnerabilities that may remain partially concealed by technological and management inputs. Understanding both the socio-ecological foundations of service provision and the wider economic dependencies built upon them provides an essential basis for the integrated interpretation presented in Table 7, where ecological vulnerability and economy-wide dependency are considered together

Figure 3 Socio-Ecological Context Assessment for Crop provision

EXAMPLE: Crop Provision

1. Ecological Perspective

- Healthy soils
- Water regulation
- Pollination
- Natural pest control
- Nutrient cycling

- Moderate recovery potential
- Long recovery for soil
- Vulnerable under monoculture

- Soil erosion
- Biodiversity loss
- Nutrient depletion
- Climate extremes
- Land use practices

2. Social & Institutional Perspective

- Food security
- Rural livelihoods and agriculture economy

Ecosystem services + human inputs (capital, labour, technology) jointly produce crop output.

- EU Common Agricultural Policy (CAP)
- Agri-environment schemes
- Land and water management regulations

3.Condition–Service Relationship

Ecosystem Condition → Service Supply

Small changes may have limited initial effects – but services decline disproportionately once ecological limits are exceeded. Soil degradation and pollinator loss compound over time.

4. Connected Monetary Values

€113 M
Rent price – most reliable anchor

€300 M
Gross value of crop products

€174 M
Agricultural subsidies attributable to food and feed production

€41 000 M
Soil restoration cost – risk-of-loss signal

€1 M
WTP for food security – welfare metric

Crop provision is a co-produced ecosystem service. Monetary values capture different dimensions of dependence on ecosystem functions, ranging from current income of land owners, production benefits to the long-term value of soil assets and the hypothetical welfare value of maintaining production capacity. They therefore represent different perspectives on value rather than competing estimates of a single “true” value.

3.4.2 Preliminary results on socio-ecological context for wood provision

4 Direction 2: Economic dependency on ecosystem services

This section addresses the structural gap: how do the economic benefits and dependencies associated with ecosystem services propagate through supply chains beyond direct users? NL results: Rozendal & Schenau, CBS 2025 (SNAC-Exiobase 2018). EE results: Oras et al., Statistics Estonia [in progress].

4.1 Motivation: why first-order users are not enough

Standard ecosystem accounts identify who directly uses an ecosystem service: the farmer who benefits from pollination, the forestry company that extracts timber, the household that enjoys cleaner air. This direct-user identification, recorded in the physical supply and use tables (PSUTs) of ecosystem services, is a major advance in linking ecological systems to economic accounting. However, it captures only the first step in a longer economic chain.

The use value of a provisioning service for example the crop yield enabled by healthy agricultural soils, does not remain with the farmer. It is processed by food manufacturers, transported, retailed, and ultimately consumed by households, both domestic and foreign. Similarly, the inputs that supply the farmer, the seeds, fertilizers, machinery, labour, are themselves produced by sectors that have no direct relationship with the ecosystem, but whose economic viability depends on its ability to provide the service. A decline in crop provision as an ecosystem service would therefore propagate not only to the farmer but to grain mills, food processors, export industries, and ultimately to consumer welfare. Environmentally extended input-output analysis (EE-IOA) provides the methodological framework to trace these dependencies. By extending the supply and use tables (SUT) of ecosystem services with a national or multi-regional input-output table, it is possible to calculate the full implications viewed from the user-side perspective (based on final-demand) and the supply-side perspective (based on value added, or also known as income-based accounting[4]) on ecosystem-service use, identifying all sectors that demand or facilitate a service and quantifying their share of the total ecosystem-related value. In conclusion: agriculture generates benefits in the form of crops by combining inputs from the rest of the economy with the ecosystem's contribution through crop provisioning ecosystem services.

This section presents a comparative analysis of economic dependency for two provisioning services, crop provision and wood (timber) provision, using method proposed by Statistics Netherlands (Rozendal and Schenau, CBS 2025) and the parallel results (based on FIGARO, 2022) for Estonia and Netherlands.

4.2 Methodological approach

4.2.1 Services selected for the analysis

Environmentally extended input-output analysis requires that a direct and clear relationship be identified between the environmental inputs or outputs (in our case, ecosystem services) on the one hand, and specific industries on the other hand. Many ecosystem services do not have an immediate obvious connection to production activities and in the European methodology (Regulation (EU) No 691/2011, as amended by Regulation (EU) 2024/3024) are indeed allocated directly to final consumption of households (or to exports, when final consumers are foreigners). This is the case of regulatory and cultural services[5]. On the contrary, provisioning services are by definition (according to SNA conventions) tightly connected with economic activities. Indeed, they have also names that strictly associate them with some economic activity or product and, most importantly, they are an essential element (contribution, input) in the production of goods, and they are measured using those goods' output as indicator (showing that the latter's production is so entangled with the ecosystem service that the human and ecosystem contributions cannot be separated, at least in physical terms). The characteristic of these ecosystem services/products, of being a joint result of the combined action of ecosystems and economic activities makes them particularly suited for a double-way analysis, as something that enables subsequent uses, and as something

[4] This approach is referred to as income-based or revenue-based accounting in the literature (Marques et al. 2012)
[5] In a resource rent, residual value or hedonic value perspective, production activities could be identified as direct users of, e.g., air filtration or local climate regulation. A completely different kind of connection of some ecosystem services with production, that allows use of input-output analysis, can be envisaged in the case of purchases of goods and services that are instrumental for the enjoyment of the ecosystem service by final consumers. Nature-based tourism provides an obvious example.

that is enabled by preceding uses of products used by their direct users. Two services are selected for the comparative analysis:

- Crop provision, direct user: agriculture (NACE 01). A provisioning service present in both countries with significant food system linkages and export dimensions.

- Wood provision (timber), direct user: forestry and logging (NACE 02). Structurally very different between the Netherlands, where forestry plays a relatively minor economic role, and Estonia, where forestry and wood processing constitute a significant economic sector.

These services provide interesting case studies because (a) both countries have compiled physical SUTs for them, and calculated corresponding and comparable connected monetary values (b), they represent different pathways of economic integration. Crop provision is deeply embedded in food supply chains, while timber provision feeds into construction and manufacturing. (C) the structural differences between the two countries (scale, forest cover, export orientation) are expected to generate interpretively interesting differences in footprint patterns.

4.2.2 Footprint concepts

The analysis uses the concept of footprints (Miller & Blair, 2022), which are the appropriate framework for identifying who across the full supply chain benefits from or facilitates the use of a given ecosystem service. Two perspectives are distinguished that redistribute the same ecosystem-service use in different ways:

- The ecosystem-service use is distributed over final output of sectors, based on input coefficients and final demand pull of ecosystem-service use (consumption-based accounting), in short: **footprint from the final demand** (user side) **perspective**. The final demand side perspective identifies the final demands, by industry delivering final goods and services, that ultimately drive ecosystem-service use in a consumption-responsibility perspective (also called “upstream” in the literature, as it refers to the “activation” of environmental pressures by final demand, through the demand for inputs following the supply chain backwards up to the primary inputs, such as ecosystem services). These are the sectors at the end of the value chain that directly or indirectly consume the output of the direct ecosystem-service user. For crop provision, the direct user is the agricultural sector; the footprint traces the final economic uses to which agricultural output is ultimately functional to.
- The ecosystem-service use is distributed over primary input of sectors, based on output coefficients and value-added push of ecosystem service generation (income-based accounting), in short: **footprint from the supply-side** (supplier side) **perspective**. The supply-side perspective identifies the activities that facilitate the direct user's extraction of the ecosystem service by supplying necessary inputs: seeds, machinery, labour, real estate. These activities would not exist if the ecosystem service did not exist, as they are complementary to it in the supply function of the direct user of the ecosystem service. Agriculture generates benefits in form of crops by combining inputs from the rest of economy with the ecosystem’s contribution which is the crop provision ecosystem service. The supplying sectors are the sectors in the supply chain that supply the direct ecosystem-service user and therefore depend on the direct ecosystem user for generating value added (income). (This is also referred to as the "downstream" perspective, as it traces environmental pressures forward through the supply chain.) For crop provision, the direct user is the agricultural sector; the footprint traces the ecosystem services required to generate the value added in sectors supplying Estonian agriculture.

The final demand perspective and supply-side perspective used in this analysis allow for a consistent attribution of ecosystem service flows to final users on the one hand, and to suppliers on the other hand, in line with established input–output accounting approaches (Marques et al 2012, Kitzes et al 2013).

4.2.3 Footprints vs. direct dependency of intermediate uses

The results presented in this paper are based on input–output footprint calculations, which attribute ecosystem-service use to final demand or primary income. These approaches provide a consistent and comprehensive view of how ecosystem services are embodied in final uses or required to enable value added across industries. However, it does not fully reveal the structure of intermediate dependencies within the production system. Ecosystem services are indirectly essential for a wide range of intermediate economic activities, which depend on the inputs provided by direct ecosystem service-using sectors. These dependencies are captured in the integrated footprint results, but their detailed structure is not visible. A more explicit representation of intermediate dependencies, for example, through analysis of direct requirements and substitution possibilities, could further enhance the understanding of economic reliance on ecosystem services. This represents a possible direction for future work.

4.2.4 Data and tools

Figaro 2022 data are used as a bases for the calculation (Eurostat, 2025). Methodology is described in the Annex A.

For the selected provisioning services, the comparison between Estonia and the Netherlands highlights two contrasting analytical situations. For timber provision, the countries differ substantially in the scale and economic importance of their forest sectors. In the Netherlands, wood provisioning had a total value of €92 million in 2018 and forestry represents a relatively minor economic activity. In Estonia, wood provision is the largest provisioning ecosystem service by market value (€762 million), with forestry playing a significant role in the national economy. These structural differences provide an opportunity to examine how ecosystem-service dependencies are distributed in economies with markedly different forestry sectors and value-chain structures.

Crop provision represents the opposite case. Dutch crop production is more than fifteen times larger than Estonian crop production in absolute terms, reflecting both the larger scale of Dutch agriculture and the overall larger size of the Dutch economy. Nevertheless, crop provisioning is an economically important ecosystem service in both countries and supports broadly comparable agricultural and food-system activities. This makes crop provision a useful case for analysing how dependencies on a similar ecosystem service are distributed across different economic structures. Starting from a comparable ecosystem-service function allows differences in supply-side and final-demand dependencies to emerge more clearly, highlighting how economic organization, trade orientation and value-chain structures influence the distribution of ecosystem-service benefits throughout the economy.

4.3 Results and Comparative Analysis

4.3.1 Comparative footprint structure

Table 4. Summary indicators of ecosystem-service dependency footprints in Estonia and the Netherlands

Indicator	Netherlands Crop	Estonia Crop	Netherlands timber	Estonia Timber
Final-demand (final uses)	64%	74%	55%	36%
Foreign final-demand (final uses)	36 %	26%	45%	64%
Domestic supply-side enablers	71%	62%	69%	69%
Foreign supply-side enablers	29%	38%	31%	31%
Own-sector final-demand (final uses)	32%	34%	50%	7%
Own-sector supply-side enablers	45%	41%	48%	39%

To complement the aggregate indicators presented in Table 4, Figures 4–7 provide a more detailed representation of ecosystem-service dependency structures from both the final-demand and supply-side perspectives. While Table 4 summarises the overall distribution of dependencies between domestic and foreign actors and between direct and indirect users, the figures reveal the sectoral composition of these dependencies. Together they illustrate how crop and timber provisioning ecosystem services propagate through economic sectors, value chains and international trade networks in Estonia and the Netherlands

Figure 4 presents the final-demand footprint of crop provision, showing which sectors' final demand ultimately activates the use of crop provisioning ecosystem services. Figure 4 shows that crop provisioning generates remarkably similar dependency profiles in Estonia and the Netherlands. In both countries, ecosystem-service benefits are concentrated in agriculture and food manufacturing, indicating that crop provision primarily supports food-system activities. The similarity of the profiles suggests that, despite differences in absolute production volumes, the economic role of crop provision within agricultural value chains remains broadly comparable across the two countries.

Figure 4. Crop provision, final-demand perspective (EE vs NL)

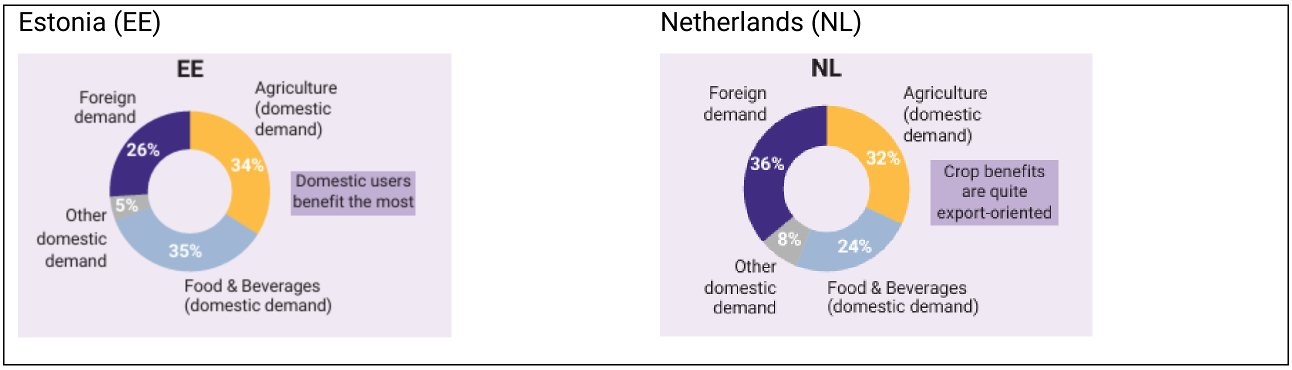


Figure 5 presents the supply-side footprint of crop provision, identifying the sectors that enable agricultural production and therefore indirectly depend on the utilisation of crop provisioning ecosystem services. In both countries, agriculture remains the dominant enabling sector, while the remaining footprint is distributed across energy, trade, transport, business services and foreign suppliers. This pattern highlights the co-produced nature of crop provision, where ecosystem functions and human inputs jointly support agricultural production.

Figure 5. Crop provision, supply-side perspective (EE vs NL)

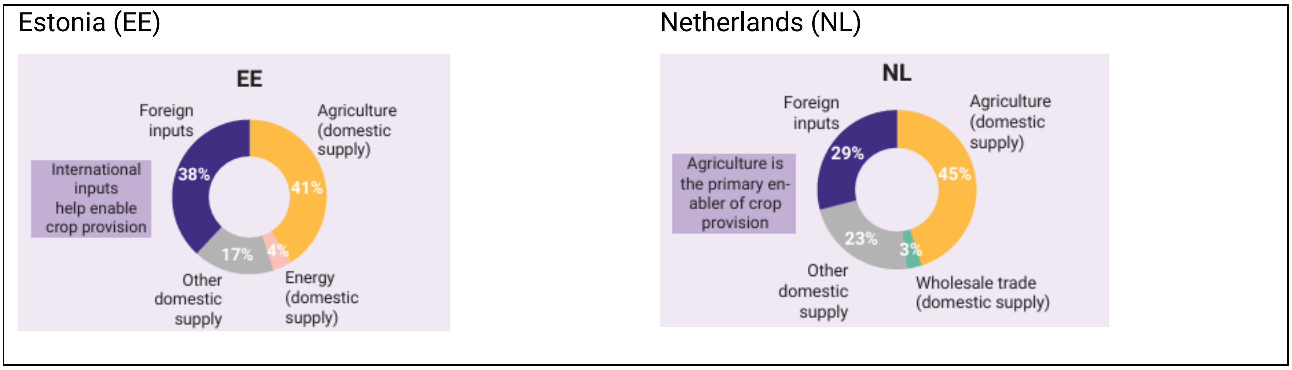


Figure 6 shows the final-demand footprint of timber provision, illustrating how timber-related ecosystem-service benefits are embodied in downstream industries and final demand. Figure 6 reveals much stronger cross-country differences. In Estonia, timber-related ecosystem-service benefits are transferred beyond the direct-user sector into wood processing, construction and export-oriented production chains. By contrast, in the Netherlands a much larger share remains concentrated within forestry itself. This suggests that timber ecosystem services support a substantially longer and more specialised value chain in Estonia than in the Netherlands.

Figure 6. Timber provision, final-demand perspective (EE vs NL)

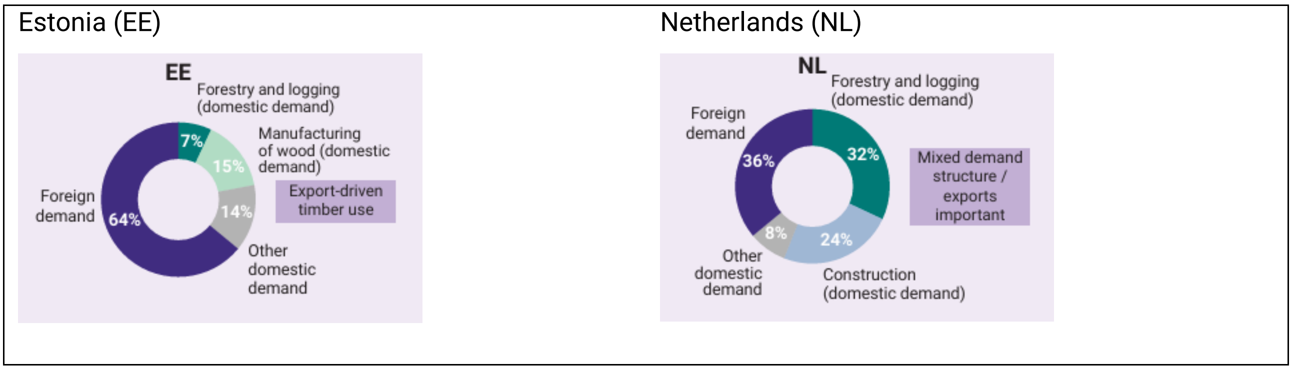


Figure 7 presents the supply-side footprint of timber provision, highlighting the sectors whose value added depends on supplying goods and services to forestry and related timber-production activities. Forestry remains the dominant enabling sector in both countries, but Estonia exhibits stronger contributions from logistics, transport and internationally connected industries. This reflects the greater integration of timber provisioning into export-oriented value chains and supporting economic activities

Figure 7. Timber provision, supply-side perspective (EE vs NL)

Estonia (EE) Netherlands (NL)

The patterns observed in Figures 4-7 are further summarised in Tables 5 and 6.

The overall footprint indicators reveal substantial differences in the way ecosystem-service dependency propagates through the two economies. While crop provisioning remains predominantly domestically embedded in both countries, timber provisioning exhibits considerably stronger international propagation, particularly in Estonia. Own-sector dependency remains important in both services, but is substantially lower for Estonian timber, indicating a broader distribution of ecosystem-service benefits across the value chain.

The comparison suggests that the economic significance of ecosystem services is influenced not only by the characteristics of the service itself but also by the structure of the economy through which the service enters production and final demand. Timber provisioning provides the clearest example: the service is associated with remarkably different dependency structures in Estonia and the Netherlands despite a common accounting framework.

4.3.2 Final-demand dependencies

Table 5. Main final users of ecosystem services (Netherlands and Estonia)

Ecosystem service	Netherlands	Estonia
Crop provision	Food industry (24%) and agriculture (32%) dominate,	Food industry (35%) and agriculture (34%) dominate
Timber provision	Forestry and logging account for 50%, construction 2%, and wood processing just 1%	Wood processing (15%), forestry (7%), construction (EE + foreign ~5–12%)

The final-demand perspective identifies the sectors whose final consumption ultimately activates ecosystem-service use. For crop provisioning, the patterns are similar in both countries. Agriculture and food manufacturing dominate the final-demand footprint, demonstrating that ecosystem-service benefits are transmitted beyond direct users into food-processing systems.

Timber provisioning presents a contrasting picture. In Estonia, ecosystem-service values are embodied further along the value chain, particularly in wood processing, construction and export-oriented production. In the Netherlands, a much larger share of the footprint remains associated with forestry itself, indicating a stronger concentration of benefits around the direct-user sector.

The differences observed in Figure 6 suggest that timber-related ecosystem-service dependency is strongly influenced by national industrial organisation and value-chain structure. Whereas crop provisioning supports a relatively similar food-system configuration in both countries, timber provisioning generates markedly different patterns of downstream dependency. This demonstrates that the economic significance of ecosystem services depends not only on the ecosystem service itself but also on the configuration of the economic system through which it is utilised.

These results show that final-demand footprints provide useful information on where ecosystem-service dependence ultimately materialises within the economy and how ecosystem-related shocks may propagate through production and consumption systems.

4.3.3 Supply-side dependencies

Table 6. Main supply-side sectors (Netherlands and Estonia)

Ecosystem service	Netherlands	Estonia
Crop provision	High own-sector input (45%), trade, and labour (3%)	High own-sector input (41%), supported by energy (4%) and basic services in Estonia and abroad
Timber provision	Forestry (48%), real estate 3%, wood industry (2%) plus machinery, maintenance, and trade inputs (2%)	Forestry (39%) plus logistics, transport and service inputs

The supply-side perspective focuses on the industries that facilitate, or enable, ecosystem-service utilisation by the direct user. For crop provisioning, both countries exhibit similar levels of own-sector dependency, indicating that agriculture itself remains a major enabling activity in ecosystem-service utilisation.

For timber provisioning, forestry remains the dominant enabling sector in both countries. However, Estonia displays stronger contributions from logistics, transport and trade-related activities, reflecting the importance of international value chains and export-oriented processing. The Dutch structure appears more concentrated around forestry and closely related activities.

Together, the supply-side results reveal the wider economic infrastructure that depends on ecosystem-service-using activities and would therefore be indirectly affected by changes in ecosystem-service availability.

The supply-side perspective demonstrates that ecosystem-service utilisation depends on a broader set of economic activities than direct-use statistics alone would suggest. Ecosystem-service use creates dependencies not only among downstream beneficiaries but also among the sectors that provide complementary inputs to direct ecosystem-service users. In this sense, supply-side footprints reveal the economic infrastructure that would be indirectly affected by changes in ecosystem-service availability or quality

4.3.4 Synthesis on input-output analyses results

The comparison of Estonia and the Netherlands demonstrates that ecosystem-service dependency is shaped primarily by economic structure. While ecosystem services generate dependencies in both countries, the distribution of those dependencies through value chains differs according to sectoral structure, export orientation and production systems. In both countries, provisioning ecosystem services generate economic linkages that extend beyond direct users and become embedded in broader production systems.

The combined interpretation of Figures 4-7 demonstrates that final-demand and supply-side perspectives capture two complementary dimensions of ecosystem-service dependency. The final-demand perspective identifies where ecosystem-service benefits ultimately materialise, whereas the supply-side perspective identifies the activities that enable ecosystem-service utilisation. Together, they provide a more complete picture of how ecosystem services are embedded within production systems and value chains.

Crop provisioning exhibits relatively similar dependency structures centred on agriculture and food production in both countries. For crop provision, both countries exhibit a food-system-centred dependency profile. Ecosystem-service benefits ultimately support agriculture and food manufacturing, while agriculture itself remains the dominant enabling sector. Despite differences in scale, the overall structure of ecosystem-service dependency is therefore relatively similar in Estonia and the Netherlands.

Timber provisioning, by contrast, reveals substantial differences associated with national forest-sector characteristics, processing capacity and export orientation. For timber provision, the dependency profile differs substantially between the two countries. Estonia exhibits an export-oriented processing-chain structure in which ecosystem-service benefits extend beyond forestry into wood manufacturing, construction and foreign demand. In contrast, the Dutch profile remains considerably more concentrated around forestry itself. These results demonstrate that ecosystem services with similar ecological functions may generate very different economy-wide dependency structures depending on the configuration of national value chains and patterns of international trade.

The analysis also demonstrates the value of distinguishing between final-demand and supply-side perspectives. The former identifies the economic uses that activate ecosystem service utilisation, while the latter identifies the activities that facilitate it. Together, they provide complementary information on how ecosystem-service dependencies are embedded in economic systems.

From a methodological perspective, environmentally extended input-output analysis substantially extends the information contained in ecosystem service supply and use tables by revealing economy-wide dependency structures beyond direct users.

4.4 Way forward with environmentally extended input-output analysis

The analysis presented here is preliminary and will be extended in several directions. First, the comparison will be expanded to additional ecosystem services, such as nature-based tourism, where both monetary values and input-output linkages are policy-relevant.

Secondly, the structure of intermediate dependencies within the production systems should be further explored. These dependencies are captured in the integrated footprint results, but their detailed structure is not visible. A more explicit representation of intermediate dependencies, for example, through analysis of direct requirements and substitution possibilities, could further enhance the understanding of economic reliance on ecosystem services. This represents a possible direction for future work. As described in chapter 4.2.3.

Third, the structure of the Estonian and Dutch industries that are direct users of ecosystem services (i.e. the two analysed through EE-IOA) would need a more thorough characterisation from the intensity-of-inputs-other-than-the-ecosystem-service point of view. Noting that the way we measure (better: indicate) the ecosystem service (i.e. the quantity of crops harvested or of wood grown) -referring to material benefits which incorporate a non-fixed quantity of human inputs – does not allow to assess the effects of changes in the ecosystem contribution separately from that of changes in human inputs. Therefore supplementary information on these inputs and on their relationship with the output is important.

Finally, the connected values that are most relevant for policy may emerge from considering the policy side. E.g. if the policy objective of food security is considered, a relevant value (both monetary and non-monetary) is the share of the food used in the country that is provided by domestic ecosystems.

5 Results overview

5.1 Integrated assessment

The two methodological strands developed in this paper address complementary dimensions of ecosystem service importance. The Socio-Ecological Context Assessment characterizes the ecological capacity underlying ecosystem-service provision and the social, institutional and spatial factors that mediate the translation of this capacity into realised service flows and societal benefits. The input-output analysis identifies the sectors and value chains that depend on that supply. Considered separately, each perspective provides only a partial understanding. Considered together, they provide an initial basis for identifying where ecological vulnerability coincides with economically significant dependency.

Table 7. Integrated socio-ecological and economic dependency dashboard

Ecosystem service	Main ecological dependency/vulnerability	Main socio-institutional mediators	Condition–service relationship	Keywords on values	Estonia dependency profile	Netherlands dependency profile	Interpretation of connected values
Crop provision	Soil structure and functioning, water regulation, nutrient cycling, pollination and pest regulation; vulnerable to soil degradation, drought and intensive management	Agricultural policy, land management, drainage, infrastructure, markets and farm management.	Positive, but non-linear	Market output, land rent and resource rent overlap; ecological contributions may be embedded in production values; loss-risk values are not market values	Food-system-centred final-demand footprint, predominantly domestic; supply-side footprint concentrated in agriculture.	Food-system-centred final-demand footprint, with stronger foreign orientation; supply-side footprint concentrated in agriculture.	Crop provision combines broad economy-wide dependency with ecological vulnerabilities that may remain partially hidden by human inputs and management. Current production, resource-rent and land-rent indicators reflect realised economic benefits but may not fully reveal declining ecological capacity. Because the negative effects of ecosystem degradation can propagate beyond agriculture into food manufacturing, trade and final consumption, risk-based, dependency-related and restoration-cost values provide important complementary information regarding long-term food-system resilience and vulnerability.
Timber provision	Forest growth and regeneration, soils, hydrology and disturbance regulation; vulnerability to drought, storms, pests and disease	Forest governance, ownership structures, harvesting regulations, conservation status, management and timber markets	Positive, but non-linear	Asset values, annual flows, resource rent and land annuity represent different concepts and should not be added; timber values capture only part of wider forest values	Wood-processing-centred final-demand footprint, predominantly foreign; supply-side footprint centred on forestry with broader sectoral links.	Forestry-centred final-demand footprint, more domestically oriented; supply-side footprint strongly concentrated in forestry.	Timber provision combines long-term ecological dependencies with economy-wide value-chain dependencies. Stock-based and flow-based values capture different aspects of forest ecosystems and should not be interpreted as equivalent measures. While timber-related values reflect current ecosystem-service use, realised timber supply is not determined solely by ecological capacity. Forest ecosystems simultaneously support biodiversity, climate regulation, recreation and other ecosystem services, meaning that societal preferences, conservation objectives and governance choices may constrain timber utilisation well before ecological limits to forest growth are reached. The dependency analysis further shows that in Estonia a substantial share of timber-related dependency is

							linked to wood-processing industries and foreign demand. Dependency indicators therefore provide important complementary information on both the wider economic significance of timber ecosystem services and the socio-ecological context within which timber production occurs.
Crop pollination	Viable and diverse pollinator communities, floral resources, nesting habitat and landscape connectivity; vulnerable to habitat loss, fragmentation and pesticide pressure	Landscape coordination, agricultural policy, pesticide regulation and habitat management	Strong positive	Dependency estimates, policy expenditure, restoration costs and willingness-to-pay measure different dimensions and are not additive	not assessed	not assessed	The ecological relationship is comparatively direct, but realised benefits depend on the spatial coincidence of pollinators and pollinator-dependent crops, as well as farm management. N.b. Economic dependency analysis has not been undertaken. Would need more granular input-output tables, otherwise it is the same as for crops in general.
Global climate regulation	Carbon retention and sequestration in biomass, soils and peat; vulnerable to drainage, harvesting, fire and severe disturbance	Climate policy, LULUCF governance, forestry and agricultural policy, drainage regulation and restoration policy	Threshold-dependent	Carbon stocks, annual flows, carbon-price equivalents, avoided damages and willingness-to-pay answer different questions and should not be combined	not assessed	not assessed	Changes in ecosystem condition can produce persistent shifts in carbon dynamics, particularly where drainage or disturbance changes ecosystems from net removal towards emissions. Large stock-based monetary estimates indicate the significance of carbon at risk rather than directly realisable economic value. N.b. Economic dependency analysis has not been undertaken. Would require establishing direct connection to industries as users.
Air filtration	Vegetation cover, leaf area, canopy structure and vegetation health; mediated by pollutant concentrations, meteorology and spatial configuration	Urban planning, green-infrastructure management, air-quality policy and location relative to pollution sources and exposed populations	Positive but non-linear	Avoided health damages most directly represent societal benefits; replacement costs and property-price effects are indirect and may overlap with other urban ecosystem services	not assessed	not assessed	Vegetation condition affects pollutant-removal capacity, but realised health benefits depend strongly on the spatial relationship between vegetation, pollution and exposed populations. N.b. Economic dependency analysis has not been undertaken. Would require establishing direct connection to industries as users.
Local climate regulation	Shading, evapotranspiration, canopy cover, permeable soils and water	Urban planning, tree protection, stormwater managemen	Unclear / insufficient evidence	Available willingness-to-pay estimates combine cooling with other	not assessed	not assessed	Green–blue infrastructure clearly contributes to cooling, but current Estonian evidence does not adequately quantify the pathway from ecosystem extent and condition to air-temperature

	availability; vulnerable to canopy loss, drought and soil sealing	t, public-health policy and green-space management		benefits; avoided health costs, energy savings and restoration costs represent different concepts			reduction and human heat-exposure benefits. This limits both condition–service characterisation and monetary interpretation. N.b. Economic dependency analysis has not been undertaken. Would require establishing direct connection to industries as users.
Nature-based tourism	Biodiversity, ecosystem integrity, scenic quality and landscape character; vulnerable to ecological degradation and loss of landscape quality	Accessibility, recreation infrastructure, protected-area management, tourism services and visitor preferences	Moderate to strong positive but non-linear, context-dependent	Visitor expenditure reflects supported economic activity rather than welfare; expenditure and willingness-to-pay measures may overlap or represent different value concepts	not assessed	not assessed	Ecological condition (ecosystem extent and quality) contributes to recreational capacity, but realised tourism flows depend strongly on accessibility, infrastructure, visitor preferences and destination management. N.b. Economic dependency analysis is planned but not yet available. Connection with industries through tourist expenditure to be established.

The integrated assessment highlights three main patterns. First, the relationship between ecosystem condition and service capacity (given the extent) differs substantially among services. Some relationships are relatively strong and direct, while others are non-linear, threshold-dependent or currently insufficiently quantified. Moreover, ecological capacity does not translate automatically into realised service flows: management, infrastructure, institutions, accessibility, spatial configuration and demand may strengthen, constrain or temporarily mask the effects of changing ecosystem conditions.

Second, the preliminary input-output results for crop and timber provision show that economic dependencies extend beyond the sectors that directly use ecosystem services. They are transmitted through downstream production and final-demand structures as well as through upstream sectors providing inputs that enable ecosystem-service use. The comparison between Estonia and the Netherlands further indicates that the geographical distribution of these dependencies depends on national production structures and trade orientation.

Third, combining socio-ecological context with economic dependency clarifies the interpretation of connected monetary values. Different indicators may relate to different stages of the pathways from **ecosystem extent and condition** on the one hand and **social context** on the other hand to **realised ecosystem-service flow** and **societal or economic benefit** and therefore cannot generally be treated as interchangeable or additive measures. The integrated framework is consequently most useful not for identifying a single measure of ecosystem-service importance, but for showing **where ecological vulnerability occurs, how realised benefits are mediated, where economic dependencies are located, and what different monetary indicators can legitimately be interpreted to represent**.

Table 7 should therefore be interpreted as an analytical synthesis rather than a formal risk assessment. Its purpose is to identify where ecological vulnerability, socio-institutional mediation and economic dependency intersect, and thereby to support the interpretation of connected values in different policy contexts.

6 Discussion and future development

6.1 Implications for ecosystem accounting

The results suggest that socio-ecological characterisation and economic dependency analysis can serve as complementary interpretation layers for ecosystem accounting. The former helps explain the conditions, vulnerabilities and constraints underlying ecosystem-service supply, while the latter identifies the sectors and value chains that depend upon such supply.

6.2 Future methodological development

Several avenues for future work remain. First, the socio-ecological assessments require completion through expert review and testing across a wider range of ecosystem services and national contexts.

Second, the dependency analysis should be extended beyond provisioning services to other ecosystem services where meaningful links to economic activity can be established. A potential avenue for future research would be to explore more systematically how different connected value indicators can be analysed through input-output frameworks. While provisioning services such as crop provision and timber provision are directly linked to economic activities represented in input-output tables as these are the direct users of the ES, other value concepts such as willingness-to-pay estimates, restoration costs or substitute costs may require additional methodological development. Future work could therefore investigate which categories of connected values can be meaningfully integrated into supply-side and final-demand dependency analyses and what types of policy-relevant questions such integration could address. A particularly promising case is nature-based tourism, where the connection between ecosystem services and economic transactions is comparatively transparent. Tourist expenditure can be allocated to the sectors providing the associated goods and services, making it possible to trace the propagation of ecosystem-service-related demand through the economy using standard Leontief-based input-output techniques. Nature-based tourism may therefore provide a useful bridge between provisioning services and a broader application of dependency analysis to other categories of connected values.

The way ecosystem services are measured (or indicated), for example through harvested crops or wood production, does not allow the effects of ecosystem contributions to be distinguished from those of human inputs. Additional information on input use is important. Also, the institutional framing of the activities or of the providing ecosystems' governance (e.g. ownership structure and prevailing management objectives) can be further characterised.

The results suggest that future development of SEEA EA may benefit from strengthening the interpretative dimension of ecosystem accounting. Existing guidance provides robust frameworks for measuring ecosystem condition, ecosystem services and associated monetary values, but less guidance is available on how these indicators should be interpreted when used for policy analysis and decision-making. The findings presented here indicate that interpretation cannot be derived directly from measurement results. Similar ecosystem-service values may emerge under very different socio-ecological conditions, while services with similar ecological foundations may support markedly different economic dependency structures. Consequently, the significance of ecosystem services cannot always be inferred from physical or monetary indicators alone.

The Socio-Ecological Context Assessment and Economic Dependency Analysis presented in this paper are proposed as complementary interpretative layers rather than new accounting tables. The first helps explain the ecological and institutional conditions that underpin service provision and the relationship between ecosystem condition and service capacity. In this regard, the approach may complement existing SEEA EA guidance by making more explicit the relationship between ecosystem condition and ecosystem-service supply, extending the logic already reflected in ecosystem-service logic chains. The second helps identify where ecosystem-service dependencies occur within the wider economy and who ultimately benefits from ecosystem services beyond direct users, thereby providing information that is not directly visible in current ecosystem-service supply and use tables. Together, these approaches suggest a possible direction for future evolution of SEEA EA: moving from a framework focused primarily on measurement towards one that also provides structured support for interpretation. Such an evolution would not require further changes to the accounting core of SEEA EA, beyond an explicit recognition that multiple monetary values may coexist, each informing different aspects of the relationships between ecosystems, the economy and society. Rather, it could take the form of supplementary guidance aimed at improving understanding of ecosystem-service viability, economic dependency and the interpretation of multiple connected values

In particular, the results highlight three areas where further methodological development may be valuable. First, a more explicit characterisation of condition-service relationships could support the interpretation of ecosystem-service indicators by clarifying when, and to what extent, changes in ecosystem-service capacity and flows can be expected to reflect changes in ecosystem condition.

Second, additional guidance on the interpretation of multiple connected values could help users understand how different monetary indicators relate to different stages of the pathway from ecosystem condition to societal benefits and why these values should not be treated as interchangeable measures of ecosystem-service importance.

Third, approaches for analysing economy-wide dependency on ecosystem services could complement existing accounts by revealing how ecosystem-service benefits and dependencies propagate through production systems, value chains, final demand and international trade. They could also support the derivation of additional connected values reflecting indirect economic dependence on ecosystem services beyond their direct users.

Taken together, these developments point towards a possible future role for supplementary interpretation layers around SEEA EA. Rather than introducing new core accounts, provided that monetary ecosystem accounting adequately recognises and accommodates multiple values, such layers could support the interpretation of ecosystem condition indicators, ecosystem-service accounts and connected values by making ecological vulnerability, socio-institutional mediation and economic dependency more explicit for policy users. In this way, they could help bridge the gap between ecosystem-service measurement and policy application while remaining fully consistent with the accounting principles of SEEA EA.

Finally, additional work is required to improve international comparability and support broader testing across European countries.

6.3 Open questions for London Group discussion

The work also raises questions for future development of SEEA EA.

This paper presents two complementary methodological extensions to the Connected Values framework. The Socio-Ecological Context Assessment addresses the interpretive gap by characterising the ecological and social conditions underpinning ecosystem-service supply, while the environmentally extended input–output analysis addresses the structural gap by tracing ecosystem-service dependencies beyond direct users through economic systems.

The results suggest that monetary values connected to ecosystem services should be considered in terms of the ecological conditions that support their delivery and the broader economic systems that depend on them.

Neither the Socio-Ecological Context Assessment nor the dependency indicators are proposed as core accounting tables. Rather, they may serve as supplementary analytical products that support the interpretation, communication and policy use of ecosystem accounts in the context of the growing recognition that multiple values may coexist and play different analytical roles in ecosystem accounting. Their combined application offers a practical way to identify situations where economically important ecosystem-service dependencies coincide with ecological vulnerability.

We invite members of the UN London Group on Environmental Economic accounting to comment on how could this work inform future SEEA EA development.

How could SEEA EA further characterize the link between ecosystem condition and ecosystem capacity, including through a more explicit treatment of condition-service relationships?

(SEEA EA Chapters 5, 6.5, Appendix A6.1, Annex II)

How could SEEA EA operationalise the assessment of economy-wide dependence on ecosystem services beyond direct users, including dependencies embodied in supply chains, final demand and international trade? (SEEA EA Chapters 11, 14.4.3, Annex II)

How could SEEA EA better build upon the recognition of multiple connected values that reflect different stages of the pathways from socio-ecological conditions to realised service flows and societal benefits? (SEEA EA Chapters 2.4, 12, 14, Annex II)

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ANNEX A Illustration of the MRIO-based ecosystem-service dependency workflow

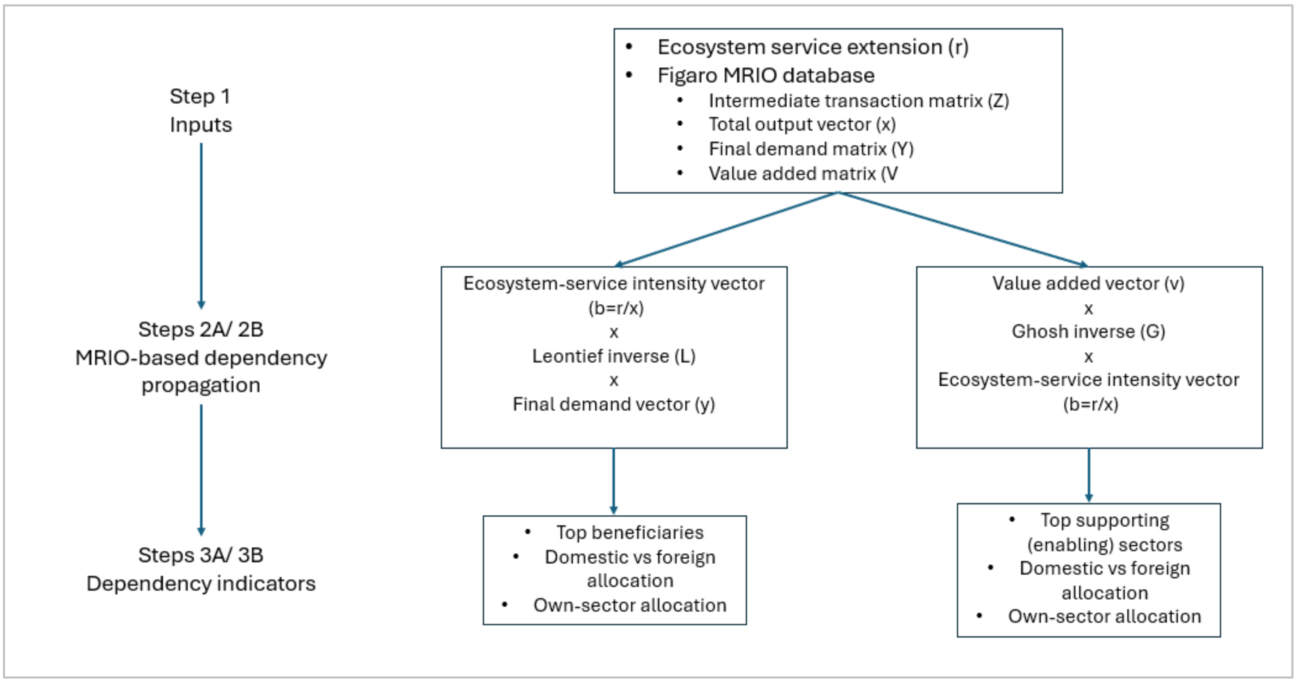
Note: Throughout the annex, lowercase bold symbols denote vectors, uppercase bold symbols denote matrices.

General workflow

The MRIO-based ecosystem-service dependency analysis combines ecosystem-service values from the ecosystem accounts with the economic production structure represented by the FIGARO MRIO database. The workflow consists of three stages: (i) preparation of the input data, (ii) propagation of ecosystem-service values through the production network using two complementary analytical perspectives, and (iii) calculation and interpretation of dependency indicators.

Figure ANNEX A1 provides an overview of the complete workflow used in this study.

Figure ANNEX A.1. Workflow for deriving ecosystem-service dependency indicators from the FIGARO MRIO framework.



The ecosystem-service extension is combined with the FIGARO MRIO database to derive two complementary perspectives on ecosystem-service dependency. The final-demand perspective (A) identifies the industries ultimately benefiting from ecosystem-service use through final demand, whereas the supply-side enabling perspective (B) identifies the industries supporting the utilisation of ecosystem services along the production chain.

Step 1. Inputs

Step 1.1. Identification of the direct user

The ecosystem-service use table identifies the economic unit that directly uses each ecosystem service.

For wood provisioning, the direct user is the **Forestry and logging** sector (NACE A02).

Ecosystem service	Direct user (NACE)	Monetary value, million euros
Wood provisioning	Forestry and logging (A02)	762

The monetary value assigned to the direct user forms the starting point for the MRIO analysis.

Step 1.2. Construction of the ecosystem-service extension

The ecosystem-service value is transformed into an ecosystem-service extension vector **(r_{ij}).**

The extension assigns the ecosystem-service value only to the direct-user sector, while all other sectors receive zero.

Sector	Ecosystem service value (r_{ij}), million euros
A02 Forestry and logging	762
All other sectors	0

The extension vector therefore represents the direct use of the ecosystem service within the economy.

Step 1.3. Calculation of the ecosystem-service intensity vector

The ecosystem-service intensity vector expresses the ecosystem-service value embodied in one monetary unit of output of each sector. It is obtained by dividing the ecosystem-service extension by the total output of each sector and forms the starting point for both the final-demand and supply-side enabling perspectives.

$$\boldsymbol{b_{ij}} = \frac{\boldsymbol{r_{ij}}}{\boldsymbol{x_{ij}}}$$

where

$\boldsymbol{rij}$ = ecosystem-service extension vector,

$\boldsymbol{xij}$ = total output vector of sector j.

Step 2. MRIO-based dependency propagation

The analysis is based on the FIGARO industry-by-industry Multi-Regional Input-Output (MRIO) database, which describes intermediate transactions, final demand and value added for 64 industries across European countries and selected non-European economies. These data describe the economic production structure through which ecosystem-service values are propagated across domestic and international supply chains.

The following steps give technical description of this propagation using two complementary analytical perspectives – final demand perspective (A) and supply-side enabling perspective (B):

Final-demand perspective

-
- **Step 2.1 (A) Construction of the technical coefficient matrix**

The intermediate transaction matrix (**Z**) records the monetary flows of goods and services exchanged between industries.

The technical coefficient matrix (A) is obtained by dividing each intermediate transaction by the total output of the purchasing sector.

$$\boldsymbol{a_{ij}} = \frac{\boldsymbol{z_{ij}}}{\boldsymbol{x_j}}$$

, where

z_{ij} - - intermediate deliveries from sector $i$to sector j,

x_j- - total output of sector j.

The technical coefficient matrix **A** describes the direct production relationships between industries. Each coefficient indicates the amount of direct input required from a supplying sector to produce one monetary unit of output in the purchasing sector.

Example: A coefficient of **0.40** means that producing one monetary unit of wood products requires **0.40 monetary units of direct forestry output**.

- ***Step 2.2 (A) Propagation through the production network***
-

The technical coefficient matrix is used to calculate the Leontief invers e

$$L = (I - A)^{-1}$$

, where

I - the identity matrix, representing the initial production required to satisfy one unit of final demand

A – technical coefficient matrix

The Leontief inverse extends the direct production relationships represented by **A** to include all direct and indirect production requirements throughout the supply chain.

- Step 2.3 (A) Footprint calculations

The final-demand dependency perspective is calculated as

FP_{FD}= *b * L * diag(y), where*

b -the ecosystem-service intensity vector,

L - Leontief inverse,

diag(y) – diagonal matrix constructed from the final-demand vector.

- **Supply-side perspective**
-
- The supply-side footprint approach follows the Ghosh framework and traces ecosystem-service contributions through the upstream production structure of the economy. The Ghosh inverse captures how primary inputs and resource-based contributions are distributed through economic supply chains
-
- **Step 2.1 (B) Construction of the allocation coefficient matrix**

The allocation coefficient matrix (**C**) describes how the output of each supplying sector is distributed among purchasing industries. It is obtained by dividing each intermediate delivery by the total output of the supplying sector.

$$c_{ij} = \frac{z_{ij}}{x_i}$$

where

c_{ij} - the allocation coefficient representing the proportion of the output of supplying sector $i$delivered to purchasing sector j;

z_{ij}- intermediate deliveries from sector $i$to sector j;

x_i - the total output of supplying sector i.

The allocation coefficient matrix therefore describes the **direct output distribution relationships** between industries. Unlike the technical coefficient matrix, which measures production requirements, the allocation coefficient matrix measures how the output produced by each sector is allocated across purchasing industries throughout the economy.

Example: A coefficient of **0.40** means that **40% of the total output of the forestry sector is supplied to the wood-products industry**.

- ***Step 2.2 (B) Propagation through the production network***

The allocation coefficient matrix is used to calculate the Ghosh inverse, which extends the direct output allocation relationships represented by the allocation coefficient matrix to include indirect distribution effects throughout the production network.

$$G = (I - C)^{-1}$$

where

$\boldsymbol{I}$ – identity matrix;

$\boldsymbol{C}$ – allocation coefficient matrix;

$\boldsymbol{G}$ – Ghosh inverse.

The Ghosh inverse extends the direct output allocation relationships represented by the allocation coefficient matrix to include indirect distribution effects throughout the production network. It is used to derive the supply-side enabling perspective by tracing how the outputs of the direct-user sector are distributed, both directly and indirectly, throughout the production network.

- ***Step 2.3 (B) Footprint calculations***

The final-demand enabling perspective is calculated as

*FPss = diag(v) * G * diag(b), where*

diag(v) – diagonal matrix constructed from the value added vector

G = Ghosh inverse

b – the ecosystem-service intensity vector