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Short Communication

Dealing with negative monetary ecosystem services values in environmental and economic accounting

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ABSTRACT

The concept of exchange values refers to the theoretical notion of an exchange happening for ecosystem services between an ecosystem asset and an economic agent. The United Nations System of Environmental Economic Accounting recommends using market prices as exchange values whenever possible, or otherwise, exchange value estimates that conceptually come close to market prices. However, in countries with highly regulated access to natural resources, the observable market prices or exchange value estimates for ecosystem services may often be distorted or even negative. When exchange values are used for decision support or as evidence base for policy making, negative values can be misleading.

To address this issue, we present ideas on how to include the institutional resource regime that governs ecosystem services into the computation of exchange values. This analysis can help identify policy interventions that increase or decrease exchange values from free-market levels and can provide guidance on how to correct for distorted value estimates. Further it can help to better understand negative exchange value estimates as well as reasons why society may be willing to accept, and eventually, compensate for them. We argue that the insurance value of ecosystems can be one such reason. To exemplify the application of the extended framework, we present a case study on the monetary valuation of water for hydropower production in Switzerland.

1. Introduction

The System of National Accounts (SNA) is an international statistical standard for national accounts. It provides a comprehensive framework to compile and present national economic data in a consistent way (European Commission et al., 2009). The United Nations System of Environmental Economic Accounting (SEEA) extends the SNA logic to ecosystems. The SEEA Ecosystem Accounting (SEEA EA) standardizes definitions, principles, and methods of the ecosystem accounting framework and the physical accounts. It also describes principles and recommendations for the monetary valuation of ecosystem services and assets (United Nations et al., 2021). Expressing ecosystem assets in monetary terms allows for comparisons with other types of assets nationally and internationally. Recent applications of the SEEA Ecosystem Accounting (SEEA EA) framework include Vysna et al. (2021), Horlings et al. (2020), Scottish government (2020), La Notte et al. (2017) and many more as reviewed in Lange et al. (2022) and Hein et al. (2020a).

According to the SEEA EA, market prices should be used for accounting purposes whenever possible (United Nations et al., 2021). A major difficulty of environmental economic accounting is that markets for ecosystem services (ES) rarely exist (United Nations and European Union, 2014). When markets and market prices are not available, so-called exchange value estimates that conceptually come close to market prices can be used as substitutes (United Nations et al., 2021). The concept of exchange values refers to the theoretical notion of an exchange happening for an ES between an ecosystem asset and an economic agent. Exchange value estimates capture ES' use values but do not reflect non-use values (e.g., existence or option values), or insurance values.

The residual value approach is one among several methods that can be used to estimate the exchange value of an ES. The residual value is computed by taking the price of the final marketed good or service, to which the ES provides an input, and then deducting the cost of all other intermediate inputs (United Nations et al., 2021). However, in countries with highly regulated access to natural resources, the observable market prices or exchange value estimates for ES may often be distorted or even

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be negative (Edens and Graveland, 2014; Obst et al., 2016). This is because institutional and market failures may cause an inaccurate recognition of ES benefits and the costs associated to their loss (Femia and Capriolo, 2022). Accordingly, using distorted values may undermine the ES' contributions to society. In the logic of ecosystem accounting, a zero or negative exchange value leads to the conclusion that the ES lacks a value in its own right (Obst et al., 2016). The conclusion by previous studies is thus that resource rent type approaches are inappropriate in cases where market structures do not permit the observed market price to incorporate a reasonable exchange value for the relevant ES (Obst et al., 2016). Alternative approaches such as replacement costs are recommended instead (Edens and Graveland, 2014).

In this paper, we discuss options to correct for distorting policies while still using the residual value approach rather than rejecting the approach because it delivers negative values. We contribute to the debate by expanding the exchange value framework developed by Horlings et al. (2020) to include elements of the Institutional Resource Regime (IRR) (Gerber et al., 2009; Lieberherr et al., 2019). Going beyond the consideration of taxes and subsidies for the derivation of resource rents (United Nations et al., 2014), we propose to expand on any public policies governing the ecosystems and the ES under consideration, and on the property rights governing the allocation of the resource considered. Taking the IRR into account has two advantages. Firstly, it facilitates identifying distortions to market prices or exchange value estimates and thus is a method to highlight institutional arrangements that may already be embodied in national accounts (Femia and Capriolo, 2022). Secondly, it provides indications on how to correct for potential distortions in ES value estimates.

To illustrate these ideas, we present a case study on surface water for hydropower production in Switzerland. According to the Common International Classification of Ecosystem Services (CICES V5.2) surface water for hydropower production is an abiotic or geophysical provisioning service. In the particular Swiss case, a large share of the water for hydropower production at high altitudes, but also in the large low-land rivers, can further be specified as a glacier ES (Cook et al., 2021). Water can pass through up to 30 hydropower stations on its way from the alpine headwater catchments to the Rhine in Basel which showcases how intensively this ES is used (Schaefli et al., 2019). The SEEA Central Framework explains how to deal with physical flows of water relating to hydropower (United Nations et al., 2014). The SEEA Ecosystem Accounting (EA) publication discusses approaches for accounting for ES in monetary terms, but it does not go into details on hydropower.

Apart from their application in environmental economic accounting, exchange values can also serve other purposes, for example as evidence base or as case studies for decision making and policy support (Turner et al., 2019). These contexts allow for flexibility in testing new approaches that may not be fully consistent with formal SNA procedures. Our research on including the IRR emerged from such a context. It resulted from a government-funded project aiming at providing a knowledge base on the values of various ES in the larger context of biodiversity conservation.

2. Extended framework

Fig. 1 is a simplified representation of the SEEA framework, building on UN DESA (2019), Hein et al., (2020b) and Horlings et al. (2020). The starting point is given by the ecosystem assets that generate ES (the upper right-side box). ES encompass a broad range of goods and services that offer economic benefits to economic agents, i.e. the beneficiaries. At the point when the ES start to benefit society, including the economy, they can be valued using economic valuation methods.

Economic inputs (lower box in Fig. 1) may be required for both managing ecosystem assets as well as generating economic benefits from ES. In these cases, economic inputs are applied to retain ecosystem specific processes and characteristics which ensure the functioning of the ecosystem and the provision of ES (United Nations et al., 2021). Economic inputs are also often required to capture and use the ES flows for producing economic goods and services. Examples are the equipment needed for harvesting in forestry and fishery, or hydropower facilities to

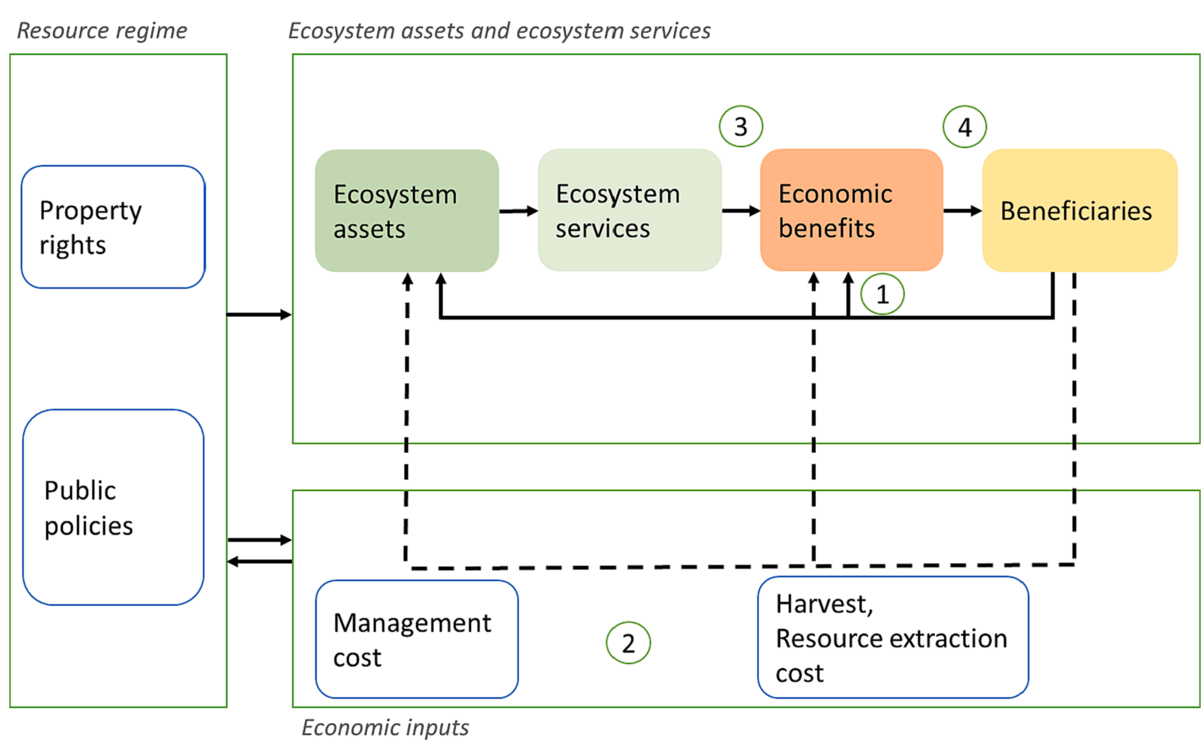

Fig. 1. ES economic valuation framework and distortion entry points. The numbered circles represent entry points for distortionary policies: Circle 1 - policies targeting company outputs, Circle 2 – policies targeting input levels, Circle 3 – policies regulating resource access, Circle 4 – consumption support policies. Source: authorś elaboration building on UN DESA (2019), Horlings et al. (2020), Gerber et al. (2009) and Lieberherr et al. (2019).

produce electricity. In Fig. 1, these relationships are represented by the dashed lines that connect the outer box titled 'Economic inputs' with the outer box 'Ecosystem assets and ecosystem services' (see boxes with green outlines). However, there can be feedback loops from economic units to ecosystem assets as well as economic benefits that do not require using economic inputs. Examples are inaction or negative externalities, but also positive effects such as conservation initiatives. Such feedback loops are captured by the solid line connecting the box titled 'Beneficiaries' with the boxes 'Ecosystem assets' and 'Economic benefits'.

The modes of managing ecosystems, generating economic benefits from ES and distributing benefits among beneficiaries are often shaped by formal institutions and property rights which form institutional resource regimes (the left side box in Fig. 1) (Gerber et al., 2009; Lieberherr et al., 2019). In highly regulated contexts, prices may be observable but rather than being the outcomes of market forces, they are strongly influenced or even determined by policy interventions (Edens and Graveland, 2014). Understanding the institutional resource regime, that may impact the exchange value of an ES can help detect distortions that can lift an ES's contribution to the economy above a free-market level or suppress it to a lower or even negative value. At this point, we depart from the SEEA framework and suggest to correct for distortionary policies. In the SNA logic, exchange values generally reflect the current institutional context, which means that distortionary policies are not corrected for. However, when exchange values are used for decision support and policy making rather than for accounting, distortions that lead to ES' negative exchange values can result in misleading conclusions. When trying to make a point that conservation is important at least because ES contribute to the economy, negative values are of little help. We expect that this extended framework will be useful particularly for practitioners who are using exchange values for decision-making and policy advice.

In Fig. 1, we have highlighted four potential entry points for different distortionary policies (see the numbered circles in Fig. 1). Distortionary policies often target various aspects of production (circles 1–3) or consumption (circle 4) (OECD, 2019). The first entry point refers to policies that target company outputs, e.g. income tax reductions, tariffs and other domestic producer price support policies (see Table 1 for further examples). The second entry point comprises all policies that target the input level. The third entry point concerns policies that affect opportunities to convert ES into economic benefits that can be placed on the market. Finally, the fourth group contains policies that offer support to consumers. The last column of Table 1 indicates whether the listed policy examples are expected to increase or decrease the exchange value of an ES, e.g. if computed with a residual value approach in a price taking economy. The expected effect of a policy instrument on the exchange value refers only to direct impacts. Indirect or cross-price effects are not considered here. We argue that controlling for distortionary policies when using observable market prices as indicators will result in estimates that more accurately reflect an ES's contribution to the economy. In the computation of an ES's residual value, distortionary policies can technically be controlled for by correcting either the observable market price or the observable production cost.

Table 1
Examples of distortionary policies based on OECD (2019).

Entry points	Examples	Effect on estimated ES exchange value
Output	Income tax reduction, deficiency payments, tariffs, domestic producers' price and export subsidies	↑
Input	Grants tied to inputs, input price subsidies, input tax reductions, wage subsidies, assumption of occupational health risk liabilities	↑
	Production standards, legal prescriptions on ecosystem asset management, regulation of input prices (e.g. wage control), import tariffs on inputs	↓
Regulation of resource access	Exclusion of international competitors, monopoly concessions, monopsony concessions, liberalization of resource access policies	↑
Consumption	Product price subsidy	↓
	Price regulation	↑↓

If the exchange value is negative after taking into account all distorting policies, then at first sight, the use of the ES is apparently occurring at a loss. The obvious question is then why the resource managers/owners are accepting to use the ES at a loss. One explanation may be that they appreciate the long-term insurance value of using the ES. The insurance value is a value component that is additional to the common value arguments, e.g. use and non-use values (Baumgärtner, 2007). It is typically a co-benefit of resource management and often has a public good characteristic (Paavola and Primmer, 2019). The SEEA frames the insurance value in relation to biodiversity and argues that it is the value of an ecosystem's resilience, or in other terms the ecosystem's ability to maintain the same level of functioning when shocks or disturbances occur (United Nations et al., 2021). Because this resilience is not a positive quantity that is exchanged, it is not included in the ecosystem accounts. The insurance value is the benefit of using an ES to hedge against the risk of sub-optimal supply of the economic benefit from other sources. For example, Baumgärtner and Quaas (2010) and Schaub et al. (2020) find that the ES biodiversity, specifically agrobiodiversity, has an insurance value for risk averse farmers as it reduces risk, e.g. in fodder production, and thereby increases farmers' robustness to environmental shocks.

Accepting that the insurance value is an additional component of an ES's economic benefit allows for a new interpretation of negative residual values. When an ES is used despite a negative residual value, we can assume that the unobserved insurance value is at least as large as the negative residual value. In terms of the SEEA, it might be considered an unrealized value.

3. Case study on hydropower in Switzerland

Hydropower is the most important renewable electricity source in Switzerland. It made up for nearly 66 % of the total electricity consumption in 2020. Roughly three-fourths of the consumed hydropower electricity was produced domestically and the remaining forth was imported (Pronovo AG, 2021). In 2020, the hydropower production in storage hydropower plants and run-of-the-river plants together amounted to 36′274 GWh.

3.1. Economic assets and inputs

In this section, we apply the framework presented in section 2 to the case of water for hydropower production in Switzerland. The ecosystem assets are the water catchment basins, rivers, and importantly the head, i.e. the vertical distance between the reservoir and the turbine, that can be used. The ES under consideration is, in this context, the volume of available water and its gravitational potential and kinetic energy. The economic benefit is the energy that can be generated per unit of water and the beneficiaries are the private and public consumers of electricity. Obviously, hydropower production necessitates economic inputs, i.e. capital (power plant equipment), to convert the water's energy into power. The objective is thus to compute the exchange value per unit of water at the various hydropower stations.

3.2. Resource regime

The Federal Constitution (Art. 76.4) establishes that the Swiss cantons shall manage their water resources. Some cantons have transferred the sovereignty over public water bodies to communes or corporations. Public waters include lakes, streams and springs with an outflow that has the character of a stream or river from the beginning.

The right to exclusively use water from a public water body for hydropower production is formalized in concessions. According to the Water Rights Act (SR. 721.80), a concession may be granted for a maximum period of 80 years. The concessions lay out the annual fee that the concessionaire must pay to the conceding administrative entity (e.g. a canton). The Ordinance on the determination of water fees (SR.721.831) stipulates that the fee is to be based on a hydropower plant's annual average gross capacity (in kilowatt) which is defined as a function of water volume and usable head. The fee that the operator of a power plant has to pay increases with water volume and head. According to Art. 76.4 of the Federal Constitution, the monetary fee based on a plant's annual average gross capacity is determined by the cantons within the limits given by federal law. The federal price ceiling has been ratcheted up several times from 41.67 CHF/kW (in 2019 prices) of gross capacity in 1918 until the most recent increase in 2015 from 100 to 110CHF/kW of gross capacity which was also the price in 2019 and will remain valid until 2024.

Further, the Energy Act (SR. 730.0) entitles operators of large hydropower plants (>10 MW) to a market premium of up to CHF0.01/kWh if their production costs exceed the electricity market price. This market premium has been available since 2018. In the beginning, 17 operators, owners or utilities received such support for a volume of power representing 23 % of the electricity generated by hydropower in Switzerland (SFOE, 2019). This gradually increased to 30 operators, owners or utilities receiving market premium support in 2021 for 46.9 % of the volume of electricity generated by hydropower in Switzerland. With the recent rise in energy market prices, only 7 operators requested and received support in 2022 for 7 % of the domestic electricity generated by hydropower (SFOE, 2022a).

Finally, the Energy Strategy 2050 explains the government's ambition to source an increasing share of energy consumption from renewable resources while simultaneously phasing out nuclear power supply. Hydropower plays a major role in this transition.

The analysis of the resource regime thus reveals that three policies are in place, that impact the exchange value of water for energy production. The first is the regulation of the water fee. The fee is determined through political negotiations and is detached from price fluctuations on the energy market. It increases production cost and decreases the residual value. The second policy is the market premium which functions as a deficiency payment. It cushions losses and thus should be subtracted from production costs. The third is the Energy Strategy 2030 which gives preference to hydropower as a renewable domestic energy source.

3.3. Results on the exchange value of water for hydropower production

Recent data from a representative survey on hydropower production costs is available for the years 2011–2016 (SFOE, 2018b). The data show that variation in average production cost per kWh is rather small across years. Given that the price ceiling for the concession fee was last adjusted in 2015, we use the production cost data for the years 2015 and 2016 only. For 2017 onward we use the average production cost of the years 2015 and 2016. For comparability, we deflate all prices to 2019, the year before markets were shaken by the Covid19 crisis and in 2022 the war in Ukraine.

In Table 2, we present two versions of the residual value approach. In the first simple version, we simply subtract the production cost of electricity generated in hydropower plants from the energy market price. The resulting values for the years 2016, 2019 and 2020 are negative with a positive value only for 2021. Given the findings of the analysis of the resource regime, we argue that we can obtain more accurate estimates by correcting for the concession fee and the deficiency payment. As can be seen from the last row of Table 2, the adjusted residual value is positive for all years. By multiplying the residual value for a certain year by the energy produced per cubic meter of water, we obtain estimates of the exchange value of water at the various hydropower stations in Switzerland. Fig. 2 shows the exchange value estimates for 2021 at the various hydropower stations. The exchange values per unit of water are generally higher in the mountains where the head can be used in (pump-)storage powerplants.

4. Discussion

Our findings reveal that a simple computation of the residual value of water for hydropower production produces negative values for several years. Using the extended SEEA estimation framework, allowed us to identify two policy interventions that directly impact the residual value. When accounting for them, we obtained an adjusted residual value that is positive for all years.

A negative exchange value estimate, at first sight, means that the ES was being used in the economy at a loss in that particular year. From the rather myopic perspective of SEEA accounting, using an ES at a loss may seem irrational. However, our investigation of the resource regime, revealed that there is political will to phase out non-renewable energy production and to transition to renewables including hydropower. The deficiency payments can be interpreted as society's willingness to pay for the insurance value of domestic hydropower production. Although deficient at first sight in some years, in the long-term, domestic hydropower production helps to hedge against supply and price risks in the international market. This insurance value became eminent in the wake of the energy crisis and enormous energy price increases resulting from the war in Ukraine. In September 2022, the Federal Council passed a new 'ordinance on the establishment of a hydropower reserve'. Its purpose is to provide a safeguard against extraordinary situations in the electricity supply, such as critical supply shortages or failures. It regulates the annual creation of a hydropower reserve by means of a call for tenders and the calling of this reserve (Federal Council, 2022). However, this ordinance was not in place yet in 2021 and thus could not affect our computation of the adjusted residual values.

Our empirical case study has limitations that may impact the numerical values obtained in the computation. Firstly, we use annual averages on production costs and spot market prices due to a lack of better data. These averages fail to reflect the diversity of production cost structures among the hydropower plants and variation in spot market

Table 2
Energy market price and production costs.

CHF/kWh in prices of 2019	2015	2016	2017	2018	2019	2020	2021
Spot market price[1]	0.0649	0.0602	0.0743	0.0840	0.0641	0.0529	0.1714
Production cost [2]	0.0635	0.0686	0.0658	0.0653	0.0650	0.0655	0.0651
Concession fee[2]	0.0147	0.0148	0.0147	0.0146	0.0145	0.0146	0.0145
Average deficiency payment per kWh produced [3]			0.0028	0.0018	0.0021	0.0038	0.0007
Simple residual value: Spot market price- Production cost	0.0014	−0.0085	0.0085	0.0188	−0.0009	−0.0126	0.1063
Adjusted residual value: Spot market price - Production cost + deficiency payment + Concession fee	0.0161	0.0063	0.0259	0.0351	0.0157	0.0058	0.1215

Data sources: 1: annual average of power spot market price for Switzerland at European Power Exchange (EPEX SPOT SE) based on Index Swissix Day Base (https://www.bricklebrit.com) converted from € to CHF using PPP exchange rates. 2: production cost and concession fee for 2015 and 2016 in prices of 2019, from 2017 onward average of 2015 and 2016 in prices of 2019 (SFOE, 2018b). 3: Media releases (SFOE, 2018a; SFOE, 2019; SFOE, 2020; SFOE, 2021; SFOE, 2022a). All values in prices of 2019 (deflated using the consumer price index).

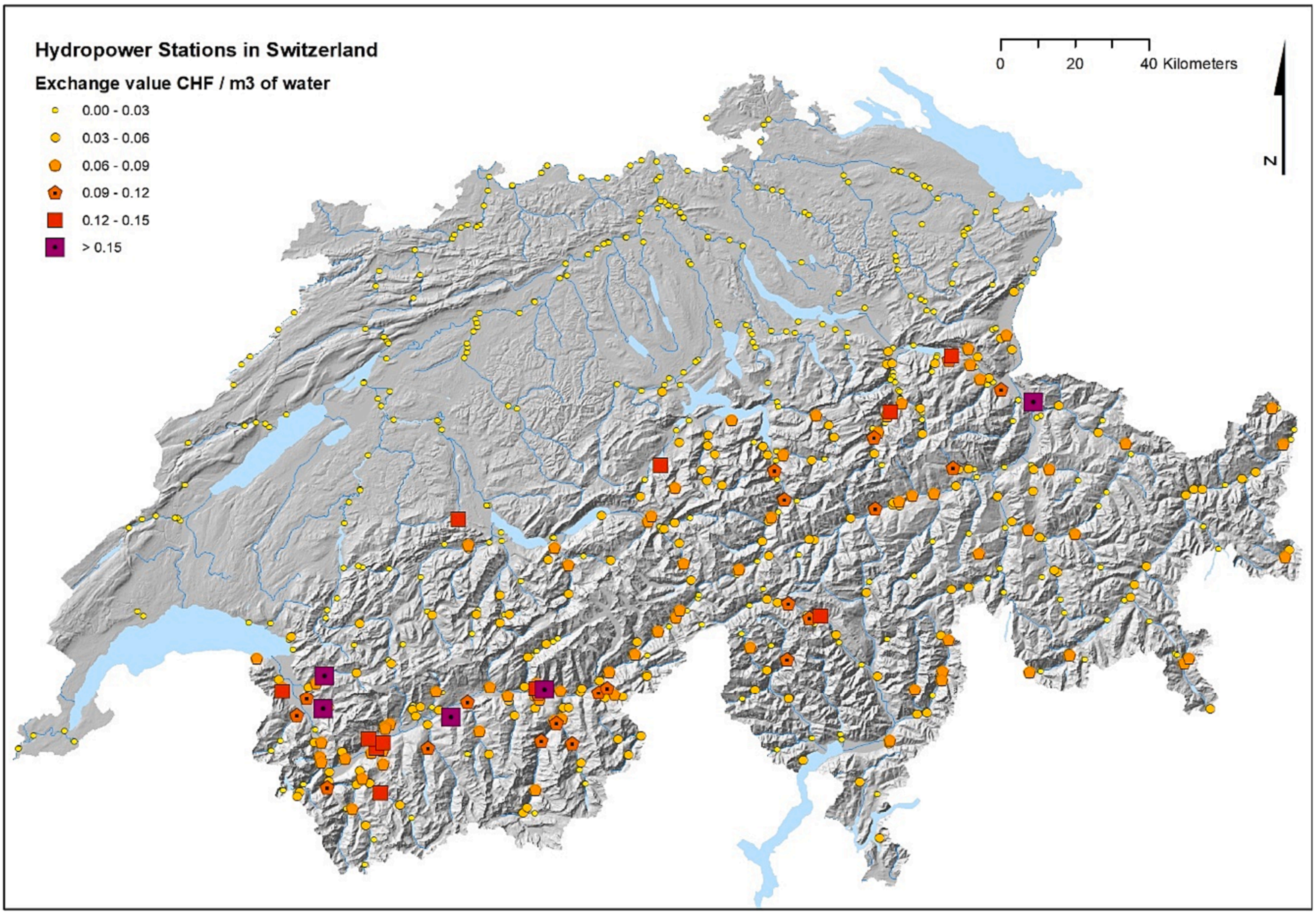

Fig. 2. Adjusted exchange value estimates for water for hydropower production in 2021 in prices of 2019 at hydropower stations in Switzerland. Sources: Swisstopo (2023); SFOE (2022b); see Table 2 for the data sources of the estimates.

prices which make up for part of the business of (pump-)storage powerplants. Further we estimate the amount of energy produced per cubic meter of water by dividing each plant's expected average energy production by the turbines' capacity in terms of cubic meters of water per year. Given that it is unlikely for turbines to run at full capacity throughout the year, our computed values likely underestimate the amount of energy produced per unit of water.

Thus, the numerical values presented in Table 2 should be interpreted with care, but anyhow the sign is of greater importance for our discussion than the exact value.

5. Conclusion

In this paper we have presented a suggestion to extend the estimation of ES exchange values by an analysis of the institutional resource regime governing the use of the ES. Accounting for ES is case sensitive, not least because of differences in institutional arrangements (Mäler et al., 2008). In line with Femia and Capriolo (2022), we argue that institutions governing ES determine their exchange values. Accounting for policy interventions that increase or decrease exchange values can be worthwhile, especially in case studies outside SNA contexts, that allow for more flexibility. There are two reasons for doing so. The first is to obtain more accurate values of an ES's contribution to the economy at a certain point in time. The second is to better understand negative ES estimate values and the reasons why society may be willing to accept, and eventually compensate for them. We argue that the insurance value of using an ES can be one such reason. In either case, including an analysis of the institutional resource regime provides depth to exchange value estimates that can increase their relevance for policy makers who may be less enticed by environmental economic accounting (Vardon et al., 2016).

Previous literature has stressed that exchange values explicitly exclude consumer surplus and thus are more conservative than estimates obtained in willingness-to-pay/willingness-to-accept studies (Obst et al., 2016). Exchange values are supposed to only reflect the prices at which ES are or could be transacted (Hein et al., 2020a). However, as seen in the Swiss case study with its particular market structure context, the simple exchange value approach produces values that are a glimpse of an ES's contribution to the economy in the status quo. Accounting for policy interventions in the estimation allows to reflect at least a share of other values that society attributes to the use of the ES. Perhaps our suggestion to consider the resource regime in the analysis can contribute to developing estimates that are between the two extremes of stated preference values on the one side and status quo market values on the other side. Rather than simply ignoring negative values or setting them equal to zero, in future research more thought is needed on how to consider insurance values related to the use of ES.

CRediT authorship contribution statement

Astrid Zabel: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Raushan Bokusheva:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Martina Bozzola:** Methodology, Writing – review & editing, Writing – original draft.

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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References

Baumgärtner, S., 2007. The insurance value of biodiversity in the provision of ecosystem services. Natural Resource Modeling 20 (1), 87–127. https://doi.org/10.1111/j.1939-7445.2007.tb00202.x.

Baumgärtner, S., Quaas, M.F., 2010. Managing increasing environmental risks through agrobiodiversity and agrienvironmental policies. Agricultural Economics 41 (5), 483–496. https://doi.org/10.1111/j.1574-0862.2010.00460.x.

Cook, D., Malinauskaite, L., Davíðsdóttir, B., Ögmundardóttir, H., 2021. Co-production processes underpinning the ecosystem services of glaciers and adaptive management in the era of climate change. Ecosystem Services 50, 101342. https://doi.org/10.1016/j.ecoser.2021.101342.

Edens, B., Graveland, C., 2014. Experimental valuation of Dutch water resources according to SNA and SEEA. Water Resources and Economics 7, 66–81. https://doi.org/10.1016/j.wre.2014.10.003.

European Commission; International Monetary Fund; Organisation for Economic Co-operation and Development; United Nations; World Bank (2009): System of National Accounts 2008. New York: United Nations.

Federal Council (2022): Verordnung über die Errichtung einer Wasserkraftreserve (WResV). Ordinance on the establishment of a hydropower reserve. Draft version. Available online at https://www.newsd.admin.ch/newsd/message/attachments/73021.pdf.

Femia, Aldo; Capriolo, Alessio (2022): Beyond valuation. Monetary aggregates for the SEEA-EA. The Italian proposal. In *OE* 7, Article e84689. DOI: 10.3897/oneeco.7.e84689.

Gerber, J.-D., Knoepfel, P., Nahrath, S., Varone, F., 2009. Institutional Resource Regimes: Towards sustainability through the combination of property-rights theory and policy analysis. Ecological Economics 68 (3), 798–809. https://doi.org/10.1016/j.ecolecon.2008.06.013.

Hein, L., Bagstad, K.J., Obst, C., Edens, B., Schenau, S., Castillo, G., et al., 2020a. Progress in natural capital accounting for ecosystems. Science 367 (6477), 514–515. https://doi.org/10.1126/science.aaz8901.

Hein, L., Remme, R.P., Schenau, S., Bogaart, P.W., Lof, M.E., Horlings, E., 2020b. Ecosystem accounting in the Netherlands. Ecosystem Services 44, 101118. https://doi.org/10.1016/j.ecoser.2020.101118.

Horlings, Edwin; Schenau, Sjoerd; Hein, Lars; Lof, Marjolein; Jongh, Linda de; Polder, Michael (2020): Experimental monetary valuation of ecosystem services and assets in the Netherlands. CBS Den Haag and Wageningen University & Research.

Lange, S., Campagne, C.S., Comte, A., Bank, E., Santos-Martín, F., Maes, J., Burkhard, B., 2022. Progress on ecosystem accounting in Europe. Ecosystem Services 57, 101473. https://doi.org/10.1016/j.ecoser.2022.101473.

Lieberherr, E., Fischer, M., Tschannen, A., 2019. Taking stock of institutional resource regime research: A meta-analysis. *Environmental Science & Policy* 97, 81–89. https://doi.org/10.1016/j.envsci.2019.04.003.

Mäler, K.-G., Aniyar, S., Jansson, A., 2008. Accounting for ecosystem services as a way to understand the requirements for sustainable development. In *Proc Natl Acad Sci USA* 105 (28), 9501–9506. https://doi.org/10.1073/pnas.0708856105.

La Notte, Alessandra; Maes, Joachim; Dalmazzone, Silvana; Crossman, Neville D. Grizzetti, Bruna; Bidoglio, Giovanni (2017): Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention. *Ecosystem Services* 23, pp. 18–29. DOI: 10.1016/j.ecoser.2016.11.002.

Obst, C., Hein, L., Edens, B., 2016. National Accounting and the Valuation of Ecosystem Assets and Their Services. *Environ Resource Econ* 64 (1), 1–23. https://doi.org/10.1007/s10640-015-9921-1.

OECD (2019): OECD Trade Policy Papers. Measuring distortions in international markets: the aluminium value chain.

Paavola, J., Primmer, E., 2019. Governing the Provision of Insurance Value From Ecosystems. *Ecological Economics* 164, 106346. https://doi.org/10.1016/j.ecolecon.2019.06.001.

Pronovo AG (2021): Cockpit Stromkennzeichnung Schweiz. Available online at https://www.strom.ch/de/dokument/cockpit-stromkennzeichnung-schweiz.

Schaefli, B., Manso, P., Fischer, M., Huss, M., Farinotti, D., 2019. The role of glacier retreat for Swiss hydropower production. Renewable Energy 132, 615–627. https://doi.org/10.1016/j.renene.2018.07.104.

Schaub, S., Buchmann, N., Lüscher, A., Finger, R., 2020. Economic benefits from plant species diversity in intensively managed grasslands. Ecological Economics 168, 106488. https://doi.org/10.1016/j.ecolecon.2019.106488.

Scottish government (2020): Scottish natural capital accounts: 2020. An Experimental Official Statistics publication for Scotland. Edinburgh, Scotland.

SFOE (2018a): Faktenblatt Marktprämie 2018. Swiss Federal Office of Energy. Available online at https://www.newsd.admin.ch/newsd/message/attachments/54391.pdf.

SFOE (2018b): Rentabilität der Schweizer Wasserkraft. Resultate einer Datenumfrage bei Betreibern von Schweizer Wasserkraftwerken im Auftrag der UREK-N. Bern.

SFOE (2019): Faktenblatt Marktprämie 2019. Swiss Federal Office of Energy. Available online at https://www.bfe.admin.ch/bfe/de/home/foerderung/erneuerbare-energien/marktpraemie-grosswasserkraft.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvOTg5Mw==.html.

SFOE (2020): Faktenblatt Marktprämie 2020. Swiss Federal Office of Energy. Available online at https://www.bfe.admin.ch/bfe/de/home/foerderung/erneuerbare-energien/marktpraemie-grosswasserkraft.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTAyNzA=.html.

SFOE (2021): Faktenblatt Marktprämie 2021. Swiss Federal Office of Energy. Available online at https://www.bfe.admin.ch/bfe/de/home/foerderung/erneuerbare-energien/marktpraemie-grosswasserkraft.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTA3Nzg=.html.

SFOE (2022a): Faktenblatt Marktprämie 2022. Swiss Federal Office of Energy. Available online at https://www.bfe.admin.ch/bfe/de/home/foerderung/erneuerbare-energien/marktpraemie-grosswasserkraft.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTExNTQ=.html.

SFOE (2022b): Statistik der Wasserkraftanlagen der Schweiz. Swiss Federal Office of Energy. Available online at https://www.bfe.admin.ch/bfe/de/home/versorgung/erneuerbare-energien/wasserkraft.html#tab_content_bfe_de_home_versorgung_erneuerbare-energien_wasserkraft_jcr_content_par_tabs.

Swisstopo (2023): Swiss Map Vector 1000. Swiss Federal Office of Topography. Available online at https://www.swisstopo.admin.ch/de/geodata/maps/smv/smv1000.html.

Turner, K., Badura, T., Ferrini, S., 2019. Natural capital accounting perspectives: a pragmatic way forward. Ecosyst Health Sustain 5 (1), 237–241. https://doi.org/10.1080/20964129.2019.1682470.

UN DESA (2019): Technical Recommendations in support of the System of Environmental-Economic Accounting 2012. Experimental Ecosystem Accounting: Department of Economic and Social Affairs Statistical Division (Studies in Methods, Series M No.97).

United Nations; European Union; Food and Agriculture Organization of the United Nations International Monetary Fund; Organisation for Economic Co-operation and Development; The World Bank (2014): System of environmental-economic accounting 2012. Central framework. New York, NY: United Nations.

United Nations et al. (2021): System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. Available online at https://seea.un.org/ecosystem-accounting.

United Nations; European Union (2014): Experimental ecosystem accounting. New York: United Nations (System of environmental-economic accounting 2012).

Vardon, M., Burnett, P., Dovers, S., 2016. The accounting push and the policy pull: balancing environment and economic decisions. *Ecological Economics* 124, 145–152. https://doi.org/10.1016/j.ecolecon.2016.01.021.

Vysna, Veronika; Maes, Joachim; Petersen, Jan-Erik; La Notte, Alessandra; Vallecillo, Sara; Aizpurua, Nerea et al. (2021): Accounting for ecosystems and their services in the European Union (INCA). Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU. 2021 edition. Luxembourg: Publications Office of the European Union (Statistical reports / Eurostat).