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ANALYSIS

Towards measuring environmental income through a refined United Nations SEEA EA: Application to publicly-owned, protected, pine-forest-farm case studies in Andalusia, Spain

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ABSTRACT

The United Nations monetary System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) does not recommend the measurement of the environmental incomes of single products from an ecosystem accounting area. The objective of this paper is to uncover the accounting period environmental income given by the environmental operating return embedded in single biological-based products consumed, plus their environmental asset gain, by applying the authors' refined extended monetary accounts of the SEEA EA. The standard System of National Accounts (SNA) and the refined SEEA EA frameworks are applied to 12 protected publicly-owned mixed-pine-forest-farm case studies in Andalusia, Spain. The comparison of results shows that the net value added for the pine-forest farms estimated under the refined SEEA EA is four times greater than that of the standard SNA, indicating the importance of uncovering the exchange values provided by the operating returns on manufactured capitals and environmental assets of products consumed without market prices. After omitting the carbon ecosystem service to avoid double counting, the ecosystem services and changes in the environmental assets made up 68% and 32%, respectively, of the aggregate environmental income from the 11 environmental assets valued in the pine-forest-farm case studies in 2010.

1. Introduction

The standard System of National Accounts (SNA) ignored the operating returns (henceforth net operating surpluses) of the manufactured capitals and ecosystem environmental assets of the final products consumed without market prices corresponding to the non-financial corporations (e.g., farmers) and government (henceforth ecosystem trustee). The SNA also omits the valuation of real capital gains at the close of the period that accrue from the invested manufactured capitals and environmental assets in the ecosystem accounting area.

To address the shortcomings of the SNA with regard to the contribution of nature, the United Nations Statistics Commission (UNSC) is currently discussing the future standardization of the extended monetary accounts of the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA), although the objective of measuring the total income of the ecosystem has not yet been incorporated (United Nations et al., 2021).

In its annual meeting on March 11, 2021, the UNSC adopted the SEEA EA chapters 8–11 as "internationally recognized statistical principles and recommendations for monetary ecosystem services and environmental asset valuations" (UNSD, 2021). These monetary chapters of the SEEA EA (henceforth SEEA) are not yet a standard and the research agenda is open to discussion on the framework of extended monetary accounts and indicators of ecosystem income beyond the narrow net domestic product (henceforth net value added) of economic activities measured by the SNA.

Oddly, the extended monetary accounts of the SEEA only measure active-use products (United Nations et al., 2021: 6.69, p. 136) but ignore the net operating surpluses of the final products consumed of landscape conservation (henceforth landscape) and wild species threatened with extinction (henceforth biodiversity) as they are considered "non-use" demand values (United Nations et al., 2021: paras 6.60–6.63–6.64–6,70,

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pp. 135–136–137; United Nations, 2022). We believe that the extended monetary accounts of the SEEA develop a narrow and inconsistent valuation of the ecosystem environmental income from individual products.

In this article we apply the SEEA principles of simulated non-market product monetary valuation derived from the application of production function, stated and revealed preference methods. We extend the ecosystem service (synonymous with the environmental net operating surplus concept in our refined SEEA EA) of the SEEA by incorporating the net operating surpluses of landscape and biodiversity in our refined SEEA EA (henceforth refined SEEA). Our refined SEEA is aimed at estimating the environmental income, which is controversially advised against by the extended monetary accounts of the SEEA (United Nations et al., 2021: paras. 12.48–12.49). The refined SEEA and the SEEA estimate the same ecosystem service values as well as the opening and closing environmental assets of the individual products, with the exception of the passive uses of landscape and biodiversity omitted by the SEEA.[1] A review of the literature shows that estimates of ecosystem services and environmental assets at farm scale incorporating valuations of private and public products in the same territorial unit are the exception. The scarce literature on the SEEA in its version prior to the most recent update is focused on larger scales than the microeconomic scale of the farms, with the exception of the cork oak and holm oak farms in the case studies of Andalusia (Campos et al., 2019a; Campos et al., 2020).

Marais et al. (2019) refer to three ecosystem accounting frameworks developed at farm scale. The first is the SEEA, which has not yet been developed to cover farm-scale extended monetary accounts although there is potential for the SEEA to be developed for use at farm scale in the future (Lammerant, 2019). A second framework proposes an 'ecological balance sheet' (EBS) that enables the application of accrual accounting principles to ecological assets at farm scale (Ogilvy, 2015). The third is the Agroforestry Accounting System (AAS) framework, this being "perhaps the most advanced of the existing frameworks […], which estimates total income accrued from a range of market and non-market products delivered by agroforestry systems" (Marais et al., 2019: p.10).

The AAS has been applied internationally at farm scale in Corsica (France) to publicly-owned Bonifatu maritime pine forests (Campos et al., 2007), in Iteimia (Tunisia) to a publicly-owned Cork-oak agroforestry system (Campos et al., 2008), on the Alentejo coast (Portugal) to privately-owned mixed Stone pine-cork oak woodland (Coelho and Campos, 2009) and in Californian (United States) to privately-owned Oak woodlands ranches (Oviedo et al., 2017).

Based on the UNSC adopted exchange value principles of the extended monetary accounts of the SEEA, the objective of this application of our refined SEEA to the protected publicly-owned mixed-pine-forest-farm case studies in Andalusia is to measure the environmental income of the ecosystem derived from a biological-based product consumed in the accounting period and/or expected to be consumed in future periods. The concept of environmental income aligned with Hicksian income is defined as the maximum possible consumption of a biological-based product from the ecosystem accounting area in a period without depleting its bio-physical productivity and ecosystem services over an infinite time horizon, all other things being equal (Campos et al., 2021a; Caparrós et al., 2003; Cavendish, 2002: 53; European Communities, 2000: 87; Hicks, 1946:179; Krutilla, 1967: 779; McElroy, 1976; NRC, 1999:192–193; Sjaastad et al., 2005).

The above mentioned shortcomings of the economic statistics under the SNA and the ongoing SEEA for forests at national/sub-national scale are mitigated by our Agroforestry Accounting System (AAS) applied at individual farm scale in Andalusian woodlands and pine forests (Campos et al., 2019b; Campos et al., 2020; Campos et al., 2021a).

In this paper, the refined SEEA and the standard SNA frameworks are applied to 12 publicly-owned pine-forest-farm case studies in the Andalusian region of Spain. In these forest farms we have previously estimated the Hicksian total income by applying our Agroforestry Accounting System (AAS) (see Campos et al., 2021a: Fig. 5 and Supplementary Table S5). In this paper, the application of the refined SEEA measures 11 products that generate environmental incomes (timber, firewood, grazing, hunting, aromatic herbs, recreation, mushrooms, carbon, landscape conservation, threatened biodiversity and regulated runoff water supply). Six products do not generate ecosystem service production factors (residential service, livestock product, agricultural crops, manufactured amenity service, conservation forestry service and fire service). In this article we compare the net values added estimated by our refined SEEA and by the Agroforestry Accounting System and the standard SNA for each single pine-forest-farm product valued.

We focus on the two main innovations in the extended monetary accounts of the SEEA with respect to SEEA applications described in the literature prior to its most recent update (La Notte et al., 2021). The first innovation in the updated SEEA is the incorporation of the government ecosystem trustee manufactured cost[2]; thus allowing the estimation of the ordinary and investment costs of public products which are hidden under the SNA. The second innovation in the SEEA is the recognition of environmental income with a transaction value meaning and therefore, consistent with estimates of ecosystem services and environmental assets under our refined SEEA (United Nations et al., 2021: paras. 12.48–12.49, p. 266). These innovations open up options for the discussion of our extensions of ecosystem services from passive-use outputs and ecosystem environmental income in the context of the UNSC research agenda for the future standardization of SEEA extended monetary accounts.

2. Background to institutional rationale and total income results for the pine- forest-farm case studies

2.1. Dominant tree species in the pine-forest-farm case studies

The case-study forest farms (FF) cover 47,262 ha in the region of Andalusia, Spain. The dominant tree species in the FF are *Pinus halepensis* Mill., *Pinus nigra* Arn., *Pinus pinaster* Ait. and *Pinus sylvestris* L. Vegetation and other land uses comprise 59% pine timber forest, 6% woodland, 17% other hardwood and mixed coniferous forest, 13% shrubland, 3% grassland, 1% agricultural cropland and 1% buildings, rocks and water body areas (Campos et al., 2021a: Tables ST1 and ST4).

Physical yields of woody natural growth and extractions along with other economic uses in the FF case studies are described in Campos et al. (2021a: Supplementary text S2, Table ST4). The FF are located within protected natural areas and parts of two pine-forest farms fall within the *Sierra Nevada National Park*, where timber harvesting and recreational hunting are excluded (Campos et al., 2021a: Fig. ST1). Traditional uses[3] by the farmer are maintained and good practices with regard to forest-fire fighting/prevention, mushroom picking, open-access recreational visits and preservation of threatened wild biodiversity are actively encouraged by the governments of Andalusia and Spain (Campos et al.,

[1] "Note that the role of habitat and biodiversity in supporting the conservation of significant species is not considered an ecosystem service and the estimation of the associated non-use values are not discussed here" (United Nations, 2022; para 4.3.12, p. 81).

[2] However, farmer (FA) products estimated on the basis of the previous SEEA versions are consistent with the updated SEEA, including the private amenity self-consumption product. This consistency of the previous SEEA versions as regards the FA products are due to the SNA admitting the manufactured intermediate product and its counterpart of own ordinary manufactured intermediate consumption (European Commission et al. 2009; para. 6.120).

[3] Traditional extractive practices by the farmer in the FF include timber, firewood, grazing, recreational hunting, livestock, water supply, and other minor products, etc.).

2021a: Supplementary text S2).

2.2. Institutional rationale for the pine-forest-farm case studies

These FF are indefinitely excluded from the competitive land market by the forestry laws of Spain and Andalusia. The relevance of this restriction of land ownership rights is that it leads to the disappearance of the private amenity product environmental asset of the farmers. In the forests of Andalusia, the land market interiorizes the enjoyment of the amenity consumption by natural person private owners (non-industrial owners). If the case-study publicly-owned forest farms cannot be sold freely on the land market over an infinite time horizon, then the possibility that it can be acquired and the private amenities enjoyed in the future by a private non-industrial owner (natural person) will disappear.

The refined SEEA (henceforth rSEEA) applied to the FF attributes the ownership of the products consumed exclusively to the farmer (FA) and the government ecosystem trustee (ET) institutional sectors (Campos et al., 2021a). We assume that the appropriation and/or consumption of final goods and services by open-access natural persons are ET final product donations.

The 17 economic products valued under the SEEA applied to the FFs are attributed to the ten private products of the farmer (timber, firewood, grazing, aromatic plants, livestock, hunting, residential service, amenity of the tenant livestock keeper, conservation forestry and agriculture) and to the seven public products of the ecosystem trustee (fire services, mushrooms, water supply, carbon, recreation, landscape conservation and biodiversity preservation).

While extractive harvests are maintained in the FFs, the economic management by the farmer and ecosystem trustee are primarily motivated by the conservation and/or enhancement of the final product consumption of public services without market prices. It is this economic rationale of the FFs that explains this lack of final product consumption (recreation, landscape conservation and biodiversity preservation) incorporated in the conservation forestry and fire service products in the rSEEA. These products, which provide manufactured intermediate products and their counterparts of own intermediate consumptions for the same values at production prices, plus a competitive imputed manufactured operating return, are mainly allocated to the landscape conservation product. The FF total product consumptions and own-account manufactured gross fixed capital formation of the FA and the ET directly, are influenced by government policies on pine forest re-naturalization (Díaz-Balteiro et al., 2015; Montero et al., 2015; Ovando and Campos, 2016). This involves continuing the biological-restoration management of the life cycles of controlled pine-tree species and other woody biota, replicating the cycles of natural regeneration over an infinite time horizon.

The results for the natural resource stocks and flows in the period confirm the biophysical sustainability of the FFs, based on programmed re-naturalization forestry (outside the market competitive price system[4]) for the provision of public final product consumption, without market prices, and accumulated as enhancement less degradation in the closing environmental assets.

We assume that the FA and ET of the case-study FFs accept the recurrent negative cash flows as being offset by competitive returns on their manufactured investments, originating from the surpluses of the non-commercial economic products (Campos et al., 2021a: Table S5; Campos et al., 2021b: Subsection 2.2.11).

[4] The concept of biological sustainability refers to the precautionary principle and has been proposed outside the price system. Biological sustainability has been defined as the Safe Minimum Standard (SMS) threshold that mitigates/avoids irreversible losses of a unique genetic variety not reproducible by human engineering (Berrens, 2001; Norton, 1987).

2.3. Hicksian total income background for pine-forest-farm case studies under the agroforestry accounting system

The authors' Agroforestry Accounting System (AAS) aims to estimate the Hicksian total income by aggregating the incomes from labour; manufactured investment and the natural environment in a manner consistent with the exchange value principle of the SNA (see details of AAS total income measurement in the case-study forest farms in Campos et al., 2021a). Our AAS aggregates other forest products in the Economic Account for Forestry which are hidden in the net value added of the Economic Account for Agriculture (EAA) and the government (ecosystem trustee) general account of the standard SNA. The AAS extends the records of the SNA to include the intermediate product and its counterpart of own ordinary intermediate consumption and the intermediate consumption of environmental work in progress used. The AAS also widens the concept of economic product of the forest by incorporating the final products consumed of surface runoff water stored further down the catchment area as well as the virtual final consumption of global-warming-mitigating carbon fixation for which the production functions lack manufactured production factors (produced with human intervention). The AAS estimates the net operating margins of the final products consumed without market prices (omitted by the SNA) by applying environmental valuation methods of consumer stated preferences (e.g. recreation service, landscape conservation service and biodiversity preservation service). The AAS estimates the environmental income of an individual product by aggregating the estimated values of the environmental net operating margin and the environmental asset gain. After reorganising their components, both terms present the environmental income as the aggregate value of the ecosystem service and the change in environmental net worth of the individual product (see comparison of key AAS and rSEEA economic indicators in Supplementary text and Figs. A1 and A2).

3. Refined SEEA environmental income concept applied to pine-forest farms

3.1. Problem of synonymy in economic ecosystem accounting

We mitigate the problem associated with synonymy in the ecosystem accounting literature by specifying the acronyms of equivalent terms. In this paper, the following synonymous terms are grouped together where they refer to the same concepts in the standard SNA and rSEEA applications to the FF: (a) government (GO) in the SNA and government ecosystem trustee (ET) in the rSEEA, (b) resource rent (RR) in the SEEA, ecosystem service (ES) in the SEEA and environmental net operating surplus (NOSe) in the rSEEA, (c) change in environmental asset (CEA) in the rSEEA and environmental asset enhancement (CEAen) and degradation (CEAde) in the rSEEA, (d) depletion as environmental work in progress used (WPeu) in the SEEA and withdrawal of environmental asset used (EAwu), (e) gross domestic product (GDP) and gross value added (GVA), (f) operating income (OI), net domestic product (NDP) and net value added (NVA) and (g) environmental income (EI) and change in environmental-asset-adjusted net environmental operating surplus (NOSead).

3.2. Valuation of environmental assets

In this paper environmental asset (EA) is defined as the present net value of the ecosystem services (resource rents) embedded in the expected future flows of product consumptions from the ecosystem accounting area over an infinite time horizon. All circumstances affecting the environmental asset valuation are assumed unchanged, except those arising from changes in forestry cycles relating to the biological growth of woody products and their harvesting, fruits (acorns) and their impact on greenhouse carbon flows and stocks. The wide variety of future environmental, institutional and economic circumstances that affect the

Table 1
Refined SEEA key single-product valuation methods and accounting applied to the pine-forest-farm case studies in Andalusia.

Class	Acronym	Measurement	Selected references
1. Livestock manufactured amenity self-consumption of non-commercial intermediate product of service accruing from private livestock keeper's revenue voluntary opportunity cost	ISSnca	It is measured as imputed competitive livestock manufactured net operating surplus (NOSmcli) less residual net operating surplus (NOSmrli) valued at an imputed competitive livestock manufactured immobilized capital (IMCmli) investment real rate of return (r) of 3%: ISSnca = NOSmcli – NOSmrli	Campos et al., 2021b
2. Manufactured non-commercial intermediate product of donation service accruing from public landowner's revenue voluntary opportunity cost	ISSncd	It is measured as a public landowner product j imputed competitive manufactured net operating surplus (NOSmj) less residual net operating surplus (NOSmrj) valued at an imputed competitive manufactured immobilized capital (IMCmj) investment real rate of return (r) of 3%: ISSncd = NOSmcj – NOSmrj	Campos et al., 2021a: Supplementary Text S3, Table S4
3. Manufactured non-commercial intermediate products of service compensation	ISSncc	It is measured as re-defined operating subsidies less taxes on production (SNT) of System of National Accounts (SNA) as ecosystem trustee compensation: ISSncc = SNT	Campos et al., 2019b: Supplementary Text S3, Table S4; Campos et al., 2021a
4. Final product consumption of forestry conservation service	FPfc	It is measured as purchased ordinary total cost (TCopfc) plus an imputed competitive manufactured immobilized capital (IMCmfc) of 3% real rate of return (NOSmcfc): FPfc = TCopfc + NOSmcfc	Campos et al., 2021a: Supplementary text S3
5. Final product consumption of fire service		It is measured as purchased ordinary total cost (TCopfs) plus an imputed competitive manufactured immobilized capital (IMCmfs) of 3% real rate of return (NOSmcfs): FPfs = TCopfs + NOSmcfs	Campos et al., 2021a: Supplementary text S3
6. Final product consumption of mushrooms gathered by open-access recreation visitors	FPcmu	It is valued as quantity gathered by visitors (Qmu) times imputed local market price (Pmu) FPcmu = Qmu*Pmu	Campos et al., 2019a: Supplementary text S6; Martínez-Peña et al., 2015: Tables 15–16)
7. Final product consumption of forest economic water runoff stored in reservoirs	FPcwa	It is valued valued at unitary resource rent (environmental price) at a real rate of 3% of environmental asset, the latter is valued by hedonic pricing method accruing from irrigated land: FPcwa = Qwa*Pwa	Beguería et al., 2015; Campos et al., 2019a: Supplementary text S4
8. Final product consumption of tree and shrub carbon product fixation	FPcca	Carbon fixation (and emission) are valued according to the European trading market system: FPcca = Qca*Pca	Campos et al., 2019a: Supplementary text S1.7; SENDECO2, 2015
9. Final product consumption of visitor open-access recreation	FPcre	It is valued through a face to face contingent valuation survey of representative Spanish households. Half the number of visits (Qre/2) times the value of the visits according to the upper bound (UB) price of the median willingness to pay ($MWTPre_{UB}$) derived from on-site contingent valuation surveys of forest visitors: FPcre = Qre/2*Pre	Campos et al., 2019a: Supplementary text S9.2; Table S14: Oviedo et al., 2015: Table 9
10. Final product consumption of preservation service for threatened wild biodiversity at risk of extinction	FPcbi	It is valued as ecosystem trustee ordinary total cost (TCobi) as the lower bound (LB) of passive consumers' marginal willingness to pay ($MWTPbi_{LB}$) plus additional marginal willingness to pay (AMWTPbi) above TCobi based on a household choice experiment survey carried out face to face among the Andalusian adult population: FPcbi = TCobi + AMWTPbi	Campos et al., 2019a: Supplementary text S9.3; Campos et al., 2021a: Supplementary Table S4
11. Final product consumption of landscape conservation service	FPcla	It is valued as ecosystem trustee ordinary total cost (TCobi) as the lower bound (LB) of passive consumers' marginal willingness to pay ($MWTP_{LB}$) plus additional marginal willingness to pay (AMWTP) above TCobi based on a household choice experiment survey carried out face to face among the Andalusian adult population: FPcla = TCola + AMWTPla	Campos et al., 2019a: Supplementary text S9.3; Campos et al., 2021a: Supplementary Table S4; Campos et al., 2020: Fig. 1

assumed expectations of future ecosystem services are of considerable uncertainty. The latter are mitigated in valuations of farmer environmental assets when full property rights to buy/sell the land are recognized. Valuations of ecosystem trustee environmental assets present greater uncertainty than those of the farmer because they depend on the simulation of consumers' marginal willingness to pay (MWTP) (Alfsen and Greaker, 2006; OECD, 2006).

The biological functions and modelling of future harvests of woody products of the four tree species and shrubs in order to estimate the flows and stocks of the environmental assets of the FFs in this paper are detailed in Campos et al. (2019a: Fig. 2, Table 1 and Supplementary texts S1.2, S2–S3 and S13) and Campos et al. (2021a: Sub-section 4.6 and Tables 1 and S1–S3).

Whatever the type of entries and withdrawals in the environmental asset balance sheet, these have no effect on the opening and closing valuations of individual assets. The inevitably subjective valuations of environmental assets lack real meaning in practice, except for those private environmental assets embedded in the land market price. The opening (EAo) and closing (EAc) environmental assets are valued independently from each other and from the recorded entries and withdrawals of the period by applying a constant real discount rate of 3% over an infinite time horizon (see the general expression of the net present value equation in Campos et al. (2019a: Supplementary text S1.2). The environmental asset balance sheet account entries and withdrawals are dependent on the interactions with the production account.

In the monetary rSEEA applied in this paper, the final product of natural growth and carbon emission consumption of environmental fixed capital are recorded in the production account, as is the case in the Agroforestry Accounting System (AAS) application to the FFs, where the virtual entries and withdrawals of the ecosystem balance sheet account are expanded without altering the environmental income and environmental asset valuations (Campos et al., 2021a: Table 1 and Fig. 4). In this circumstance, in the rSEEA, the only ecosystem asset records required to estimate the environmental income are those of the opening (EAo) and closing (EAc) environmental assets, the withdrawal used (EAwu)[5] and the residual value of the revaluation of the environmental asset (EAr) (see Supplementary text S1).

However, despite the absence of entries and virtual withdrawals in this rSEEA application to the FF, the physical movements which take place as regards the biological assets are known, which makes it possible to independently estimate the closing asset of the product in the same way as the opening asset was estimated. Thus, in this study, the change in the environmental asset corresponds to the values of the enhancements and degradations and the timing effect of the discount rate in the period, given the assumptions of price stability, absence of catastrophic environmental destructions, changes in soil and vegetation uses, transfers of property rights and consumer demands, all else being equal.

3.3. Refined SEEA product function and production factor remunerations

The rSEEA values a product j (Pj) by quantity (Q) times transaction price (P) observed in formal markets or simulated in the case of a product consumed without market price. The simulated transaction prices are estimated by the upper bound (UB) of marginal willingness to pay ($MWTP_{UB}$) revealed and/or stated by physical persons and/or the institutions that represent them. Once estimated, the Pj is allocated among its manufactured and environmental production factors of the production function (F) (Edens and Hein, 2013: eq. (1)):

$$Pj \equiv F(ICj, LCj, FCmj, EAj) \quad (1)$$

where ICj is manufactured intermediate consumption (purchased and own), LCj is labour compensation (employee and self-employed), FCmj is manufactured fixed capital that gives rise to its user cost in the form of manufactured consumption of fixed capital (CFCj) and manufactured net operating surplus (NOSmj), and EAj is the ecosystem environmental asset that provides the environmental net operating surplus (NOSej) composed of the environmental work-in-progress used or depletion (WPeu = EAwu) and the ordinary environmental net operating margin (NOMeoj).[6]

The rSEEA function F of product j gives rise to the accounting identity, the components of which are described in the production and generation of income account (United Nations et al., 2021: para. 9.36, p. 196):

$$Pj_{rSEEA} = ICj + LCj + CFCj + NOSmj + NOSej \quad (2)$$

Product j is distributed among the production factors with preference criteria known in advance and with environmental services being the last to be remunerated. The preferred remunerations of the production factors in the first possible observed or simulated transaction of the product are employee labour compensation (LCej), purchased manufactured intermediate consumption (ICpj), own ordinary manufactured intermediate consumption (ICmooj), imputed self-employed labour compensation (LCsej), manufactured consumption of fixed capital (CFCj), competitive/residual manufactured net operating surplus as the return on immobilized manufactured capital (NOSmc/rj), environmental work-in-progress used (WPeuj = EAwuj) and, as the balancing item, the competitive/residual ordinary environmental net operating margin (NOMeoj).

Given the general application of the product function F (Pj), the dependence on the type and remuneration of the production factors is specific to the property rights of the area and rationales of the economic agents and consumers in the period when the product is consumed. The valuation method chosen in each case of WPeu and NOMeo depends on the specific institutional conditions of property rights and the capacity of the analyst to produce the required information (see Table 1 for key products concepts and valuation methods applied in FFs case studies).[7]

3.4. Measurement of non-market final product consumptions of biodiversity preservation and landscape conservation services

The extended monetary accounts of the SEEA denote the government general account of the SNA referring to the total public spending on biological-based products, manufactured capital and environmental assets of the ecosystem accounting area as government ecosystem trustee.

Landscape conservation refers to the option chosen by the consumer in the current period to pay an additional premium through a tax over an agreed period of time. In return, the ecosystem trustee guarantees that the quantity of goods and services available to the consumer in the current period in the ecosystem accounting area will not decline by the end of the period. The additional tax (marginal willingness to pay additional to the government ordinary total cost) does not include the threatened wild biodiversity preservation service. The procedure for calculating the additional premium is the same as that for the threatened

[5] Environmental asset withdrawal used (EAwu) is equivalent to work in progress used (WPeu) inventoried and valued according to its resource rent at the opening of the period. The rSEEA generation of income account registers WPeu as a component of environmental net operating surplus (NOSe).

[6] Generally, a product provides only one component of environmental net operating surplus (NOSe), although it may occur that a consumed product is composed of both components (e.g., inventoried non-migrant game captures are classified as WPeu, while non-inventoried game captures are classified as NOMeo).

[7] In order for the market or simulated price of a consumed product to match its NOSe (equivalent to ecosystem service and resource rent) its production function must depend solely on the services of the environmental asset.

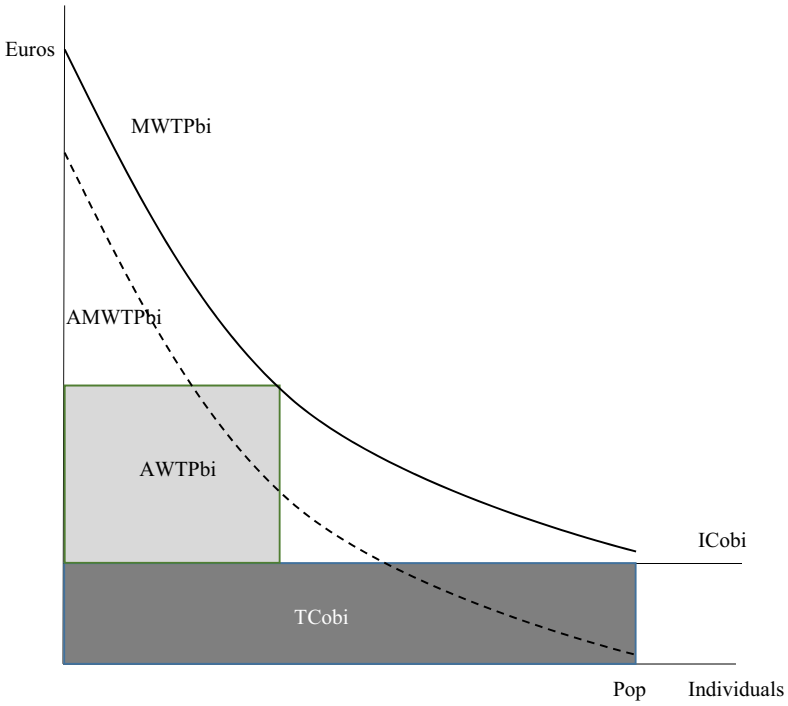

Fig. 1. Stylized simulated total demand for preservation of the threatened biodiversity and landscape final product consumption services applied in pine-forest-farm case studies in Andalusia.
Acronyms: MWTPbi is maximum marginal willingness to pay (the solid downward sloping line): Adding vertically the AMWTPbi and ICobi lines yields the MWTPbiTCobi is ordinary total manufactured cost observed only for the current 224 number of threatened species (Qbi*): current taxes paid by passive consumers. AWTPbi is additional willingness to pay by passive consumers (is equivalent to net operating surplus-NOSbi): dashed line in Fig. 1, light grey area in Fig. 1.ICobi is each individual paying a constant amount, where I stands for individual (the horizontal line).Pop is total adult population in Andalusia.

biodiversity additional tax (see Fig. 1).

The passive-use final products consumed, represented in the case-study forest farms by landscape conservation and the preservation of wild biodiversity threatened with extinction (henceforth biodiversity), are measured using the same valuation methods and calculation procedures. This sub-section is limited to a description of the steps followed in the estimation of the consumption of the biodiversity service final product. However, their product concepts differ. Landscape conservation is a passive use by consumers which represents the "insurance premium" paid in return for assuring that the landscape will continue to offer at least the same natural-biological products as currently exist for a future period of three decades. The landscape conservation service product (FPcla) is considered public given its open-access character and the fact that it is financed directly through donations of intermediate products of services (ISSncd) by the public owners of the FFs and indirectly by the passive consumers via taxes and valued at transaction prices based on consumer preferences (see detailed definition of landscape governance in Council of Europe, 2000).

The precautionary principle prevails over consumer preferences in public policies that seek to avoid/mitigate the risk of losing a unique wild genetic variety forever. Whilst these geo-referenced ecosystem service results are very useful for land management purposes, when dealing with issues such as biodiversity existence value, maximising income should not be the only indicator used in decision-making. Where public investments are motivated by the preservation of unique biotic natural variety, the policy maker could implement interventions that require compensation for loss of income to local economic units, such as farmers. Moreover, the whole of society may suffer losses of income due to government investment aimed at avoiding the extinction of threatened wild species. The possible loss of income would be justified by the public investor on the basis of the precautionary principle and social tolerable cost.

The consumers are considered the primary collective owners of the immobilized capital in the production of the service of threatened biodiversity preservation. The government acts as the exclusive subrogated owner (ecosystem trustee) of the existence value of the final product consumed (FPcbi) of the service for the preservation of biodiversity threatened with extinction. Consumers improve their well-being by "paying" for the service of preserving threatened biodiversity, which means avoiding/mitigating an increase, by one individual species, in the number (Qbi) of those threatened with extinction at the closing of the current period. This threatened biodiversity service is a final product consumed (FPcbi) valued at its simulated transaction price.

The existence value output of a unique wild genetic variety at risk of extinction is the maximum marginal willingness to pay (MWTPbi) by passive consumers. In this paper, the rSEEA measures the biodiversity existence value as the maximum simulated transaction price, whereby the ecosystem trustee "charges" for one part and "sells" another part as a "benefit" to the passive consumers of the FPcbi of the threatened biodiversity. The part of the FPcbi that the ecosystem trustee "charges" to consumers is the ordinary total manufactured cost (TCobi) financed through taxes and the part that it "sells" is the net operating surplus (NOSbi) valued according to the additional willingness to pay (AWTPbi), stated by consumers, above the TCobi.

The total cost (TCobi) of biodiversity preservation was observed in the forest farms. As the total cost was observed only for the current level of threatened species (Qbi*), we focused the analysis on the preservation of this number of species. Assuming that all adults in Andalusia pay the same amount via taxes (which is a simplification), Fig. 1 shows that each individual is paying a constant amount (the horizontal line, or ICobi, where I stands for individual). Multiplied by the total adult population in Andalusia (Pop), this yields the observed TCobi (the dark grey area in Fig. 1).

In Fig. 1, the solid downward sloping line shows the MWTPbi of passive consumers for the preservation of threatened species. This MWTPbi includes the total amount that consumers are willing to pay to ensure the preservation of the threatened species. As each consumer is already paying, via taxes, the ICobi, we estimated, through a choice experiment, the 'additional' marginal willingness to pay by each individual in the population (the dashed line in Fig. 1, or AMWTPbi, where individuals are ranked from more willing to pay to less willing). More specifically, we estimated a logit function that included the additional willingness to pay for biodiversity and landscape preservation; although for simplicity in Fig. 1 we have drawn it as a function that can be fully attributed to biodiversity preservation (the procedure used to isolate the part assumed to correspond to biodiversity can be found in Campos

Table 2
Comparisons of monetary variable extensions under the SEEA and refined SEEA application to the estimation of pine-forest-farm environmental income.

Name of the variable	Acronym	SEEA	This paper refined SEEA application	Ecosystem accounting register	Ecosystem accounting identity
Environmental income	EI	Explicit measurement of environmental income is excluded by the SEEA EA 2021. In practice, it does measure its components: change in environmental asset (CEA), ordinary net environmental operating margin (NOMeo), depletion (WPeu = EAwu) and carbon ordinary net environmental operating margin (NOMeoca)	The environmental income (EI) is estimated as the ordinary net environmental operating margin (NOMeo) plus the environmental asset gain (EAg). These components of EI are equivalent to the ecosystem service (ES) plus the change in environmental asset (CEA) due to physical enhancement/degradation and the timing effect of expected discounts of ecosystem services at the closing relative to the opening of the period less carbon ordinary environmental net operating margin (NOMeoca)	• Generation of income account registers WPeu, NOMeo and NOMeoca. • Environmental balance sheet account registers the CEA components of opening (EAo) and closing (EAc) environmental assets, and environmental asset withdrawal used (EAwu = WPeu)	EI = NOMeo +EAg EI = WPeu + NOMeo + CEA – NOMeoca EI = ES + CEA – NOMeoca EI = NOSead, applying function F
Environmental asset gain	EAg	The SEEA EA does not explicitly estimate the environmental asset gain (EAg). However, it does estimate its components: implicitly, the change in environmental asset (CEA) and explicitly, environmental asset withdrawal used (EAwu) and adjustment for the double counting of the carbon ordinary environmental net operating margin (NOMeoca)	Environmental asset revaluation (EAr) less double counting of carbon ordinary environmental net operating margin (NOMeoca)	• Generation of income account registers NOMeoca • Environmental balance sheet account registers the CEA components of opening (EAo) and closing (EAc) environmental assets, environmental asset withdrawal used (EAwu = WPeu) and environmental asset revaluation (EAr)	EAg = EAr – NOMeoca EAg = CEA + EAwu – NOMeoca
Environmental asset revaluation	EAr	The SEEA EA does not explicitly estimate the environmental asset revaluation (EAr). However, it does estimate its components implicitly: the change in environmental asset (CEA) and explicitly, environmental asset withdrawal used (EAwu)	Change in environmental asset (CEA) assuming constant resource rent price plus environmental asset withdrawal used (EAwu) of provisioning resource inventoried at opening of period valued at resource rent price	• Environmental balance sheet account registers the CEA components of opening (EAo) and closing (EAc) environmental assets, environmental asset withdrawal used (EAwu = WPeu) and environmental asset revaluation (EAr)	EAr = CEA + EAwu
Net operating surplus	NOS	Manufactured net operating surplus (NOSm) plus environmental net operating surplus (NOSe). NOSe components are depletion (EAweu = WPeu) and ordinary environmental net operating margin (NOMeo) (United Nations et al., 2021: para. 9.35)	Manufactured net operating surplus (NOSm) plus environmental net operating surplus (NOSe). NOSe components are depletion (EAweu = WPeu) and ordinary environmental net operating margin (NOMeo) (United Nations et al., 2021: para. 9.35)	• Generation of income account registers NOSm, NOSe, WPeu and NOMeo	NOS = NOSm + NOSe NOSe = WPeu + NOMeo
Environmental net operating surplus	NOSe	Depletion plus net return on environmental assets (United Nations et al., 2021: para. 9.35)	Environmental work in progress used (WPeu = EAwu) plus ordinary environmental net operating margin (NOMeo)	• Generation of income account registers NOSe, WPeu and NOMeo	NOSe = WPeu + NOMeo
Depletion	EAwu	Environmental asset withdrawal used of provisioning resource (EAwu) inventoried at opening of the period valued at resource rent price (United Nations et al., 2021: para. 10.28)	Environmental asset withdrawal used of provisioning resource (EAwu = WPeu) inventoried at the opening of the period valued at resource rent price	• Balance sheet account registers depletion (EAwu) as withdrawal of provisioning resource inventoried at the opening of the period valued at resource rent price • Production account registers environmental work in progress used (WPeu) as intermediate consumption	EAwu = WPeu =
Change in environmental asset	CEA	Enhancement and degradation of environmental asset assuming constant resource rent price (CEA) (United Nations et al., 2021: Table 10.1, paras. 10.15–10.21)	Change in environmental asset assuming constant resource rent price (CEA)	• Balance sheet account registers the opening and closing environmental assets	CEA = EAc –EAo CEA = EAr – EAwu
Change in environmental asset adjusted to environmental net operating surplus	NOSead	Explicit measurement of NOSead is excluded by the SEEA EA 2021. In practice, it does measure its components of implicit change in environmental assets (CEA), and explicitly, depletion (WPeu = EAwu), ordinary environmental net operating margin (NOMeo), and carbon ordinary environmental net operating margin (NOMeoca)	Change in environmental asset (CEA) adjusted environmental net operating surplus (NOSe)	• Generation of income account registers environmental net operating surplus (NOSe) • Environmental balance sheet account registers change in environmental asset components of EAo and EAc	NOSead = NOSe + CEA NOSead = EI, applying function F

(*continued on next page*)

Table 2 (*continued*)

Name of the variable	Acronym	SEEA	This paper refined SEEA application	Ecosystem accounting register	Ecosystem accounting identity
Carbon environmental income	EIca	The SEEA EA adopts an eclectic description of the transaction value of carbon global warming mitigation. The SEEA EA still faces the challenge of monetary ecosystem accounting for carbon. The SEEA EA does not present the definition of the transaction value of the product and its ecosystem service natural production factor (United Nations et al., 2021; para. 13.4, Annex 13.2)	This article estimates the product of the carbon consumed by the exchange value of its fixation (FPcca) for trees and shrubs at the trading price of the European industrial emissions market. Carbon product does not incur manufactured costs and therefore the values of the product consumed (FPcca) and its ordinary environmental net operating margin (NOMeoca) coincide and this in turn coincides with the ecosystem service (ESca). The biological functions of the expected future tree and shrub growth and harvest give the values of the environmental carbon assets at the opening and closing of the period discounted at the real rate of 3%. The change in the carbon environmental asset (CEAca) gives the carbon environmental income (EIca	• Carbon generation of income account registers ordinary environmental net operating margin (NOMeoca) • Carbon environmental balance sheet account registers the opening and closing environmental assets	EIca = NOMeoca + CEAca – NOMeoca EIca = CEAca CEAca = EAcca – Eaoca
Ecosystem service	ES	The SEEA EA defines ecosystem service as the environmental asset exchange value contribution embedded in consumption of total products (TPc) in the accounting period. The ES components are depletion (WPeu = EAwu) plus ordinary environmental net operating margin (NOMeo) (United Nations et al., 2021: para. 9.35)	This paper registers the ecosystem service (ES) according to its production function F implicitly embedded in the total product consumed (TPc) and explicitly as environmental net operating surplus (NOSe) natural production factors of function F. The ES components are depletion (WPeu = EAwu) plus ordinary environmental net operating margin (NOMeo)	• Production accounts register the consumptions of total (intermediate and final) products (TPc) • The generation of income account registers the environmental work in progress used (WPeu) and ordinary environmental net operating margin (NOMeo)	ES = WPeu + NOMeo ES = NOSe ES = RR

et al., 2019a). Adding vertically the AMWTPbi and ICobi lines yields the MWTPbi.

The additional willingness to pay, or AWTPbi (light grey area in Fig. 1), was identified assuming that the government sets an additional "price" aimed at internalizing the maximum willingness to pay not captured in the TCobi.

3.5. *Expanding the standard SNA and the monetary SEEA towards the refined SEEA*

Theses FF applications of the refined monetary SEEA concepts and valuation methods are consistent with the principle of observed and/or simulated exchange values of total product consumptions (TPc) with and without market prices (Campos et al., 2019a, Campos et al., 2021a; Caparrós et al., 2017; Oviedo et al., 2015, 2016; United Nations et al., 2021: chapters 8–11). The extended monetary accounts of the SEEA maintain the inconsistent income criterion of the SNA net operating surplus of incorporating the ecosystem production factor of environmental work-in-progress used (WPeu) in the environmental net operating surplus (NOSe).

In the rSEEA applications to FFs, open-access harvested goods are not included under "other human activities" of the institutional household sector as in the SNA, but rather, under the ecosystem trustee, which we assume 'donates' the harvested products to open-access visitors who collect them. This criterion is supported by the fact that open-access harvesting of products is governed by good practices regulated by law, which do not distinguish between the type of farmer, but depend on the conservation status of the wildlife species. This convention is due to having assumed collective ownership of mushrooms by the ecosystem trustee and considering recreational mushroom pickers as direct consumers of the final product of mushrooms.

The rSEEA estimates total product in the ecosystem accounting area classified by individual product, farmer and ecosystem trustee institutional sectors and the forest farms (FFs) as a whole.

The rSEEA applied in the FF reveals the environmental net operating surplus (NOSe) that is hidden in the net operating surplus (NOS) and simulates the exchange values of the net operating surpluses (NOS), omitted by the SNA, for the final product consumption (FPc) without market price corresponding to the farmer and ecosystem trustee. In addition, the rSEEA applied in the FFs expands the standard SNA economic products of the ISIC[8] list by incorporating natural water runoff stored in public reservoirs and carbon-based products that lack factors of production (see Table A1 for detailed description of SNA and rSEEA links).

This paper provides several extensions in comparison to the UNSC recommended monetary SEEA framework, without affecting the valuations of single ecosystem services and environmental assets (United Nations et al., 2021), except for the final products consumed of the landscape conservation and threatened biodiversity preservation services. Below we describe four key refinements to the SEEA.

First, the SEEA total output (TO) does not follow the production function F (United Nations et al., 2021: Table 11.3). The refined SEEA (rSEEA) in this paper estimates intermediate product (IP) and final product (FP) components as total product at social prices (TP) according to function F (eq. 1). The rSEEA estimate of TP allows the ecosystem service to be considered an environmental production factor rather than a product. This rSEEA criterion avoids the double counting of ecosystem services embedded in SNA products so that they are instrumentally incorporated in the intermediate consumption (United Nations et al., 2021: Table 11.3).

Second, as is the case with the SNA criterion, the SEEA considers operating subsidies less taxes on production (SNT) as transfers. In this paper, SNT are re-defined as additional intermediate products of the

[8] International Standard Industries Classification (UNSD, 2008).

Table 3
Stylized sequence of environmental income accounts under the rSEEA applied to the pine-forest-farm case studies in Andalusia (2010: €/ha).

Class	Farmer (FA)	Ecosystem trustee (ET)	Forest farms (FFs)
Production account			
1. Total product (TP)	64.8	325.4	390.2
1.1 Manufactured intermediate product (IPm)	42.2	34.7	76.9
1.1.1 Grazing raw material (IRMgr)	1.1		1.1
1.1.2 Honey raw material (IRMho)	0.1		0.1
1.1.3 Manufactured services (ISSm)	41.1	34.7	75.7
1.1.3.1 Commercial (ISSc)	*24.9*	*34.7*	*59.6*
1.1.3.2 Non-commercial (ISSnc)	*16.2*		*16.2*
1.1.3.2.1 Compensated (ISSncc)	*5.2*		*5.2*
1.1.3.2.2 Auto-consumed (ISSnca)	*2.9*		*2.9*
1.1.3.2.3 Donated (ISSncd)	*8.1*		*8.1*
1.2 Final product (FP)	22.5	290.8	313.3
1.2.1 Final product consumption at producer price (FPc_{pp})	23.7	283.4	307.0
1.2.1.1 Timber	*7.6*		*7.6*
1.2.1.2 Firewood			
1.2.1.3 Grazing	*0.1*		*0.1*
1.2.1.4 Hunting	*5.9*		*5.9*
1.2.1.5 Aromatic herbs	*2.2*		*2.2*
1.2.1.6 Residential	*0.3*		*0.3*
1.2.1.7 Livestock	*4.6*		*4.6*
1.2.1.8 Agriculture	*0.1*		*0.1*
1.2.1.9 Amenity	*2.9*		*2.9*
1.2.1.10 Recreation		*60.1*	*60.1*
1.2.1.11 Mushrooms		*5.7*	*5.7*
1.2.1.12 Carbon (FPcca = NOMeoca)		*53.1*	*53.1*
1.2.1.13 Landscape		*110.2*	*110.2*
1.2.1.14 Biodiversity		*13.5*	*13.5*
1.2.1.15 Water supply		*40.6*	*40.6*
1.2.2 Manufactured gross capital formation (GCFm)	−1.1	7.4	6.2
1.2.2.1 Gross fixed capital formation (GFCF)	*0.0*	*7.4*	*7.4*
1.2.2.2 Change in livestock inventory less purchases (CINli)	*−1.2*		*−1.2*
2. Manufactured intermediate consumption (ICm)	32.5	91.3	123.8
2.1 Purchased intermediate consumption (ICb)	28.5	18.4	46.9
2.2 Own ordinary intermediate consumption (ICoo)	4.0	72.8	76.9
3. Gross value added (GVA)	32.3	234.2	266.4
Generation of income account			
4. Gross value added (GVA)	32.3	234.2	266.4
5. Manufactured consumption of fixed capital (CFCm)	2.5	4.8	7.3
6. Net value added (NVA)	29.8	229.4	259.1
6.1 Labor compensation (LC)	16.6	40.8	57.4
6.1.1 Employee labour compensation (LCe)	15.9	40.8	56.7
6.1.2 Self-employed labour compensation (LCse)	0.7		0.7
6.2 Net operating surplus (NOS)	29.0	229.4	258.4
6.2.1 Manufactured net operating surplus (NOSm)	24.8	45.5	70.3
6.2.2 Environmental net operating surplus (NOSe = ES = RR)	4.3	183.9	188.2
6.2.2.1 Work in progress used (WPeu = EAwu)	*2.7*		*2.7*
6.2.2.2 Ordinary environmental net operating margin (NOMeo)	*1.6*	*183.9*	*185.5*
Environmental asset account			
7. Change in environmental asset (CEA)	39.3	23.3	62.7
7.1 Provisioning (CEApr)	39.3		39.3
7.2 Regulating-maintenance (CEAre)		23.3	23.3
7.3 Cultural (CEAcu)			
8. CEA adjusted environmental net operating surplus (NOSead)	43.6	207.2	250.8
9. Environmental income (EI = NOSead − NOMeoca)	**43.6**	**154.1**	**197.7**

farmer compensated (virtual purchase) by the ecosystem trustee. Intermediate product compensation also affects the allocation of the farmer and ecosystem trustee net operating surplus between manufactured (NOSm) and environmental (NOSe) surpluses. As the non-commercial intermediate product of compensation service (ISSncc) is considered an own ordinary non-commercial intermediate consumption service (SSncooc), it does not affect the net operating surplus NOS_{FF} of the FFs as whole.

Third, in this rSEEA paper, the carbon product ecosystem service application is controversial as it follows the production function F, which does not register the carbon emission as an environmental intermediate consumption or consumption of fixed asset.

Fourth, in theory, the SEEA incorporates the measurement of the provisioning degradation-adjusted environmental net operating surplus ($NOSead_{SEEA}$) only as the negative change in the environmental asset (CEA < pr 0), although in practice it is an ongoing challenge for future research to incorporate the so called "non-use" final product consumption of landscape and biodiversity. In this rSEEA paper we estimate both whole ecosystem enhancement-maintenance (CEA $\geq$ 0) and ecosystem degradation (CEA < 0).

3.6. Products without economic dependence on natural bio-physical factors

In the FF, livestock products do not generate their own ecosystem service. Livestock grazing is recorded as an intermediate product, valued at the imputed market price. This market price incorporates the manufactured and ecosystem service (equivalent to grazing resource rent) production factors. The final livestock product incorporates the intermediate product of grazing as intermediate consumption of manufactured raw material. Thus, it is the grazing product that shows the possible residual value of the ecosystem service of grazing consumed by livestock. The FF non-industrial livestock keeper's self-consumed private amenity is valued at competitive manufactured voluntary opportunity cost.

In the FF, the agricultural crop ecosystem service has a zero residual value.

The residential final service is an 'in-kind' compensation to permanent employees valued by the imputed rental price of the real estate market in nearby towns. The final amenity and residential products consumed could omit ecosystem services if they were valued alternatively, using revealed/stated potential consumer preference methods.

The intermediate products of conservation forestry and fire services are valued at manufactured production cost plus their competitive manufactured net operating margin for the forestry product and at manufactured production cost for the fire services product. These intermediate products are incorporated in the landscape conservation final product consumption.

3.7. Ecosystem services under the refined SEEA

The rSEEA definition of ecosystem excludes human intervention and therefore any preceding flow from the ecosystem is physical up until the moment of human appropriation, when it is incorporated into the economic system. The aim of the generation of income account in the rSEEA

should be to make visible the contribution of the environmental net operating surplus (NOSe) hidden in the net operating surplus (NOS) of the individual products of the FF (see Supplementary text S1). The NOSe is defined as the residual accounting exchange value of the ecosystem service (ES)(Table 2).[9]

Ecosystem services (ES) that contribute to the total products (intermediate and final products) consumed in the period may reveal transaction prices if they are appropriated by individual physical or collective/institutional persons. The definition of transaction price implies agreement between physical persons or entities on behalf of the former.

The SEEA distinguishes between the physical and economic flows of the ecosystem (United Nations et al., 2021: Figs. 2.1–2.2). In the case of physical rSEEA flows, ecosystem services arise prior to the natural biophysical ecosystem assets (EA) as environmental flows without economic value. Thus, ES are incorporated through their physical flows from the ecosystem into the total product consumptions (TPc) of the independent economic units, revealing possible environmental prices (unit resource rent prices) equal to or greater than zero. The rSEEA estimates ecosystem service (ES) embedded in total product consumption (TPc), valued by their observed or simulated revealed/stated residual transaction prices derived from the upper bound of consumers' marginal willingness to pay (MWTP).

In the case of the rSEEA, the generation of income account incorporates the ES, termed NOSe production factor, either non-economic bio-physical or economic, embedded in the TPc generated in the period in the ecosystem accounting area. The two components of NOSe are depletion (EAwu = WPeu) and operating return of environmental asset (ordinary environmental net operating margin-NOMeo) (United Nations et al., 2021: para. 9.36 and Table 2).

WPeu is not a new value arising during the process of generating the final product consumptions of the period. The inclusion of WPeu in the NOSe implies that it is not accounted for in the SEEA and rSEEA as an ordinary environmental intermediate consumption (ICeo = WPeu), this criterion being inconsistent with the concept of ecosystem environmental operating income applied by the Agroforestry Accounting System (Campos et al., 2021a and Supplementary text S2).

The uncertainty of the residual valuation of the NOMeo is derived from the estimate of the competitive manufactured net operating surplus (NOSmc). The latter depends on the subjective choice of the competitive rate of return on ordinary immobilized manufactured capital (IMCmo) (Campos et al., 2021a: Table S3). In the SEEA the possible residual exchange value of the NOS over the respective NOSmc and WPeu gives the ordinary environmental net operating margin (NOMeo), when this residual value is higher than zero. If it is a negative value, then it is assumed that the NOMeo is zero. Given this latter case, the NOSm becomes the residual value:

$$\mathrm{NOSmc} = \mathrm{r}^{*}\mathrm{IMCmo} \tag{3}$$

$$\text{if } \mathrm{NOS–NOSmc–WPeu} > 0, \text{then } \mathrm{NOMeo} = \mathrm{NOS–NOSmc–WPeu} \tag{4}$$

$$\text{if } \mathrm{NOS–NOSmc–WPeu} < 0, \text{then } \mathrm{NOMeo} = 0 \tag{5}$$

$$\text{and } \mathrm{NOSm} = \mathrm{NOS–WPeu} \tag{6}$$

3.8. Developing the environmental income meaning of the rSEEA change in environmental asset adjusted NOSead

The environmental income (EI) is an expected subjective residual value which cannot be measured without linking its estimation to the subjective Hicksian total income of the individual products of the ecosystem accounting area (Campos et al., 2021a). The EI is estimated as the ordinary net environmental operating margin (NOMeo) plus the environmental asset gain (EAg). Rearranging the NOMeo and EAg components of the EI results in a second accounting identity of the EI components of ecosystem service (ES) plus change in environmental asset (CEA), except for the carbon product because of instrumental double-counting (Table 2; Campos et al., 2019a: Supplementary text S1.7). The CEA is due to physical enhancement/degradation along with the timing effect of expected discounts of ecosystem services at the closing relative to the opening of the period (Table 2).

The SEEA does not explicitly estimate the environmental asset gain (EAg), but it does estimate its components implicitly as environmental asset revaluation (EAr) and explicitly as the adjustment for double counting of the ordinary environmental net operating margin of carbon (NOMeoca).

The rSEEA revaluation of the environmental asset (EAr) has income significance since it is the value of the change in the environmental asset (CEA) plus the depletion (EAwu).

The ecosystem service (term synonymous with NOSe) is a concept that may not consistently represent ecosystem environmental income (EI) because it includes the depletion (EAwu = WPeu) cost and does not consider the change in environmental asset (CEA). One possible interpretation of the CEA adjusted environmental net operating surplus (NOSead) adopted by the SEEA is to restrict the adjustment only to the negative CEA (degradation of provisioning environmental assets) (United Nations et al., 2021: Table 11.3).

The application of the rSEEA to the case-study FFs adopts the possibility of a broader interpretation of CEA-adjusted NOSead, which incorporates the positive (enhancements) and negative (degradations) changes in the environmental assets (CEA) (Table 2). According to this criterion, we provide an interpretation of the monetary SEEA which confirms that the NOSead is the implicit measurement of the environmental income (EI) of the individual economic product of the ecosystem that satisfies the production function F (United Nations et al., 2021: Fig, 2.2, Tables 10.5–11.3) (Table 2). The NOSead is a term which is also synonymous with the CEA-adjusted ecosystem service (ESad).

The rSEEA notion of the environmental income as the adjusted environmental net operating surplus (NOSead) is a controversial aspect of the SEEA in that it does not include environmental income among the recommended monetary indicators (United Nations et al., 2021: 12.48). The SEEA assertion that the SNA does not incorporate capital gain in the net operating surplus (NOS) is not correct, as evidenced by the SNA valuations of livestock inventory change in the final product and consumption of fixed capital at replacement price (McElroy, 1976). The corollary of the interpretation of the monetary SEEA in this rSEEA paper is that the NOSead, as measured by rSEEA, is coincident with that of environmental income (EI) and consistently integrated in the Hicksian total income (European Communities, 2000: 87).

Products that are expected to be consumed in the future, in successive replicated periods of infinite duration, generate the possibility of environmental asset revaluation (EAr). In the absence of extraordinary destructions, we define the environmental asset gain (EAg) as the revaluation of environmental assets (EAr) minus the adjusted environmental asset (EAad) due to double counting. In the FFs, double counting refers to consumption of the final carbon product (FPcca) valued by its ordinary environmental net operating margin (NOMeoca) at the closing of the accounting period (Table 2, Supplementary text S1).

The environmental asset revaluation (EAr) of the rSEEA applied in

[9] We remind the reader that in this paper the NOSe and ES variables of a product are used as synonyms for the resource rent (RR).

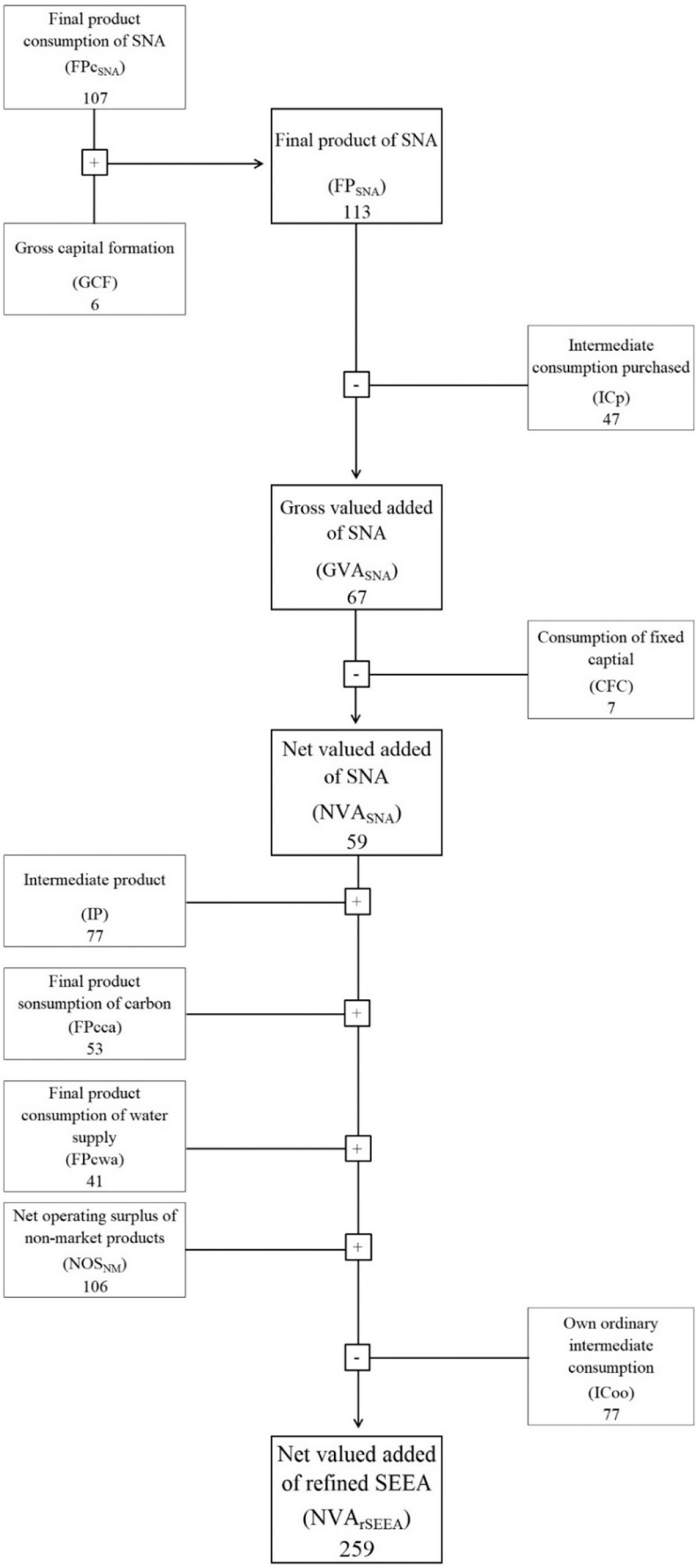

Fig. 2. Comparison of net value added in pine-forest-farm case studies under rSEEA and SNA applications (2010: €/ha).

Table 4
Ecosystem services under the rSEEA applied to the pine-forest-farm case studies in Andalusia (2010: €/ha).

Class	Farmer (FA)	Ecosystem trustee (ET)	Forest farms (FFs)
1. Provisioning services	4.3	45.7	50.0
1.1 Timber	1.1		1.1
1.2 Firewood	0.0		0.0
1.3 Grazing	1.1		1.1
1.3.1 Grass and browse	*1.0*		*1.0*
1.3.2 Acorns	*0.1*		*0.1*
1.4 Hunting	1.5		1.5
1.5 Aromatic herbs	0.5		0.5
1.6 Mushrooms		5.1	5.1
1.7 Water		40.6	40.6
1.8 Livestock	*na*(*)		*na*(*)
1.9 Agriculture	0.0		0.0
2. Regulating-maintenance services		88.0	88.0
2.1 Carbon		53.1	53.1
2.2 Landscape		26.9	26.9
2.3 Biodiversity		8.0	8.0
2.4 Conservation forestry		*na*(*)	*na*(*)
2.5 Fire services		*na*(*)	*na*(*)
3. Cultural services		50.2	50.2
3.1 Private amenity	*na*(*)		*na*(*)
3.2 Public recreation		50.2	50.2
3.3 Residential	*nd*(**)		*nd*(**)
Total	**4.3**	**183.9**	**188.2**

na(*): not applicable.
nd(**): no data.

the FFs includes the changes in the environmental asset in the period due to the discount-time preference effect and the changes in physical yields of the provisioning environmental assets.

As the net present value (NPV) of the closing environmental asset is estimated at constant prices, the rSEEA environmental asset revaluation (EAr) does not incorporate nominal price change (holding gain). The results for the components of the EAr with real economic significance are coincident with the changes in environmental asset enhancement (CEAen) and degradation (CEAde).

3.9. Carbon ecosystem service exchange value accounting

The SEEA still faces the challenge of building monetary ecosystem accounting for carbon global warming mitigation (United Nations et al., 2021; paras. 13.4.3, Annex 13.2). This paper estimates the product of the carbon consumed according to the exchange value of its fixation (FPcca) by trees and shrubs at the trading price of the of the European industrial emissions market (SENDECO2, 2015). The carbon product does not incur manufactured costs and therefore the values of the product consumed (FPcca) and its ordinary environmental net operating margin (NOMeoca) coincide and these in turn equate with the carbon ecosystem service (ESca). The biological functions of the expected future tree and shrub growth and harvest give the values of the environmental carbon assets at the opening and closing of the period, discounted at the real rate of 3%. The change in the carbon environmental asset (CEAca) gives the carbon environmental income (EIca). In the case of carbon, the ESca is the only production factor embedded in the FPcca. In this paper, the NOMeoca of carbon is double counted in the generation of income account and in the change in environmental asset.

4. Economic results for pine-forest-farm case studies under the rSEEA and standard SNA

A detailed description of the total income of individual products and physical results derived from the application of the Agroforestry Accounting System (AAS) in the FF case studies can be found in Campos et al. (2021a). In this section, we focus on the valuation of the applied rSEEA and SNA value added, environmental assets and environmental incomes of the individual product, aggregated products of the farmer and ecosystem trustee institutional sectors, and the overall products of the FFs. The rSEEA individual results for the 17 economic products valued in the FFs are shown in Appendix A (Table A2). The links between the AAS and rSEEA ecosystem service and environmental income results are shown in Appendix A (Figs. A1 and A2).

4.1. rSEEA and SNA forest-farm total products comparison

The total product (TP) of an individual good or service (henceforth product) of the FFs does not incur double counting of its intermediate product (IP) in the final product consumed (FPc). In contrast, the aggregate TP of the farmer (FA) and ecosystem trustee (ET) do incur double counting when the IP are used in their own FPc. The aggregate TP of the FFs incur double counting of the IP embedded in the FPc of the FFs as a whole (Table A2).

Intermediate products (IP), through their own ordinary intermediate consumption counterparts (ICoo), account for 25% of the final products consumed (FPc) of the FF measured by the rSEEA (Tables 3 and A2). Conservation forestry and fire service products make up 78% of the IP (Table A2).

The final product consumption of the farmer and ecosystem trustee estimated by the rSEEA are 0.9 and 3.5 times greater, respectively, than those estimated by the SNA (Table 3 and Supplementary text S3: Table ST1). The final product consumption of forest farms estimated by the rSEEA is 2.9 times that estimated by the SNA (Table 3 and Fig. 2).

The rSEEA non-commercial final product consumption (FPcnc)[10] represents 93% of the total final products consumption of the FFs (Table A2). Ecosystem trustee final products consumed are all non-commercial and account for 92% of the FPcnc of the FFs as a whole.

The rSEEA estimation of final products consumed from landscape conservation (FPcla) is 1.6 times that of the SNA (Tables 3 and ST1). FPcla make up 36% and 66% of the FPc_{FF} estimated by the rSEEA and SNA, respectively (Tables 3 and ST1).

4.2. Net value added

It is assumed that the variable with the greatest impact on economic consumption in the FFs is the net value added (NVA) of the total products, which includes the physical and economic contributions of the ecosystem services. The latter, in addition to their economic contribution to the total product consumption, sustain the biophysical contribution, enabling the generation of labour compensation and return on manufactured capital of natural-biological products. In other words, the residual environmental price of the ecosystem services could be zero and their physical contribution continue to fulfil the conditions for existence and continued generation of manufactured net value added of the natural-biological product consumption.

The differences in the results for the net value added of the FFs estimated by the rSEEA and the SNA are larger than those observed for the FPc of FFs. The farmer and ecosystem trustee net values added estimated by the rSEEA are 1.9 and 4.7 times higher than the respective SNA estimates. The net value added estimated by the rSEEA is 4 times greater than the corresponding SNA estimate. (Tables 3 and ST1 and Fig. 2).

The FF net operating surplus of the rSEEA is 36.4 times higher than that of the SNA (Tables 3, A2 and ST1). The farmer net operating surplus of the rSEEA is 4.1 times that of the SNA. As mentioned in Section 3, the SNA adopts the subjective convention of attributing a zero value to the ecosystem trustee net operating surplus (Table ST1).

[10] In the rSEEA applied to the FFs, non-commercial products are amenity, conservation forestry, fire service, recreation, mushrooms, carbon, landscape, biodiversity and water. The commercial products are timber, firewood, grazing, hunting, aromatic herbs, residential, livestock and agricultural crops.

Table 5
Environmental assets under the rSEEA applied to the pine-forest-farm case studies in Andalusia (2010: €/ha).

Class	Opening	Entry	Withdrawal	Revaluation	Closing
	(EAo)	(EAe)	(EAwu)	(EAr)	(EAc)
1. Farmer (FA)	1387.8		2.7	42.0	1427.1
1.1 Timber	644.7		1.1	38.9	682.5
1.2 Firewood	39.3			2.0	41.3
1.3 Grazing	578.8			−0.5	578.4
1.4 Hunting	108.3		1.5	1.5	108.3
1.5 Aromatic herbs	16.7				16.7
1.6 Amenity	$na^{(*)}$				$na^{(*)}$
2. Ecosystem trustee (ET)	4983.8			23.3	5007.2
2.1 Recreation	1796.9				1796.9
2.2 Mushrooms	191.4				191.4
2.3 Carbon	761.0			23.3	784.3
2.4 Landscape	903.8				903.8
2.5 Biodiversity	299.8				299.8
2.6 Water	1031.0				1031.0
3. Environmental asset (FFs)	6371.6		2.7	65.3	6434.3

Pine-forest farms surface area: 47,262 ha.
$na^{(*)}$: not applicable.

4.3. Ecosystem services under rSEEA measurement

The rSEEA ecosystem services (ES) of the FFs account for 49% of total product consumption (TPc) generated by 10 of the 17 products valued (Tables 3 and 4 and A2). The FF WPeu and NOMeo contributions to the ES are 1% and 99%, respectively (Table 3). However, in relative terms, the contribution is 62% to farmer ES (Table A2). The low rate of timber extraction in the period ($0.8m^3$/ha) explains the contribution to the provisioning ecosystem services of the FFs, which contrasts with the predominant contribution of provisioning ecosystem services of the FF, namely, water and mushrooms (Table 4; Campos et al., 2021a: Table ST4). The ecosystem trustee ES makes up 98% of the FFs ecosystem services (Tables 3, 4 and A2).

The FF ecosystem services ($ES_{FFs} = NOSe_{FFs}$) account for 73% of the NOS_{FFs} and 61% of the final product consumption (FPc_{FFs}) under the rSEEA (Tables 3 and A2). The regulating-maintenance ecosystem services of the FFs account for 47% of the ES_{FFs} (Table 4). This high contribution is mainly due to the carbon and landscape products (Tables 4 and A2). The recreation service is the only cultural ecosystem service estimated in the FFs and slightly exceeds the provisioning ecosystem services (Table 4).

4.4. Environmental income under the rSEEA

The environmental income (EI) of the period is partly dissipated in the form of ecosystem services (ES) embedded in the products consumed and partly accumulated in the ecosystem due to the value of the change in the environmental asset (CEA). The environmental income represents the maximum possible sustainable ES value that occurs when the CEA of an environmental asset is zero. The CEA in this case means that the enhancement (CEAen) and degradation (CEAde) of the environmental asset are coincident at real transaction prices. The FFs present positive environmental asset value changes for timber, firewood and carbon products, negligible negative values for grazing and zero values for hunting, aromatic herbs, mushrooms, water, recreation, landscape and biodiversity. The CEA of timber and firewood make up 97% and 100% of their respective environmental incomes. The five farmer products provide an aggregated environmental income of 44 €/ha, with the CEA contributing 90% (Table A2). In the FFs, five ecosystem trustee (ET) products are estimated to be in steady state and therefore their CEAs are zero, where their ES and EI coincide (Table A2).

The rSEEA environmental asset balance sheet account applied to the FFs does not record entries and the only withdrawal recorded is the provisioning environmental asset withdrawal used (EAwu). The latter has a resource rent (RR) value of 3 €/ha (Tables 5 and A2). The environmental asset revaluation (EAr) of 65 €/ha represents the change in environmental asset (CEA) plus depletion (EAwu = WPeu). This EAr is due to the discounting effect of timing and future physical removals embedded in the ecosystem services of provisioning and regulating assets (Table 5) (see full details of pine-forest case-study environmental asset entries and withdrawals in Campos et al., 2021a: Table 1).

The environmental income of the FF is 198 €/ha. In its first accounting identity it links the ordinary environmental net operating margin (NOMeo: 186 €/ha) of the generation of income account and the environmental asset gain (EAg: 12 €/ha) of the environmental asset balance sheet account (Tables 2, 6 and A1). Provisioning, regulating-maintenance and cultural environmental assets make up 45%, 30% and 25% of the environmental income, respectively (Tables 6 and A1). The EI of the ET is 3.5 times that of the FA (Table 6).

For the individual products of the FFs, the changes in environmental assets (CEA) that supply ecosystem services are all positive values for the 2010 period, with an aggregate value of 63 €/ha (Tables 3, 5 and A2). The CEA in the case of the farmer is 1.7 times that of the ecosystem trustee (Tables 3, 5 and A2).

The EI in the rSEEA makes up 94% of ordinary environmental net operating margin (NOMeo) (Tables 3 and A2). Environmental asset gains (EAg) only account for 6%.

The contributions of ES_{FF} and CEA_{FF} to the FFs environmental income are 77% and 23% (excluding the carbon product), respectively (Tables 3 and A2). In the case of the farmer, the contribution of CEA_{FA} accounts for 90% of the environmental income whereas in the case of the ecosystem trustee the CEA does not contribute to the environmental income (excluding the carbon product). The farmer and ecosystem trustee environmental incomes account for 22% and 78% of the FFs environmental income, respectively (Tables 3 and A2).

Only carbon has a CEA value that coincides with that of its environmental income. This is because carbon emission is not an environmental production factor of carbon sequestration. In the case of carbon, the environmental income comes from the ESca plus the CEAca adjusted for NOMeoca double counting (Table A2).

The change in the environmental asset of carbon (CEAca) implicitly incorporates the reclassification of the carbon fixation for the period recorded as expected at the opening and as produced at the closing, revalued according to the discount effect. Carbon emission is recorded as carbon produced at the opening and is implicitly deducted in the environmental carbon asset produced at the closing of the period. The absence of explicit movements of carbon entries and withdrawals and the inclusion of WPeu as income in the components of the NOSe implies their double counting in the CEA. This problem is solved by the environmental asset gain (EAgca) which is estimated by subtracting from the EArca the double-counting of the carbon final product consumed (FPcca: 53 €/ha) in the NOMeoca (Tables 4–6 and A2).

Under the rSEEA the components of the environmental income registered in the production, income generation and environmental asset balance accounts are linked. The general equation for the

Table 6
Environmental incomes under the rSEEA applied to the pine-forest-farm case studies in Andalusia (2010: €/ha).

Class	Farmer (FA)	Ecosystem trustee (ET)	Forest farms (FFs)
1. Provisioning services	43.6	45.7	89.3
1.1 Timber	38.9		38.9
1.2 Firewood	2.0		2.0
1.3 Grazing	0.6		0.6
1.3.1 Grass and browse	0.6		0.6
1.3.2 Acorns	0.1		0.1
1.4 Hunting	1.5		1.5
1.5 Aromatic herbs	0.5		0.5
1.6 Mushrooms		5.1	5.1
1.7 Water		40.6	40.6
2. Regulating-maintenance services		58.2	58.2
2.1 Carbon		23.3	23.3
2.2 Landscape		26.9	26.9
2.3 Biodiversity		8.0	8.0
3. Cultural services		50.2	50.2
3.1 Amenity	$na^{(*)}$		$na^{(*)}$
3.2 Recreation		50.2	50.2
Environmental incomes	**43.6**	**154.1**	**197.7**

Pine-forest farms surface area: 47,262 ha.
$na^{(*)}$: not applicable.

environmental income in the rSEEA is that which is estimated by aggregating the ordinary environmental net operating margin and the environmental asset gain. The latter is derived from the revaluation of the environmental asset adjusted for the double counting of work in progress used and other instrumental double counting due to the type of entry and withdrawal movements registered in the environmental asset balance account.

The general equation of the rSEEA applied in the case-study of public forest farms in Andalusia registers the double counting of the work in progress used and the ordinary environmental net operating margin of carbon. In this case the reorganisation of the components of the general equation for the environmental income permits a new equation composed of the ecosystem service plus the change in the environmental asset net of the ordinary environmental net operating margin for carbon (equivalent to the ecosystem service of carbon).

The schematic sequence for the calculation of the environmental income of a product is presented in Fig. 3. This figure takes into account that the component of environmental net operating surplus of a product of work in progress used and the environmental asset withdrawal used are the same product, but termed differently in the income generation account and the environmental asset balance account.

The adjustment of the work in progress used is due to the fact that it does not form part of the income as it is an input in the production function which comes from standing products on the farm inventoried at the opening of the period and valued according to the resource rent unit value. The adjustment of the ordinary environmental net operating margin for carbon is due to the fact that it is also a value which corresponds to the environmental asset variation for carbon, when, as in the rSEEA application, no entries or withdrawals are registered in the environmental asset balance account.

5. Discussion on SEEA incomes and assets and policy implications

5.1. Challenges of updated monetary SEEA environmental incomes and assets

5.1.1. Uncertainty of the simulated transaction price

The incorporation by the SEEA of final products of services consumed without market prices valued at simulated transaction prices is controversial. This valuation status as stated/revealed prices by consumers may differ from that observed if their real market were implemented (Alfsen and Greaker, 2006; OECD, 2006). While caution must be exercised with regard to simulated exchange values, this practice is not a novelty with respect to the SNA valuations applied by governments to measure the income produced in the national territory (McElroy, 1976). The SNA simulates an exchange value of zero for the net operating surplus in the government general production and generation of income accounts, embedded in the final products consumed of public services without market prices. This practice in the SNA is an arbitrary convention of government that, in exchange for its objectivity, may not minimise the uncertainty of the result relative to what might be collected from actual market implementation or through government environmental charges on product consumption by actual consumers of free public services.

5.1.2. Uncovering the SEEA environmental income

The proximity between ecosystem service and environmental income of a product indicates that the change in environmental asset is close to a transaction value of zero. This result may indicate a situation near to the biophysical steady state of the good or service production function. In the pine-forest-farm case studies, given that stable prices have been assumed in the future and that there are no variations other than those derived from biophysical modelling of woody extractions and greenhouse carbon, the meaning of the environmental income is also one of bio-physical sustainability of the pine-forest-farm nature management.

The relevance of the valuation of the adjusted net environmental operating surplus (NOSead) as an implicit component of the NOSad recommended by the SEEA is that it implies the recognition of the estimation of the environmental income (EI) of ecosystems (see Supplementary text S1). This is a notable novel finding of the application of the updated SEEA to the FFs. In other words, we argue that the explicit statement in the SEEA that it does not recommend the estimation of EI because it incorporates the environmental asset gain (EAg) is not correct, although the SEEA recognises that EI does represent an exchange value consistent with the SEEA's observed and revealed/stated transaction price valuations (United Nations et al., 2021: paras. 12.47–12.48).

5.2. Lessons learned from the application of the rSEEA in the RECAMAN project

In the RECAMAN project, 4.4 million hectares were valued at the scale of Spanish Forest Map (SFM) tiles, attributing the physical values documented in the Third National Forest Inventory together with our own research based on shrubland field work and forest inventories for some of the studied farms (Campos et al., 2015). The public administration of Andalusia collaborated through the provision of new primary information not published by the statistics office of the Andalusian region.

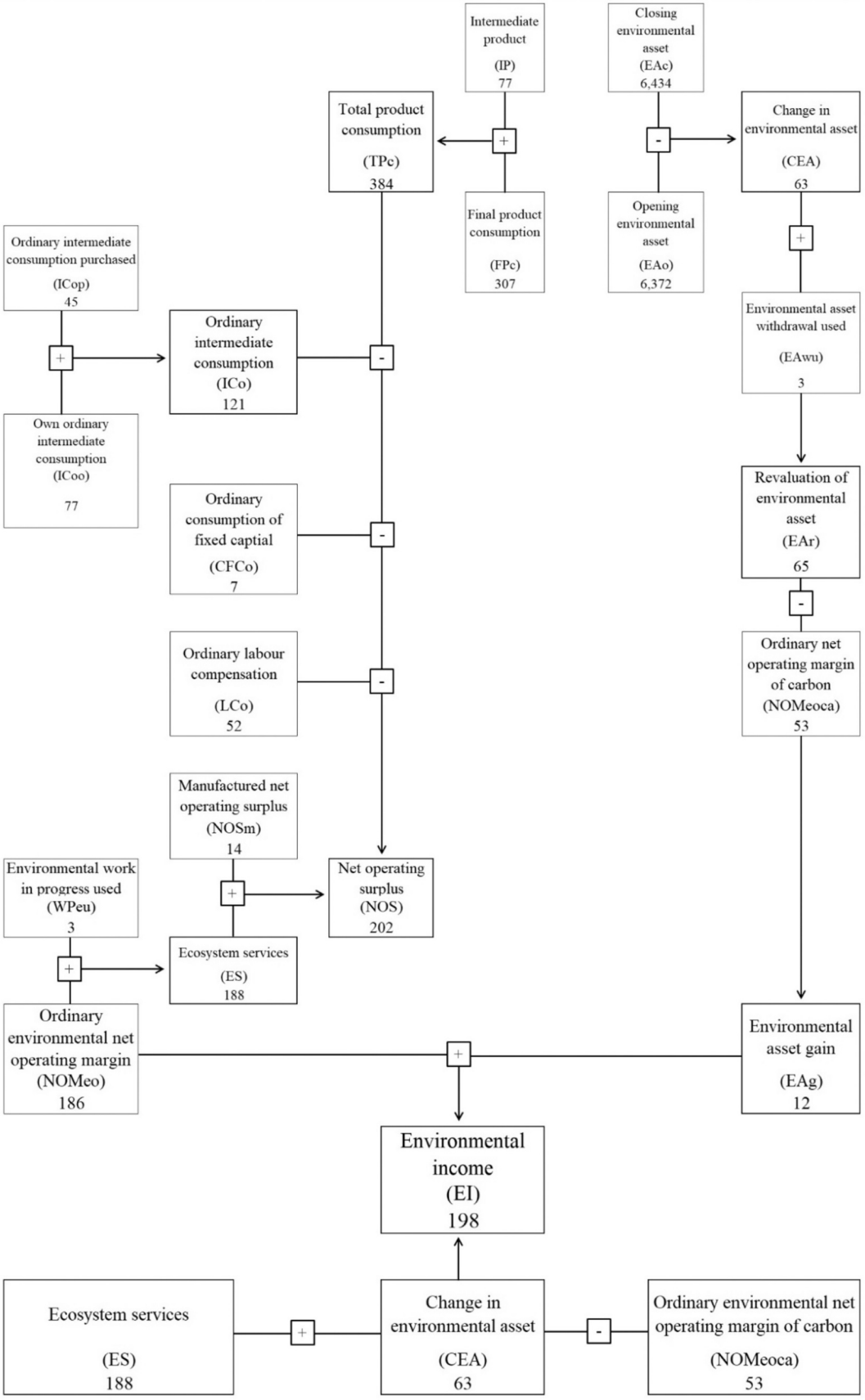

Fig. 3. Stylised sequence of environmental income measurement under rSEEA for pine-forest-farm case studies (2010: €/ha).

The public spending undertaken was determined via ad hoc protocols carried out by the researchers in the RECAMAN project based on primary information from the public administration of Andalusia.

The application of our agroforestry accounts System (AAS) for total income and its factorial distribution among labour produced (manufactured) capital and land (ecosystem) necessitated a farm-scale case study. 58 large forest farms in Andalusia were studied, covering a total of 108,000 ha. Contingent valuation and choice experiment surveys were conducted among consumers of free-access public services. A telephone survey of free-access mushroom collectors was also carried out. Publications were obtained on the hedonic prices of the environmental asset of irrigation water in the main hydrographic catchment to which surface water precipitated in the Andalusian forests contributes.

The research work conducted by the participating institutions over the four years of field work in the RECAMAN project represented a total cost to the public administration of Andalusia of $<1.5€$/ha. Bearing in mind that it was necessary to create all the methodology from scratch as this was the first year of the valuation of total income of the Andalusian forests, this amount can be considered the maximum cost, thus, the cost of periodically updating the statistical data through repeating the complete study every 5 years along with annual revisions could be socially tolerable.

Analysing the uses of information in the design and implementation of forest management will allow us to determine the level of interest by the public administration in providing the public service of environmental and economic statistics on the forests at a minimum scale of national forest inventory tiles, based on the micro economy of forest farms. The results obtained through the application of the AAS to the Andalusian forests provide geo-referenced information for the 2010 period at the scale of map-tiles, municipalities, provinces and Andalusia as a whole according to vegetation, physical variable and economic types (Campos et al., 2015).

We believe that prices can be imputed from other markets for the product where there are only small changes in the supply of the products. In contrast, it is not acceptable to transfer prices and consumptions of products from certain areas to others which do not correspond to the simulations of revealed or stated demand from real active or passive consumers in the estimation of environmental incomes from ecosystem products. We need real information on consumption and simulation of the marginal prices of the demand for products without market prices. This new information must be supplied by the government offices for statistics.

5.3. Policy implications of future monetary SEEA standardization

The SEEA hidden environmental income is particularly relevant to government interventions aimed at preventing and/or mitigating appropriations deemed illicit from the current de facto distribution of economic property rights to renewable environmental assets of ecosystems. The explicit estimation by the SEEA of the environmental income could reveal the implicit, unwilling donations of ecosystem incomes between economic agents and consumers of nature-based products and assets at national/sub-national and global scales. In other words, measurements of environmental incomes from ecosystems could result in the emergence of demands by economic agents and consumers for changes in public and private economic property rights to ecosystem environmental assets, both within the national territory and between nations involved in the production and consumption of nature-based products.

The importance of the implicit inter-generational legacy of forest landscape conservation by the public owner and the government should persuade governments to prioritize a change in the budget of the offices for statistics destined to the periodical production of primary forest physical and economic data. This requires the implementation of forest ecosystem accounting that allows the environmental income of multiple-use forest to be measured.

It has been shown that the standard SNA applied at any scale does not provide the information required to implement economic ecosystem accounts. The United Nations Statistical Commission (UNSC) has not yet agreed on a standard economic SEEA, but has recommended concepts and methods for valuation of ecosystem services and net values added adjusted for changes in environmental assets due to enhancements and degradations of environmental assets. This paper has verified that the SEEA economic concepts and methods make it possible to measure environmental income with tolerable uncertainties to support its prompt standardization in the future.

The standard Farm Accounting Data Network (FADN) methodology owes its existence to the European Commission's need to support the economic efficiency and income equity aims of the Common Agricultural Policy (European Commission, 2018). The FADN excludes forestry and agro-silvo-pastoral farms. Furthermore, in these types of farms, the government is concerned with the efficiency and equity of the conservation of the cultural landscape and the preservation of unique wild genetic variety threatened with extinction. In the case of the pine-forest-farm case studies in Andalusia, livestock and crop farming products are of little relevance and therefore do not meet the criteria for the selection of the FADN sample of farms.

The application of the refined SEEA in the case study of protected publicly-owned forest farms demonstrates that new physical and economic statistics are required, without which it is not feasible to estimate geo-referenced ecosystem services and environmental incomes at plot and farm (economic unit) scales.

The Statistical Office of the European Union (Eurostat) agreed in 2021 to incorporate an ecosystem accounts module in the next revision of the environmental accounts regulation, following the standard physical SEEA EA agreed by the UNSC (United Nations et al., 2021; UNSD, 2021). The application of the SEEA in the case-study forest farms is consistent with the agreed UNSC recommendations in chapters 8–11 of the monetary SEEA (Campos, 2023). It has been shown that with an expected lower degree of uncertainty than that represented by the current lack of public service statistics on total forest income and its factorial distribution, the implementation of ecosystem environmental income accounts constitutes an irreplaceable pillar to inform the design and implementation of environmental conservation and economic development policies for natural areas, among which forests provide one of the most widespread components globally.

6. Concluding remarks

The ecosystem accounting results confirm consumer preference for the economic use of public goods and services provided by the case-study Mediterranean-pine-forest farms. Linking the individual economic products of the farmer and government ecosystem trustee institutional sectors is a necessary condition to allow the hidden environmental income from forests to be uncovered in the updated monetary SEEA recommended by the UNSC.

The above description of the economic results of the refined SEEA application to the FFs reveals that the ecosystem service of timber harvesting is negligible and that the environmental income from timber only accounts for a moderate part of the total environmental income from the FFs. The public products without market prices of recreation and landscape as well as public products with imputed market prices (e.g. water and carbon) are those which contribute most to the total

environmental income of the FFs. Ecosystem services make up 49% and 95% of total product consumptions and environmental incomes, respectively, of the FFs. The predominance of ecosystem services in the public products consumed is further emphasized by the limited physical productivity of timber and grazing associated with the four Mediterranean pine tree species valued in the FFs. This highlights the type of management of the native pine-tree species adopted by the farmer and ecosystem trustee, which is aimed mainly towards the conservation of the working landscape in order to maintain high natural ecological and economic values.

The economic statistics provided by the National Statistical Offices (NSOs) do not estimate the total income from the economic goods and services, both market and free-access (provided by the public administrations), this not being viable without new information being produced for economic accounts as part of whatever type of ecosystem accounting that may be agreed in the future aimed at estimating the income from employment, the capital income produced in the ecosystem (or manufactured net operating surplus), the ecosystem service (or environmental net operating surplus), the real environmental asset gain, and finally, the environmental income of the ecosystem.

Governments fail to provide the public service of economic ecosystem accounting statistics. However, as discussed in the previous sections, primary data on the environmental income components of operating return on environmental asset and environmental asset gain have been implicitly incorporated in the SEEA generation of income and environmental asset balance sheet accounts. Thus, future United Nations developments of the monetary SEEA should recommend the explicit measurement of the environmental income indicator, as it is a better indicator of sustainable income from nature than ecosystem services.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Table A1
Comparison of monetary variable extensions in the standard System of national Accounts (SNA) and the refined System of Environmental-Economic Accounting – Ecosystem Accounting (rSEEA) applications to the estimation of factorial allocation of net value added (NVA) of the pine-forest farms (FFs).*

Class	Acronym	SNA		This paper refined SEEA		
		Scope	Measurement methods	Scope	Measurement methods	Accounting identities
1. Intermediate product	IP	Market good or service produced in the period, which is used as input of manufactured intermediate consumption by the same activity which produces it or by other activities in the farm during the accounting period.	Not applied in practice.	Market or non-market good or service produced in the period and which is used as input of manufactured intermediate consumption by the same activity which generates it or other activities of the farm during the accounting period.	Valued according to the manufactured ordinary total cost (TCo) incremented by the immobilized competitive remuneration (eg., fire services) or imputed price of other proximate markets (e.g., residential services) or the simulated voluntary monetary revenue opportunity cost of the manufactured capital (ISSnca and ISSncd) or the ordinary government compensation (ISSncc).	IP_{rSEEA} is manufactured commercial intermediate raw material (IRM) plus manufactured intermediate services (ISS): $IP_{rSEEA} = IRM + ISS$. ISS is manufactured commercial intermediate services (ISSc) plus manufactured non-commercial intermediate services (ISSnc): $ISS = ISSc + ISSnc$. $ISSnc = ISSnca + ISSncd + ISSncc$
2. Market final product consumed	FPc_M	Good or service consumed which is generated with the	Valued according to the observed market transaction price at	Generated with the contribution of at least one natural	Economic surface water precipitated on the farm and stored in	$FPc_{M,rSEEA} = FPc_{M,SNA} * FPcwa + FPcca$

(*continued on next page*)

Table A1 (*continued*)

Class	Acronym	SNA		This paper refined SEEA		
		Scope	Measurement methods	Scope	Measurement methods	Accounting identities
		contribution of at least one manufactured production factor and which is appropriated by the owner of the land or livestock	the farm gate or imputed price of transactions observed in other proximate markets net of transport cost.	(environmental) or manufactured production factor and is appropriated by the owner of the land o livestock (e.g. private amenity) and in a simulated form by the government (e.g. carbon and water) and it is assumed to be enjoyed for free by the population. It extends the SNA with water storage further down the watershed and greenhouse effect carbon fixation.	reservoirs further down the watershed (FPcwa) is valued by its resource rent estimated using the hedonic price method applying the price of irrigated land assuming a real discount rate of 3% for the environmental asset of water. Carbon (FPcca) is valued according to an imputed price for European market transactions.	
3. Non-market final product consumed	FPc_{NM}	Generated with the contribution of at least one manufactured production factor and its appropriation by the government is simulated, being enjoyed by the population for free (e.g. free-access recreation, landscape and biodiversity services).	The free access services of recreation, landscape and biodiversity are valued according to the manufactured ordinary total cost (TCop) at purchase price net of subsidies and taxes linked to production. The TCop is recorded embedded in the government general production account	The final non-market products consumed of recreation (re), landscape (la) and biodiversity (bi) are valued according to the simulated transaction value derived from active and passive consumer preferences.	Free-access recreation services are estimated using the contingent valuation method based on the upper bound (UB) marginal willingness to pay declared by the recreational visitors ($MWTPre_{UB}$). The landscape and biodiversity are valued according to the manufactured ordinary total cost (TCo) plus the simulated transaction value estimated using the choice experiment stated preference method based on the additional marginal willingness to pay (AMWTP) over the TCo of the consumers. The latter coincides with the net operating surplus (NOS_{NM}) estimated as a whole and the AMWTP values are separated into landscape and biodiversity using econometric tools and the additional prices (P_{AD}) are given by applying the simulated exchange value method.	$FPcre_{SNA} = TCopre$ $FPcla_{SNA} = TCopla$ $FPcbi_{SNA} = TCopbi$ $NOS_{rSEEA} = AMWTPla$ $FPcre_{rSEEA} = MWTPre_{UB}$ $FPcla_{rSEEA} = MWTPla_{UB}$ $MWTPla_{UB} = TCola + AMWTPla$ $FPcbi_{NM,rSEEA} = MWTPbi_{UB}$ $MWTPbi_{UB} = TCobi + AMWTPbi$
4. Manufactured gross capital formation	GCF	Own-account market goods both finished and work in progress accumulated at the close of the period to be used with	The inanimate goods (GCFin) are valued at replecement price and the livestock (GCFli) inventoried at the close of the	Same as the SNA.	Same as in the SNA.	$GCF = GFCFin + GCFli$ $GFCFin = TCiin$ $GCFli = Qlic*Pli - Lip$

(*continued on next page*)

Table A1 (*continued*)

Class	Acronym	SNA		This paper refined SEEA		
		Scope	Measurement methods	Scope	Measurement methods	Accounting identities
		production factors in future periods in the farm which produced them	period is valued by multiplying the quantity (Qlic) by the imputed market prices (Pli) observed in proximate local markets prior to subsidies and taxes linked to production and net of livestock purchases in the period (Lip).			
5. Total product	TP	na	na	The value incurs double counting of the aggregate intermediate products of the individual farm. Double counting of individual products does not arise apart from in the case of honey as an agricultural product.	Its estimation is necessary to estimate the net value added of the individual products. It is estimated as the sum of the intermediate product (IP) and the final product (FP). The latter is composed of the final product consumed (FPc) and the gross formation of own account manufactured capital (GCF.)	
6. Manu factured intermediate consumption	IC	Estimates the production factors of purchased manufactured raw materials (MPp) and services (SSp) used in the period in the generation of the final market product	Valued at purchase price net of subsidies and taxes linked to production	Extends the intermediate consumptions by incorporating own ordinary manufactured intermediate services (SSoo).	The SSoo are the counterpart of the intermediate products of services (ISS).	$IC_{SNA} = ICp$ $ICp_{SNA} = RMp + SSp$ $IC_{rSEEA} = ICp + ICoo$ $ICoo = IP$ $ICoo = RMoo + SSoo$ $SSoo = SSc + SSnc$ $SSnc = SSooa + SSood + SSooc$
7. Gross value added	GVA	Remunerations of the production factors of employee (paid) labour and self-employed labour along with the user cost of immobilized capital which contributes to the final market products consumed.	Estimated directly from the final product (FP_{SNA}) of market and non-market products with at least one manufactured production factor less the manufactured intermediate consumption purchased (ICp)	Extends the products of the SNA by incorporating the intermediate products (IP) and the final market products of water (FPcwa) and carbon (FPcca) which do not remunerate manufactured production factors. Extend the intermediate consumptions with the inclusion of own ordinary intermediate consumptions (ICoo). Extends the valuation of the non-market products in the SNA by incorporating the not operating surplus (NOS_{NM}) omitted by the SNA.	The FPcwa is valued by the resource rent estimated using the hedonic price method for the price of irrigated land in the Guadalquivir river catchment area. The value of the FPcca is imputed according to the market price in the European market emissions trading scheme in 2010.	$GVA_{SNA} = FP_{SNA} - ICp$ $GVA_{rSEEA} = TP_{rSEEA} - IC$ $GVA_{rSEEA} = GVA_{SNA} + FPcwa + FPcca + NOS_{NM}$

(*continued on next page*)

Table A1 (*continued*)

Class	Acronym	SNA		This paper refined SEEA		
		Scope	Measurement methods	Scope	Measurement methods	Accounting identities
8. Consumption of fixed capital	CFC	Imputed value of the deterioration through use or the obsolescence of inanimate durable goods that contribute as production factors to the generation of the final product in the period.	Estimated by multiplying the annual technical coefficient for the service life (T) of the good (1/T) by the replacement price of the same good (Pre)	Same as in the SNA.	Same as in the SNA.	$CFC = 1/T^{*}Pre$
9. Net value added	NVA	Remuneration of labour and the benefit measured by the net operating surplus (NOS) of the immobilized capital in the generation of the final market products with the use of at least one manufactured production factor.	The NVA_{SNA} is estimated directly by the GVA_{SNA} less the CFC.	Extends the NVA_{SNA} by incorporating the FPcwa, the FPcca and the NOS_{NM}.	The NVA_{rSEEA} is estimated directly by the GVA_{rSEEA} less the CFC.	$NVA_{SNA} = GVA_{SNA} - ICp$ $NVA_{SNA} = LC + NOS_{SNA}$ $NVA_{rSEEA} = GVA_{rSEEA} - CFC$ $NVA_{rSEEA} = LC + NOS_{rSEEA}$ $NVA_{rSEEA} = NVA_{SNA} + IP + FPcwa + FPcca + NOS_{NM} - ICoo$
10. Manu factured total cost	TC	Manufactured production factors of the final market and non-market products (FP_{SNA}) with at least one manufactured production factor	Estimated by aggregating the manufactured intermediate consumption purchased (ICp), labour cost (LC) and inanimate manufactured fixed capital consumption (CFC)	Manufactured production factors of the market and non-market total products (TP_{rSEEA}) with at least one environmental or manufactured production factor.	Estimated by aggregating the manufactured intermediate consumption (IC), labour cost (LC) and consumption of inanimate manufactured fixed capital (CFC)	$TC_{SNA} = ICp + LC + CFC$ $TC_{rSEEA} = IC + LC + CFC$ $TC_{rSEEA} = TC_{SNA} + ICoo$
11. Net operating surplus	NOS	Manufactured net operating surplus ($NOSm_{SNA}$) and environmental net operating surplus ($NOSe_{SNA}$) of the immobilized capital of the final market products (FP_{SNA}) with at least one manufactured production factor	Estimated according to the final product (FP_{SNA}) less the manufactured total cost (TC_{SNA})	Net operating surplus, both manufactured ($NOSm_{rSEEA}$) and environmental ($NOSe_{rSEEA}$) of the immobilized capital of the market and non-market total products (TP_{rSEEA}) with at least one manufactured or environmental production factor.	Estimated by the total product (TP_{rSEEA}) less the manufactured total cost (TC_{rSEEA})	$NOS_{SNA} = FP_{SNA} - TC_{SNA}$ $NOS_{SNA} = NOSm_{SNA} + NOSe_{SNA}$ $NOS_{rSEEA} = TP_{rSEEA} - TC_{rSEEA}$ $NOS_{rSEEA} = NOSm_{rSEEA} + NOSe_{rSEEA}$
12. Environ mental net operating surplus	NOSe	Environmental net operating surplus ($NOSe_{SNA}$) of the natural environment (ecosystem) for final biological-nature-based market products (FP_{SNA}) with at least one manufactured production factor	Estimated by aggregating the environmental work in progress used (WPeu) and the ordinary environmental net operating margin (NOMeo) valued by their respective resource rents of the FP_{SNA}.	Natural environment (ecosystem) environmental net operating surplus ($NOSe_{rSEEA}$) of the market and non-market total products (TP_{rSEEA}) with at least one manufactured or environmental production factor.	Estimated by aggregating the environmental work in progress used (WPeu) and the ordinary environmental net operating margin (NOMeo) valued by their respective resource rents of the TP_{rSEEA}.	$NOSe_{SNA} = WPeu_{SNA} + NOMeo_{SNA}$ $NOSe_{rSEEA} = WPeu_{rSEEA} + NOMeo_{rSEEA}$

* na stands for not applicable.

Table A2
Stylized sequence of single-product environmental income accounts under the SEEA-EA 2021 applied to pine-forest-farm (FF) case studies in Andalusia (2010: €/ha).

Class	Timber	Firewood	Grazing	Con. forestry	Hun-ting	Aromatic herbs	Residential	Livestock	Agriculture	Amenity	Fire services	Recreation	Mushrooms	Carbon	Landscape	Biodiversity	Water	Pine forest farms
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	∑1–17
Production account																		
1. Total product (TP)	7.7	0.0	1.2	25.9	12.7	2.2	0.3	11.6	0.1	2.9	37.8	62.5	5.7	53.1	111.7	14.0	40.6	390.2
1.1 Manufactured intermediate product (IP)	0.2	0.0	1.1	25.9	6.8			8.1			34.7							76.9
1.1.1 Grazing raw material (IRMgr)			1.1															1.1
1.1.2 Honey raw material (IRMho)								0.1										0.1
1.1.3 Manufactured services (ISS)	0.2	0.0	0.1	25.9	6.8			8.0			34.7							75.7
1.1.3.1 Commercial (ISSc)				*24.9*							*34.7*							*59.6*
1.1.3.2 Non-commercial (ISSnc)	*0.2*	*0.0*	*0.1*	*1.0*	*6.8*			*8.0*										*16.2*
Compensated (ISSncc)					*0.0*			*5.2*										*5.2*
Auto-consumed (ISSnca)								*2.9*										*2.9*
Donated (ISSncd)	0.2	0.0	0.1	1.0	6.8													8.1
1.2 Final product (FP)	7.6		0.1		5.9	2.2	0.3	3.4	0.1	2.9	3.1	62.5	5.7	53.1	111.7	14.0	40.6	313.3
1.2.1 Final product consumption (FPc)	7.6		0.1		5.9	2.2	0.3	4.6	0.1	2.9		60.1	5.7	53.1	110.2	13.5	40.6	307.0
1.2.2 Manufactured gross capital formation (GCF)					0.0			−1.2			3.1	2.4	0.0		1.4	0.4		6.2
1.2.2.1 Inanimate gross fixed capital formation (GFCFin)					0.0						3.1	2.4	0.0		1.4	0.4		7.4
1.2.2.2 Change in livestock inventory less purchases (GCFli)								−1.2										−1.2
2. Manufactured Intermediate consumption (IC)	3.0			16.6	1.6			8.4	0.0	2.9	11.7	3.6	0.0		74.6	1.3		123.8
2.1 Purchasedintermediate consumption (ICp)	3.0			16.6	1.6			7.2	0.0		11.7	2.7	0.0		2.7	1.3		46.9
2.2 Own ordinary intermediate consumption (ICoo)					0.0			1.2		2.9		0.9			72.0			76.9
3. Gross value added (GVA)	4.7	0.0	1.2	9.3	11.2	2.2	0.3	3.1	0.1		26.1	58.9	5.7	53.1	37.0	12.6	40.6	266.4
Generation of income account																		
4. Gross value added (GVA)	4.7	0.0	1.2	9.3	11.2	2.2	0.3	3.1	0.1		26.1	58.9	5.7	53.1	37.0	12.6	40.6	266.4

(*continued on next page*)

Table A2 (*continued*)

Class	Timber	Firewood	Grazing	Con. forestry	Hun-ting	Aromatic herbs	Residential	Livestock	Agriculture	Amenity	Fire services	Recreation	Mushrooms	Carbon	Landscape	Biodiversity	Water	Pine forest farms
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	∑1–17
5. Manufactured consumption of fixed capital (CFCm)	0.1		0.0	0.5	0.3	0.0		1.5	0.0		1.0	1.1	0.0		2.2	0.4		7.3
6. Net value added (NVA)	4.6	0.0	1.2	8.8	10.9	2.1	0.3	1.7	0.1		25.1	57.8	5.7	53.1	34.8	12.3	40.6	259.1
6.1 Labor compensation (LC)	2.7			7.7	3.9	1.6		0.7	0.0		25.1	4.6	0.1		7.7	3.3		57.4
6.1.1 Employee labour compensation (LCe)	2.7			7.7	3.8	1.6		0.1			25.1	4.6	0.1		7.7	3.3		56.7
6.1.2 Self-employed labour compensation (LCse)					0.1			0.6	0.0									0.7
6.2 Net operating surplus (NOS)	4.6	0.0	1.2	8.8	10.7	2.1	0.3	1.1	0.1		25.1	57.8	5.7	53.1	34.8	12.3	40.6	258.4
6.2.1 Manufactured net operating surplus (NOSm)	3.5	0.0	0.1	8.8	9.2	1.6	0.3	1.1	0.1		25.1	7.6	0.6		7.9	4.2		70.3
6.2.2 Environmental net operating surplus (NOSe = ES = RR)	1.1		1.1		1.5	0.5						50.2	5.1	53.1	26.9	8.0	40.6	188.2
6.2.2.1 Environmental work in progress used (WPeu)	1.1				1.5													2.7
6.2.2.2 Ordinary environmental net operating margin (NOMeo)			1.1			0.5						50.2	5.1	53.1	26.9	8.0	40.6	185.5
Environmental asset account																		
7. Change in environmental asset (CEA)	37.8	2.0	−0.5											23.3				62.7
7.1 Provisioning (CEApr)	37.8	2.0	−0.5															39.3
7.2 Regulating-maintenance (CEAre)														23.3				23.3
7.3 Cultural (CEAcu)																		
8. CEA adjusted environmental net operating surplus (NOSead)	38.9	2.0	0.6	*na*$^{(*)}$	1.5	0.5	*nd*$^{(**)}$	*nd*$^{(**)}$	0.0	*nd*$^{(**)}$	*na*$^{(*)}$	50.2	5.1	76.5	26.9	8.0	40.6	250.8
9 Environmental incomes (EI = NOSead – NOMeoca)	**38.9**	**2.0**	**0.6**	***na*$^{(*)}$**	**1.5**	**0.5**	***nd*$^{(**)}$**	***nd*$^{(**)}$**	**0.0**	***nd*$^{(**)}$**	***na*$^{(*)}$**	**50.2**	**5.1**	**23.3**	**26.9**	**8.0**	**40.6**	**197.7**

Pine-forest farms surface: 47,262 ha.
na$^{(*)}$ stands for not applicable *and nd*$^{(**)}$ is no data.

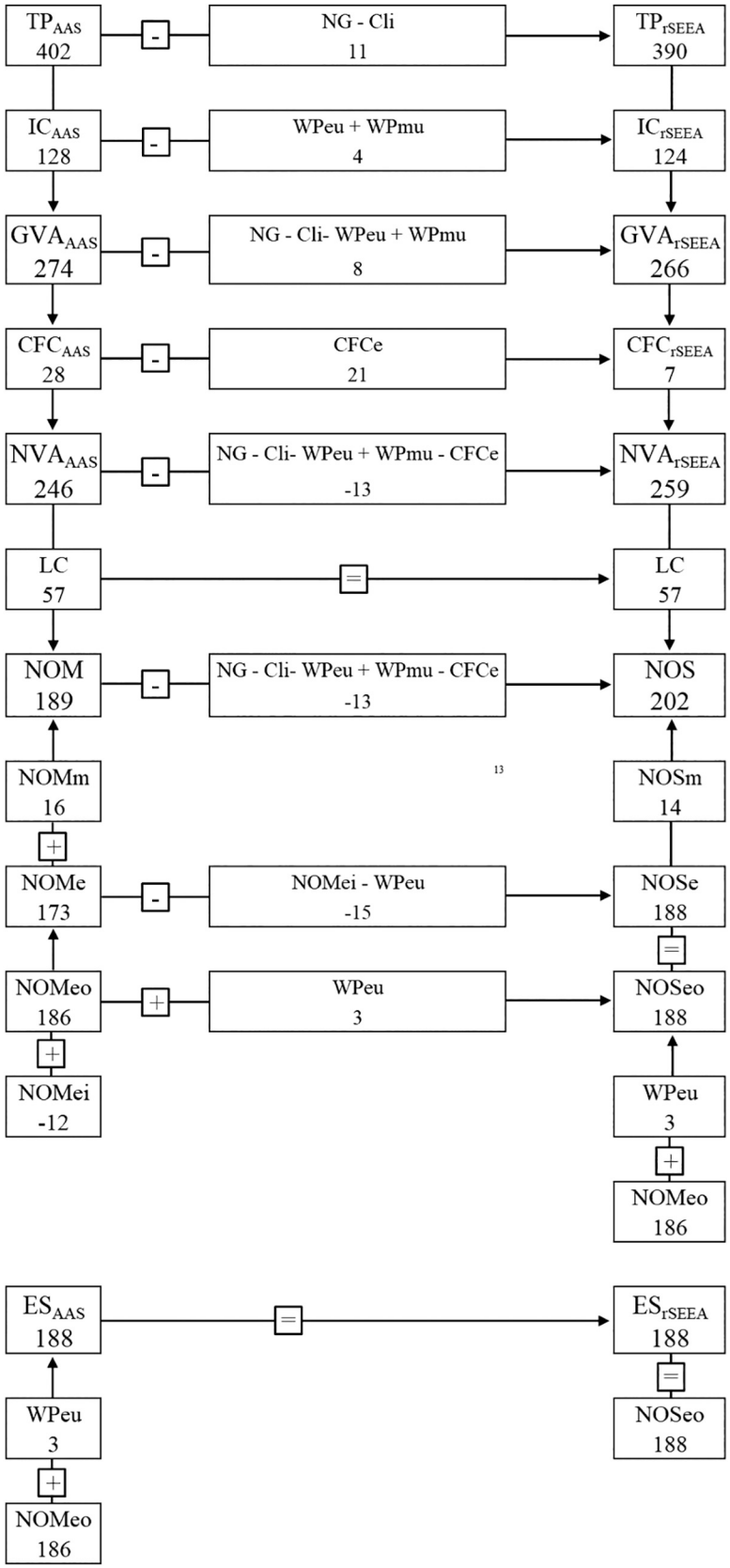

Fig. A1. Ecosystem services under AAS and rSEEA applications of pine-forest-farm case studies in Andalusia (2010: €/ha).
Acronyms: TP_{AAS} is total product of AAS; NG is natural growth; Cli is change in livestock inventory less purchases; TP_{rSEEA} is total product consumption of rSEEA; IC_{AAS} is intermediate consumption of AAS; WPeu is environmental work in progress used; WPmu is manufactured work in progress used; IC_{rSEEA} is intermediate consumption of rSEEA; GVA_{AAS} is gross value added of AAS; GVA_{rSEEA} is gross value added of rSEEA; CFC_{AAS} is consumption of fixed capital of AAS; CFCe is environmental consumption of fixed capital; CFC_{rSEEA} is consumption of fixed capital of rSEEA; NVA_{AAS} is net valued added of AAS; NVA_{rSEEA} is net valued added of

rSEEA; LC is labour cost; NOM is net operating margin; NOMei is investment environmental net operating margin; NOS is net operating surplus; NOMm is manufactured net operating margin; NOSm is manufactured net operating surplus; NOMe is environmental net operating margin; NOSe is environmental net operating surplus; NOMeo is ordinary environmental net operating margin; NOSeo is ordinary environmental net operating surplus; ES_{AAS} is ecosystem services of AAS; ES_{rSEEA} is ecosystem services of rSEEA.

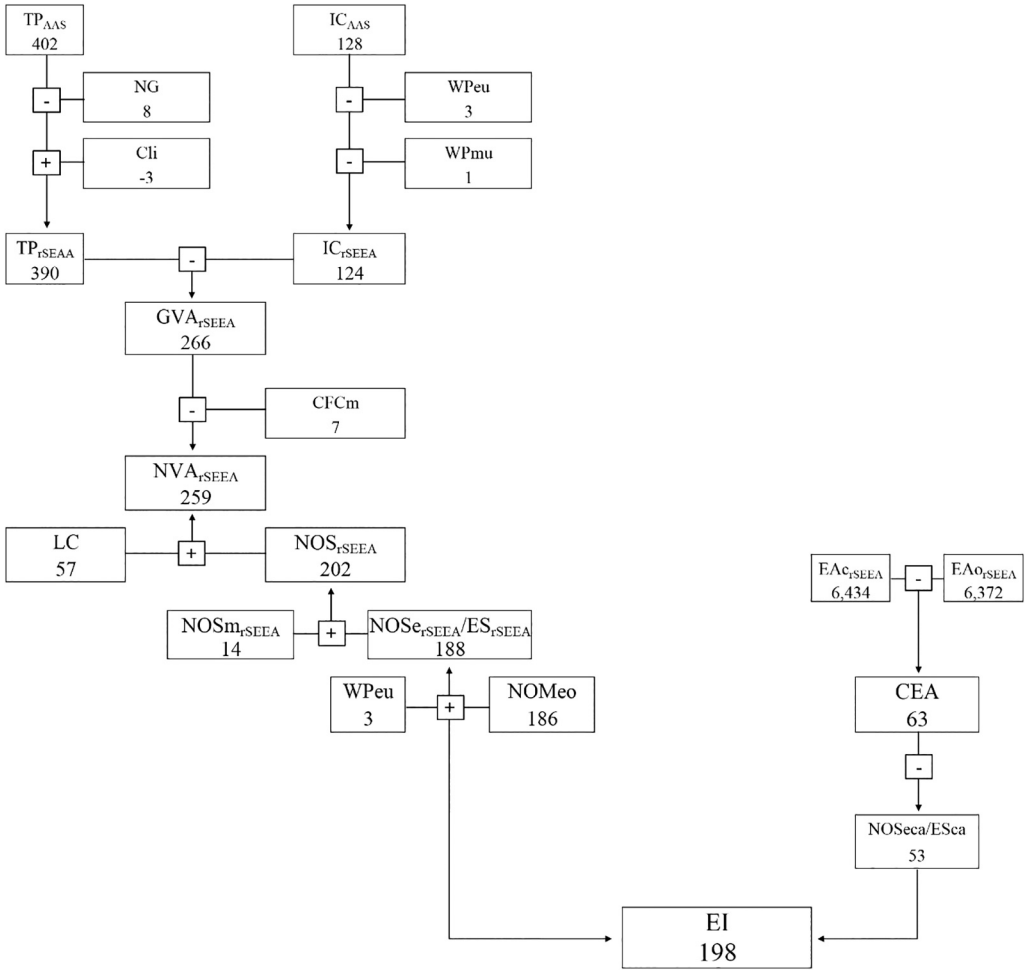

Fig. A2. Environmental income under the AAS and rSEEA applications in pine-forest-farm case studies in Andalusia (2010: €/ha).
Acronyms: TPc_{AAS} is total product of AAS; IC_{AAS} is intermediate consumption of AAS; NG is natural growth; WPeu is environmental work in progress used; Cli is change of livestock inventory less purchases; WPmu is manufactured work in progress used; TP_{rSEEA} is total product of rSEEA; IC_{rSEEA} is intermediate consumption of rSEEA; GVA_{rSEEA} is gross value added of rSEEA; CFCm is manufactured consumption of fixed capital; NVA_{rSEEA} is net valued added of rSEEA; LC is labour cost; NOS_{rSEEA} is net operating surplus of rSEEA; $NOSm_{rSEEA}$ is manufactured net operating surplus of rSEEA; $NOSe_{rSEEA}/ES_{rSEEA}$ is environmental net operating surplus of rSEEA or ecosystem services of rSEEA; EAc_{rSEEA} is rSEEA closing environmental asset; $EAor_{SEEA}$ is rSEEA opening environmental asset; NOMeo is ordinary environmental net operating margin; CEA is change in environmental asset; NOSeca/ESca is environmental net operating surplus of carbon or ecosystem services of carbon; EI is environmental income.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2022.107570.

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