Value-transforming financial, carbon and biodiversity footprint accounting

Sami El Geneidy[1,2,*], Stefan Baumeister[1,2], Maiju Peura[1,3] & Janne S. Kotiaho[1,3]

[1] School of Resource Wisdom, University of Jyväskylä, P.O. Box 35, FIN-40014 University of Jyväskylä

[2] School of Business and Economics, University of Jyväskylä, P.O. Box 35, FIN-40014 University of Jyväskylä

[3] Department of Biological and Environmental Science, University of Jyväskylä, P.O. Box 35, FIN-40014 University of Jyväskylä

[*]Corresponding author email: sami.s.elgeneidy@jyu.fi

Abstract

Transformative changes in our production and consumption habits are needed to enable the sustainability transition towards carbon neutrality, no net loss of biodiversity, and planetary well-being. Organizations are the way we humans have organized our everyday life, and much of our negative environmental impacts, also called carbon and biodiversity footprints, are caused by organizations. Here we show how the financial accounts of any organization can be exploited to develop an integrated carbon and biodiversity footprint account. As a metric we utilize spatially explicit potential global loss of species which, we argue, can be understood as the biodiversity equivalent, the utility of which for biodiversity is similar to what carbon dioxide equivalent is for climate. We provide a global Biodiversity Footprint Database that organizations, experts and researchers can use to assess consumption-based biodiversity footprints. We also argue that the current integration of financial and environmental accounting is superficial, and provide a framework for a more robust financial value-transforming accounting model. To test the methodologies, we utilized a Finnish university as a living lab. Assigning an offsetting cost to the footprints significantly altered the financial value of the organization. We believe such value-transforming accounting is needed in order to draw the attention of senior executives and investors to the negative environmental impacts of their organizations.

Main Text

Introduction

Biodiversity loss is directly driven by human land and sea use and their changes, direct exploitation of nature, climate change, pollution, and introduction of invasive alien species(1). These direct drivers result from various underlying indirect root causes such as human population dynamics, consumption patterns, trade, and governance, which are in turn underpinned by societal values and behaviours(1–3). Managing the direct drivers of biodiversity loss alone will not produce sustained outcomes sufficient to bend the curve of biodiversity loss(4, 5). Instead, we must direct our efforts to the root causes such as consumption and trade.

Everyday life and the economics of societies are organized through organizations, be they private businesses, public services, or non-governmental organizations. The negative environmental impacts of nearly any organization extend through international trade and supply chains to all over the planet(6–8). While carbon footprint assessments are abundant(9–11) and a few biodiversity footprint assessments have been attempted(12–15), we take the approach a significant step further by showing how the financial accounts of any organization, coupled with global trade databases and a spatially explicit global biodiversity footprint indicator, can be used to estimate the potential global loss of species. We argue that this indicator can be understood as the biodiversity equivalent, the utility of which for biodiversity is similar to what CO_2 equivalent is for climate. The approach we have developed here allows financial and environmental accounting to be integrated to the extent that with some adjustments to public policy(16) (e.g. taxation or mandatory offsetting of the footprints) the financial value of the accounts can be transformed based on the environmental impacts.

Financial accounting

Decision-making in organizations is ultimately guided by information obtained from financial accounts(17–21). The International Accounting Standards Board defines the objective of financial reporting to be to provide financial information to management, investors, regulators and the general public(22). Financial accounting links the company activities with performance and distils all this information into a single unit of account: money(20). Financial accounts define what are included and excluded in assets and liabilities and how profit and loss are calculated, which consequently defines the size, structure and performance of the organization(18). Unfortunately, conventional financial accounting neglects the complex web of societal and environmental impacts organizations have beyond their socially constructed, and thus only presumed, boundaries(18, 20).

In the economics literature, these neglected impacts are called externalities(23). Externalities are something that happen to a seemingly uninvolved third party, such as the environment, when actions are taken to meet the needs of the so-called true stakeholders, such as the shareholders. Conventional financial accounting overlooks environmental externalities(21, 24, 25) and is therefore ill-equipped to be conductive to the sustainability transition. To facilitate a transformative change to more sustainable production and consumption patterns in organizations, we need to reconfigure the financial accounting to internalize the environmental impacts.

Environmental accounting

Environmental accounting should be a fundamental part of organizational decision-making. Unfortunately, environmental accounting seems to remain isolated within organizations and even when it is integrated with other reporting practices like financial reports it can still remain unexploited in management decisions(17, 19, 21, 24). It has even been argued that the integrated reports of companies merely exploit the concept of sustainability in order to buttress the dominant financial discourses of development and growth(26).

Basic principles for environmental accounting have been set by several standards such as the Sustainability Reporting Standards of the Global Reporting Initiative(27) and the International Financial Reporting Standards' Sustainability Disclosure Standard(28). Some standards are set to provide guidance for specific dimensions of environmental accounting, for example the Greenhouse Gas Protocol(29) or the Natural Capital Protocol(30). In addition, the International Integrated Reporting Framework(31) has developed a framework that brings financial, social and environmental information under a single report.

The qualitative characteristics set by the different sustainability reporting frameworks somewhat align with the basic principles of conventional financial accounting standards(22, 32). However, it seems that scrutiny of the latter is still much more profound than of the former(24, 33). For management decisions to be truly conductive to sustainability transition, the scrutiny of the two should be equal(19).

Integrating financial and environmental accounting and the results from the living lab

To integrate financial and environmental accounts we developed a five-step framework for value-transforming integrated financial-environmental accounting that can be replicated in any organization with financial accounts. We will focus on how environmental impacts, more specifically carbon and biodiversity footprints, can be estimated, communicated and prioritized by utilizing financial accounts. While the first steps towards integrating environmental information into financial accounts have already been taken(21, 24, 34–37), generalizable applications remain to be articulated.

We demonstrate the utility of the framework by assessing the carbon and biodiversity footprint of our living lab, the University of Jyväskylä in Finland, and construct a value-transforming integrated financial-environmental impact statement. In each step of the framework, we present general principles and then apply them to the living lab.

STEP 1: Choose the report of financial accounts

In environmental impact assessment through financial accounts, the boundaries of the assessment are set by the financial accounts. Thus, the first step is to choose an appropriate report of the financial accounts. Since we are interested in the environmental impacts of consumption, we focus on financial expenses exclusively and disregard revenues and other financial flows. The revenue of the organization might be of interest, however, if the analysis is expanded to consider handprints, that is, potential positive environmental impacts(38) that the organization produces. Some expenses are deemed not relevant regarding environmental impacts, for example staff salaries.

Reports with varying level of detail can be produced from the financial accounts. While a more detailed financial report might reduce error and provide more granulated data, using a more cursory financial report can limit the necessary work, especially during the harmonization of accounts (step 3), and makes future automated annual calculation more feasible. The most important consideration is that the chosen report provides account classification that retains enough detail to remain fit for the purpose. A typical financial impact statement where expenses are provided in very broad categories, for example in materials and services, is not sufficiently detailed for the evaluation of environmental impacts.

Here we utilize financial reports of the University of Jyväskylä containing 123 different expense categories for the years 2019–2021. The reports were procured from the university administration.

STEP 2: Choose environmental accounting methods and indicators

The hybrid EEIO-LCA methodology combines environmentally extended input-output (EEIO) analysis with life cycle assessment (LCA) and can be utilized to account the environmental impacts of organizations(36, 39–41). For this paper, it is enough to state that EEIO analysis connects the inputs an organization needs (measured as financial consumption revealed by the financial reports) with the environmental impacts of those inputs upstream in the supply chain. For certain financial accounts, such as energy and travel-related accounts, the LCA can reveal the environmental impacts more accurately by utilizing process-based impact factors obtained from service providers or from scientific literature. Hybrid EEIO-LCA combines the strengths of EEIO analysis and LCA approaches, and we anticipate that in the future we will see a stronger merger of the two.

Of the direct drivers of biodiversity loss[3], the EEIO and LCA databases generally cover land and water use (i.e. water stress), pollution, and greenhouse gas emissions. There are several sub-categories within each of the included drivers in the databases. For example, land use is divided into several land use types. The quantity of each of the drivers alone is not sufficient for the evaluation of the biodiversity footprint. However, by further integrating the EEIO or LCA analysis with other existing databases and frameworks, such as LC-IMPACT(42) or ReCiPe(43), the quantity of the driver can be converted to biodiversity loss.

Carbon footprints are generally expressed in carbon dioxide equivalents (CO_2e). Emissions other than carbon dioxide such as methane, nitrous oxide and fluorinated gases are converted into CO_2e based on their global warming potential(44). Biodiversity footprints can be measured with several indicators(14, 45–47). We opted for the global potentially disappeared fraction of species(42) for one specific reason: as an indicator, it has desirable characteristics much like CO_2e in that it provides a common currency for measuring biodiversity loss across the planet. For this reason we refer to the indicator as biodiversity equivalent (BDe). In essence, BDe tells what fraction of the species of the world are at risk of going extinct globally if for example 1 km^2 of land is continuously exploited by a specific driver of biodiversity loss, such as land use for intensive forestry(42), in any given country. The same amount of area occupied by the same driver causes less global biodiversity loss in relatively species poor areas than what it causes in relatively species rich areas. On the other hand, if both areas experienced a loss of the same amount of BDe, this would indicate both areas experienced the same global biodiversity loss. Different species would be lost in different parts of the world, but the fraction of globally potentially lost species would be the same.
Climate change and biodiversity loss are interconnected and thus should be solved together(1, 48, 49). In this regard the methodology we describe here is convenient: As climate change is one of

the drivers of biodiversity loss, assessing the carbon footprint becomes an obligatory intermediate step when assessing the biodiversity footprint.

To assess the carbon and biodiversity footprint of the consumption of the University of Jyväskylä we utilized a hybrid EEIO-LCA methodology. We derived emission impact factors (CO_2e/€) directly from the EEIO database EXIOBASE(50), amended by some of the service providers, and the LCA methodology (SI Appendix Dataset S5, S6). To obtain spatially explicit biodiversity loss impact factors (BDe/€) we combined the EXIOBASE with the LC-IMPACT (SI Appendix Table S5, S6). We provide the full dataset in https://doi.org/10.5281/zenodo.8369650.

STEP 3: Harmonize the accounts

The categorization of the financial accounts of the organization is usually not directly compatible with the EEIO economic activity categorization, and the account categorizations must be harmonized. Determining a suitable match from the EEIO categorization for all financial accounts of the organization can be onerous but it helps when the chosen EEIO database has high sectorial detail. The harmonization can be done based on the chart of accounts containing information about all accounts in the general ledger of the organization.

There are generally two further key transformation operations needed: inflation adjustment and conversion of the purchaser prices in the financial accounts of the organization to the basic prices in the EEIO databases.

In the living lab we opted for the EEIO database EXIOBASE because it has relatively high sectorial detail, allowing the University of Jyväskylä's accounts to be harmonized with it. Inflation adjustment and price conversions were calculated according to the equations presented in the Methods section (see also SI Appendix Table S7 and Dataset S3).

STEP 4: Calculate results

For the carbon footprint assessment, the monetary consumption (€) in each of the account categories of the organization is first multiplied with the category-specific emission impact factor (CO_2e/€) derived from the EXIOBASE. Carbon footprints that have been assessed by the service providers or with the LCA methodology can be directly imported to the specific account category. The total carbon footprint is then calculated by summing across all the account categories.

The biodiversity footprint is first calculated for each driver of biodiversity loss individually by multiplying the money (€) in each of the account categories of the organization with the category-specific biodiversity footprint impact factor (BDe/€) derived from the merger of EXIOBASE and LC-IMPACT, and then by summing the biodiversity footprint across the categories within each of the three impacted ecosystem types: terrestrial, freshwater and marine ecosystem. Finally, to arrive at a single BDe value for the organization, the biodiversity footprints in different ecosystem types are merged by taking a species-weighted average of biodiversity footprints over ecosystem types (see

Methods section). The complete process flowchart depicted in Fig. 1 illustrates the sequence of the calculations.

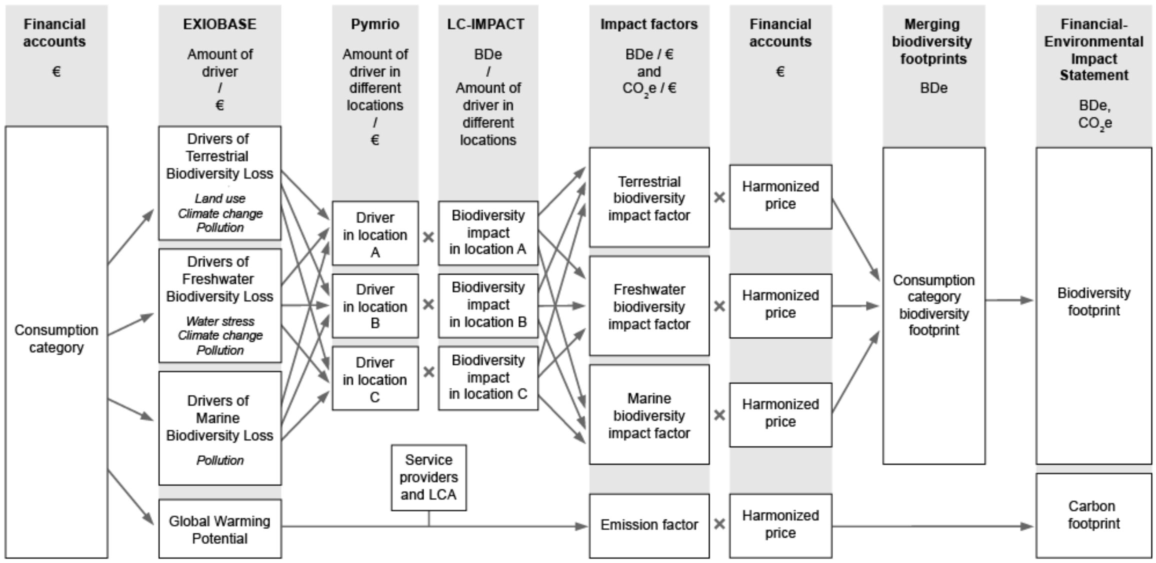

Fig. 1 | Process flowchart for calculation of the biodiversity and carbon footprints from financial accounts. Explanation of each of the steps are provided in the main text and further details for the calculations in the Methods.

To illustrate the results, we aggregated the consumption information of the University of Jyväskylä to 12 broad consumption categories and calculated the relative importance of each to carbon and biodiversity footprints (the carbon footprint and biodiversity footprints for each of the 123 accounts are tabulated in SI Appendix Dataset S4). The total annual carbon footprint decreased by 16% from 16 150 t CO_2e in 2019 to 13 570 CO_2e in 2020 (SI Appendix Table S1). Similarly, the total biodiversity footprint decreased by 19% from 4.17E-08 BDe in 2019 to 3.38 BDe in 2020 (SI Appendix Table S2). However, as biodiversity footprint is not cumulative over the years, we averaged the three years and on average 0.0000037% of the species of the world are potentially globally lost due to the operations of University of Jyväskylä, if no action is taken to reduce the pressures i.e. the consumption continues as is over time(42). The global biodiversity footprint impact factors we have calculated are provided for further research and applications in SI Appendix Datasets S1 and S2. Disaggregated results by ecosystem type can be found from SI Appendix Fig. 1 and SI Appendix Table S3.

The decrease of the total annual carbon and biodiversity footprints were both largely driven by a decrease in business travel and related services (Fig. 2a). From Fig. 2a we can also see that energy and water consumption had the highest overall carbon footprints while IT supplies, licenses and services, and machinery, equipment and supplies had the highest overall biodiversity footprints. As the chosen time interval coincides with the outbreak of the COVID-19 pandemic, some of the greatest annual variations are likely caused by signatures of the pandemic. Most obvious is the plummeting of the carbon and biodiversity footprints attributable to business travel and related services since 2019. Other clear changes are the increased footprints due to IT supplies and machinery and the decreased footprints due to food and related services. Both of these were likely caused by the increase in remote working practices due to the pandemic.

The annual share of terrestrial biodiversity footprint from land use, climate change and pollution was on average 47%, 46% and 7% respectively while the annual share of freshwater biodiversity footprint from water stress, climate change and pollution was 55%, 42% and 3%. In marine ecosystems pollution is the only driver that can currently be incorporated to the assessment (SI Appendix Table S4).

Assessing the carbon and biodiversity footprints simultaneously allowed us to see that the consumption categories had similar relative impacts on both. This similarity can be seen from Fig. 2b where we have plotted the relative carbon footprint of each consumption category against those of the relative biodiversity footprint. As was alluded to above nearly half of the biodiversity footprint was due to climate change in terrestrial and freshwater ecosystems, and therefore this similarity is easy to understand. These results illustrate that there are clear synergies to be obtained in combating climate change and biodiversity loss simultaneously. However, the disaggregated results by ecosystem type (SI Appendix Fig. S1 and Table S3) illustrate that there were also some residual impacts beyond climate change on biodiversity footprints that may need separate focus.

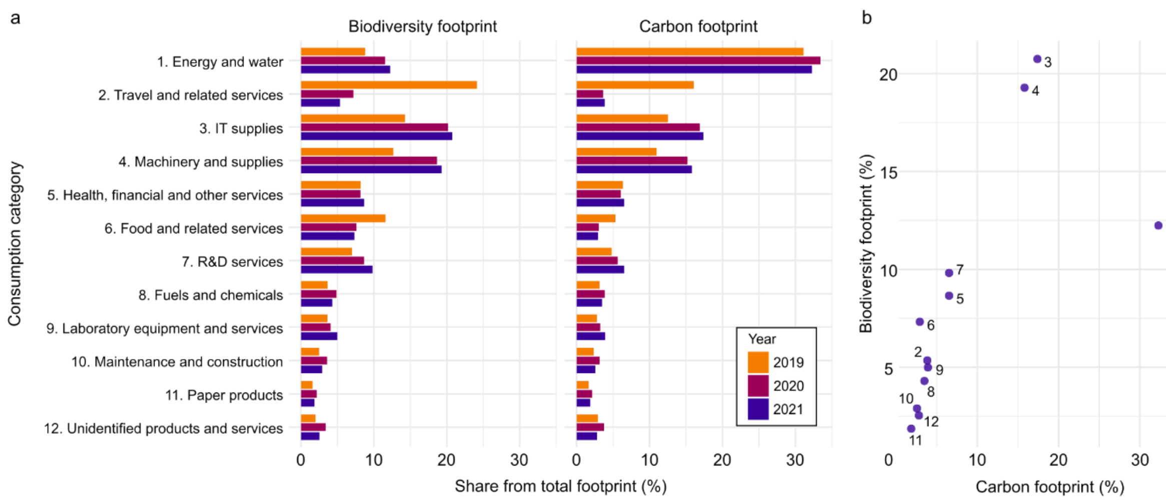

Fig. 2 | The composition of the carbon and biodiversity footprint of the University of Jyväskylä. The relative contribution (%) of different consumption categories of the University of Jyväskylän during 2019-2021 for the carbon and biodiversity footprints (**a**) and a scatterplot of the relative carbon footprint of each consumption category on the relative biodiversity footprint of the corresponding consumption category in 2021 (**b**). Small numbers in the scatter plot of panel b refer to the consumption categories in panel a.

The approach we have developed is spatially explicit (at a country level), and thus we were able to determine the geographical location of the carbon and biodiversity footprints of the University of Jyväskylä. In terms of the carbon footprint, largest share of the emissions was generated in Finland, Russia and China (Fig. 3a). Largest threats to biodiversity (Fig. 4b), can be observed in Estonia, United Arab Emirates, Palestinian Territory, Italy, Indonesia, Finland, and in several small island states (e.g. Guam and Seychelles) that cannot be distinguished from the map. It is notable that 66 % of the carbon footprint and 98 % of biodiversity footprint is situated outside of Finland. Furthermore, the data illustrates that the spatial analysis of the direct drivers of biodiversity loss produces a different outcome to the consequential global biodiversity footprint they cause (Fig. 4c-f).

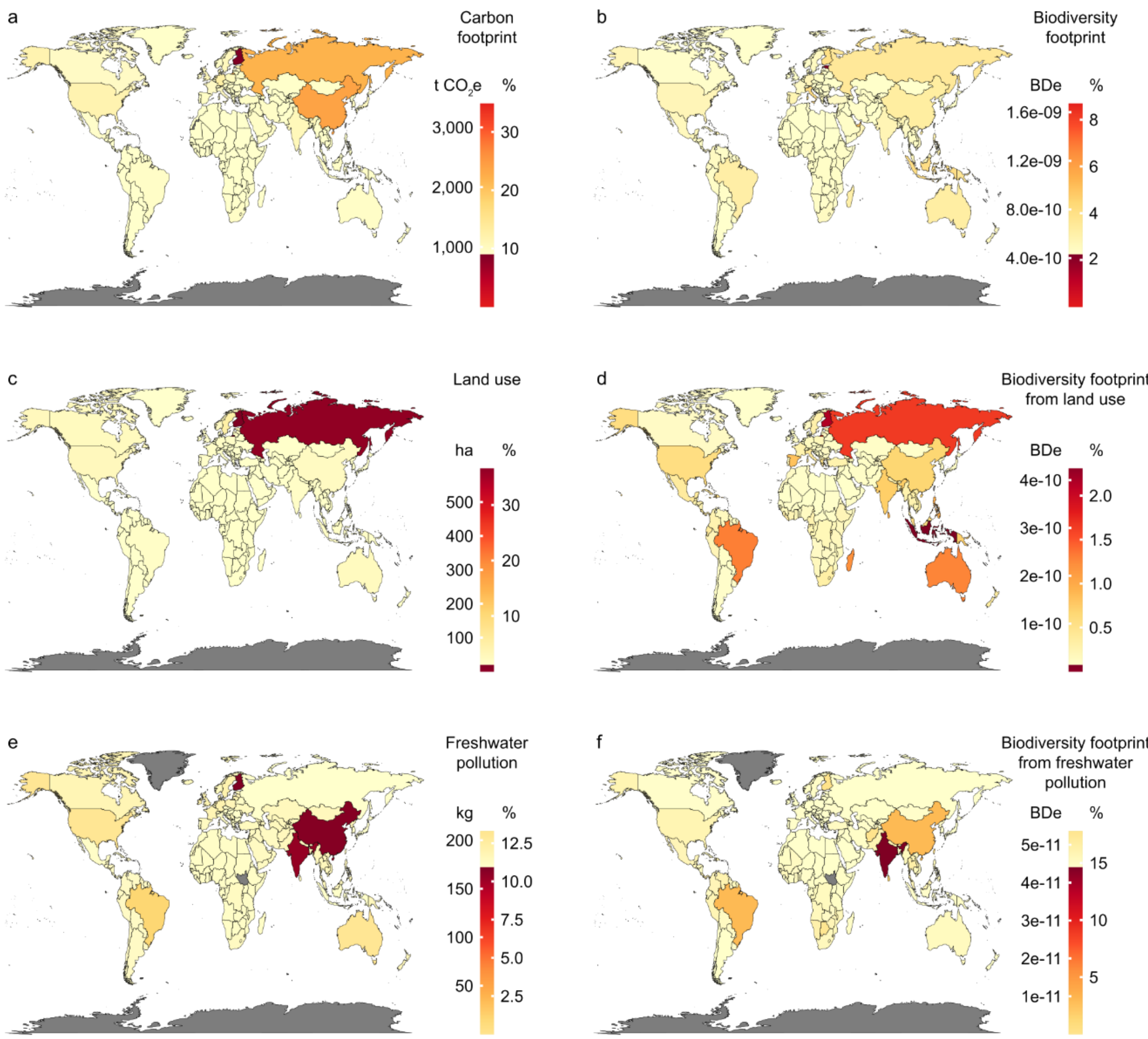

Fig. 3 | Geographical analysis of the carbon and biodiversity footprints of the University. The geographical location of the University's carbon footprint (tCO_2e) (panel a), biodiversity footprint (BDe) (panel b), land use (ha) and biodiversity footprint (BDe) due to land use (panels c and d respectively) and freshwater pollution (kg) and biodiversity footprint (BDe) due to freshwater pollution (panels e and f respectively). Small island states that are not visible in the map were excluded from the scales of the map. Although in the analysis the carbon footprint contains all greenhouse gases, in this figure, only CO_2 is depicted. Detailed data for each country, including the small island states', is provided in SI Appendix Dataset S7. Analysis was done in R.

STEP 5: Assemble the value-transforming financial-environmental impact statement

In financial accounting, the relevant information is generally compiled in an income statement and a balance sheet. For carbon and biodiversity footprint analysis it is the income statement which contains most of the information needed, that is, the incomes and expenses of the organization. The balance sheet, which contains information about the organization's assets, could be used in natural capital(34) and handprint(38) analyses, but these fall outside the scope of our current paper.

To transform the financial value, the carbon and biodiversity footprints need to have a cost that is visible in the income statement. One way to do this is to purchase offsets matching the footprints. To evaluate the offsetting cost of the carbon footprint, we used the World Bank's carbon pricing statistics for the European Union, which varied between 24.51 $/tCO2e in 2019 and 49.78 $/tCO2e in 2021(51). As no such statistics are available for biodiversity footprints, we developed one to demonstrate the idea.

As stated above, a desirable characteristic of the BDe is that it provides a common currency for measuring biodiversity loss across the planet. While we first used BDe to measure biodiversity loss due to factors like continued land use, here we reverse the logic and use the same land use biodiversity impact factors to estimate avoided loss(52), that is, the biodiversity gain achieved if the continuous exploitation is ceased for the purpose of offsetting biodiversity loss. For the sake of the example, here we only consider the biodiversity footprint in the year 2021. Potential leakage of the benefits is taken into account with a multiplier, as explained in the Methods section. Using the LC-IMPACT database, we calculated the area of land used for intensive forestry that should be permanently removed from use in Finland or in Brazil to offset the global biodiversity footprint of the University of Jyväskylä. To offset the 3.66E-08 BDe caused by the consumption of the university, altogether 574 000 or 6 800 ha should permanently be removed from intensive use in Finland or in Brazil, respectively. By multiplying the area with the average price of forest land in Finland (6524 €/ha(53)) or Brazil (901 €/ha converted from 979 $/ha(54)) (see Methods for details), we arrived at the total cost of 3 747 743 k€ in Finland or 6 117 k€ in Brazil to be transferred to the income statement. If the cost is distributed across 30 years, similar to the depreciation of large investments, the annual cost would be around 125 000 k€ if the offset was completed in Finland and 204 k€ if it was completed in Brazil.

Finally, building on earlier research(16, 34), we compiled a financial-environmental impact statement. By amending the statement with the carbon and biodiversity footprint offset values, we arrived at the value-transforming integration of financial and environmental accounts (**Error! Reference source not found.**). In financial accounts, net income is generally the deduction of expenses from revenue. By adopting the same logic, the net carbon and biodiversity footprint is the deduction of the footprints from their respective offsets. The integrated financial-environmental impact statement can be used to quickly deduce the economic and environmental position of the organization.

Table 1 | The financial-environmental impact statement of the University of Jyväskylä in 2021. As units we use thousands of euros (k€), tonnes of carbon dioxide equivalents (tCO_2e) and pico (10^{-12}) biodiversity equivalents (pBDe).

	Financial footprint (k€)	Carbon footprint (tCO_2e)	Biodiversity footprint (pBDe)
Revenue			
Government funding	148 826	-	-
Other revenue from operations	67 881	-	-
Expenses / Footprints			
Staff expenses	152 868	224	797
Depreciation	2 281	799	2 409
Grants	2 768	436	1 365
Raw materials, equipment, and goods	11 802	3984	12 008
Services	13 613	3146	12 059
Rents	25 575	4795	4 865
Travel	1 094	366	1 259
Other	9 700	747	1 887
Total Expenses / Footprints	**219 701**	**14 498**	**36 649**
Losses and Gains			
Fundraising	4 768	-	-
Investment gains and losses	31 666	-	-
Appropriation	-4 328	-	-
Internal impact pricing			
Carbon offsets	673	-14 498	-
Biodiversity offsets if in Finland	125 000	-	-36 649
Biodiversity offsets if in Brazil	204	-	-36 649
Net Income / Footprints			
Footprints without offsets	**29 112**	**14 498**	**36 649**
Footprints with offsets if in Finland	**-95 888**	**0**	**0**
Footprints with offsets if in Brazil	**28 908**	**0**	**0**

Discussion

The value-transforming integration of financial and environmental accounting presented here is motivated by the observation that environmental accounting has remained isolated and unexploited in management decisions(17, 19, 21, 24). While earlier research on linked financial and environmental accounting(16, 34–36, 55) has been pioneering, discussion about the implications of the integration for accounting itself(35–37, 41) or its wider societal importance(16, 17, 21) has remained scant. We think that extensive adoption of value-transforming integration is

essential in order to influence decision-making in organizations and to facilitate the much-needed transformative change in our production and consumption practices in support of planetary well-being(2, 56).
Adoption of the new accounting system is, however, not only a technical accounting issue; it is also a public policy issue(16). The mere existence of the framework does not guarantee that the value-transforming integration of financial and environmental accounting is adopted. Some forerunner corporations have called for mandatory assessment and disclosure of their impacts on nature(57) and mandatory reporting might indeed be a more effective strategy compared to voluntary reporting(58–61).

The introduction of mandatory offsetting is one policy intervention that would transform financial values of the accounts of the organizations. Taxes or subsidies based on the environmental footprints might be another(62), and internal pricing (or so-called internal offsetting(41)) of environmental impacts could be yet another. In internal pricing a cost is set for environmental impacts based on an agreed internal valuation scheme. The money is then placed in an internal fund to support activities that mitigate the footprint or enhance the handprint of the organization. Previously, it has been stressed that value-transforming economic instruments to protect biodiversity, including biodiversity offset programs, do not and most likely cannot operate without robust regulation and government involvement(63–67). Therefore, the value-transforming integration of financial and environmental accounting should be made mandatory for all organizations with financial disclosure obligations.

A massive 98% of the biodiversity footprint caused by the University of Jyväskylä's consumption is exported outside Finland through complex supply chains. As assessment of the biodiversity footprint of consumption is not yet mainstream, also the question of how to offset these exported biodiversity impacts has remained unexplored. We open the debate by arguing that as BDe provides a common currency for measuring biodiversity loss across the planet, it may also provide a location-independent common currency for offsetting the loss. While biodiversity is different from place to place, BDe focuses on the contribution of any activity anywhere on the planet to global species loss. As such, it measures biodiversity loss potential similarly to how the location independent CO_2e measures the global warming potential. To highlight this point, we provided a rough example of how the biodiversity footprint of the University of Jyväskylä, the majority of which is causing biodiversity loss outside Finland, could nevertheless be offset by protecting forests in Finland or in Brazil. Ideally, of course, the offsetting should be made in the countries and ecosystems where the biodiversity loss actualizes. From the global biodiversity perspective Finland is relatively species poor and much larger areas need to be protected as offsets than would be needed if the offsets were completed in relatively more species-rich areas such as in Brazil. Optimally locating the global offsets would therefore have an impact on the cost of offsetting, as our rough comparison between offsetting the biodiversity loss in Finland or Brazil clearly illustrated. Further supportive argument for the global offsetting comes from our finding that nearly half of the biodiversity footprint is actually driven by climate change, which may be challenging to offset locally.

As climate change is a major driver of biodiversity loss, it is easy to understand that the consumption categories had similar relative impacts on both. This observation is nevertheless important and confirms that environmentally informed prioritization of actions can yield synergies and thus cost savings when mitigating the negative climate and biodiversity impacts. A further interesting observation is that carbon footprint assessment is indeed an obligatory intermediate stage in biodiversity footprint assessment. Although currently the independent analysis of carbon footprints is common, we may see a merger of carbon and biodiversity footprint assessments in the future.

Setting boundaries between different organizations and how their financial-environmental impact statements might interact with each other will need some further development and conventions.

This is because the environmental impacts caused by consumption are simultaneously the environmental impacts of production along the supply chain. This is something that needs to be considered if environmental taxation, subsidies, or offsetting schemes are designed based on the value-transforming integration of financial and environmental accounting presented here. Indeed, if all organizations globally would offset their own direct footprints and transfer the cost of offsetting to the supply chain, the environmental accounting of supply chain impacts would become redundant. However, such a transformation needs time and the methodologies presented here are an important albeit perhaps only a temporary phase in our quest to stop biodiversity loss and climate change.

Materials and Methods

About the Living Lab, University of Jyväskylä

The University of Jyväskylä is a research and teaching institution that brings together education and psychology, natural sciences, humanities and social sciences, sport and health sciences, and business and economics. Finnish-language teacher education began here in 1863, and today the university is still Finland’s largest teacher education provider. The university has 14 300 degree students, 2 800 staff members and 220 million euros in turnover(68).

Detailed step-by-step methods for the framework

Step 1. Choose the report of financial accounts

We selected a financial report containing 123 different expense accounts and conducted the analysis separately for three consecutive years 2019–2021. The reports of the financial accounts were procured from the university administration.

A common trait of financial accounting in organizations is depreciation value. Depreciation of goods is customarily applied on an annual basis, which means a fraction of the cost of the depreciated goods is visible in the financial accounts each year until their purchase value is zero. Depreciation accounts can be calculated annually like any other cost account, but it is worth noting that depreciation will distribute the environmental impact of the goods over several years like it does for the cost of the goods. If depreciated goods are purchased continuously across the years with approximately the same annual budget, depreciation has no great impact on the footprints of any given year.

Step 2. Choose environmental accounting methods and indicators

EEIO databases can be used to assess the environmental impacts of financial consumption. Fundamentally, input-output methodology assesses the inputs an economic sector needs to produce its goods and services and the outputs an economic sector provides to other sectors or to final consumption(69, 70). Environmentally extended input-output (EEIO) databases, such as EXIOBASE, Eora, GTAP and WIOD, connect environmental impacts, such as greenhouse gas emissions, land use and water pollution, with economic activities and transactions, thus aiming to reveal both direct and indirect environmental flows associated with downstream consumption of products and services by organizations, the public sector, households and final consumers(69, 70). One of the strengths of EEIO databases, especially in terms of biodiversity footprints, is that they allow modelling the location of supply chain environmental impacts. The impact factors of different product categories need to be extracted from the EEIO database for each country being analysed (place of consumption). For example, EXIOBASE provides readily calculated monetary impact factors for carbon footprints and for many of the direct drivers of biodiversity footprints(71). Pymrio is an open-source tool that can be used for calculating the environmental impact factors (impact/€) of some EEIO databases if the impact factors are not readily available(72). Furthermore, Pymrio can be used to analyse the location of the environmental impacts in the EEIO databases by modelling the structure of supply chains.

In the case study we used the EEIO database EXIOBASE(50) to calculate environmental impacts of financial consumption. EXIOBASE is suitable for assessing the financial accounts of organizations (as presented before(36)) because it has relatively high sectorial detail, namely, 200 different product categories (an advantage when harmonizing EEIO categories with financial accounts), and because it is open access. The latest version 3.8.2(71) was used in this study to gain access to the most up-to-date data. Nevertheless, the data utilized is derived from the year 2019 in terms of impact factors and 2011 in terms of the location of the drivers of biodiversity loss. One of the currently unavoidable downsides of EEIO databases is that the data is accumulating retroactively.

The assessment of carbon and biodiversity footprints based on financial consumption also has some other shortcomings. The categories in EXIOBASE and similar databases in general are relatively limited and only provide a snapshot of the numerous consumption activities of organizations. It is also currently not possible to distinguish between the footprints of two different products in the same sector. This will limit the possibilities for organizations to track the impact of their positive actions on the footprint, especially when actions are taken within a specific sector, for example by procuring more sustainable hardware. Nevertheless, with the currently available methodologies it is very difficult and time consuming to get accurate data about the life cycle impacts of many consumption activities, for example by using the life cycle assessment method (LCA). There is a clear need form more research on the methodologies and databases, as some recent evidence points out that LCA and EEIO databases may produce different results for the same activities(73). Even with these shortcomings, footprints derived from hybrid EEIO-LCA methodology provide valuable information on what sectors an organization should primarily focus on when mitigating its footprints.

In our living lab case, the hybrid EEIO-LCA approach meant that to calculate the carbon footprint we applied LCA approaches to obtain process-based impact factors for five accounts: electricity, heating, water, travel services and travel grants. The carbon footprint of these accounts was calculated based on non-monetary consumption information (e.g. MWh of electricity consumption by electricity generation type and kilometres travelled by different modes of transportation) collected during the preliminary screening of the footprints of the University of Jyväskylä(13, 74). The biodiversity footprint of these accounts was nevertheless calculated with the EEIO methodology because the LCA methodology does not currently offer the opportunity to determine all the environmental impacts needed for biodiversity footprint analysis or the location of the impacts in the supply chain. We used the knowledge used in the carbon footprint assessment about the share of different energy production and travel methods to enhance the accuracy of the analysis and assumed that the costs would be distributed similarly. Nevertheless, differences in calculation methodologies between carbon and biodiversity footprints could explain the differences in the relative importance of energy and water consumption footprints to the total footprint, when looking at the results.

For the carbon footprint of financial consumption, we use the indicator recommended by The International Reference Life Cycle Data System (ILCD)(75), global warming potential during a period of 100 years, which is readily available in EXIOBASE. For the carbon footprint of non-monetary consumption (energy, water, travel), we used impact factors provided by the stakeholders responsible for producing those services (SI Appendix Dataset S5 and S6). For travel grants, we calculated the emissions by utilizing the impact factor (t CO_2e/€) of travel services, which was in turn calculated with process-based impact factors.
We built the biodiversity footprint assessment on estimating the impact of the direct drivers of biodiversity loss, including land use, direct exploitation (water stress), climate change and

pollution. We combined indicators of direct drivers of biodiversity loss from EXIOBASE(50) with the LC-IMPACT life cycle assessment database(42, 76) (SI Appendix Table S5) to calculate the biodiversity footprints of financial accounts, similar to whtat has been previously done(77). The indicator of biodiversity loss in LC-IMPACT is the potentially disappeared fraction of species(42), which we describe in this paper as the biodiversity equivalent (BDe) because it has similar characteristics to the carbon dioxide equivalent indicator (CO_2e). Previous studies on the biodiversity footprints of organizations have mostly used regional indicators of biodiversity loss(12, 15, 42). While it is important to look at both regional and global species loss to cover different viewpoints on biodiversity loss(42), regionally lost species do not necessarily translate to global extinctions. Furthermore, in this context, where we have assessed global supply chains, it is important that we are able to unify the loss of species in different parts of the world under a single indicator that can be used to compare global supply chains with each other. Next, we explain the methodology for calculating the biodiversity footprint of financial accounts.

EXIOBASE contains impact factors (i.e. what is the amount of the driver of biodiversity loss per unit of consumption, such as euro) for land use, blue water consumption (water stress), pollution and greenhouse gas (GHG) emissions associated with the financial consumption of products and services, while the share of the world's species that potentially will go extinct globally if the pressure continues over time is provided by LC-IMPACT. The most recent EXIOBASE datasets can be extracted from the Zenodo repository(71). The impact factors can be found in the satellite accounts folder and multipliers datasheet. However, to determine the share of the world's species that potentially will go extinct globally associated with the direct drivers of biodiversity loss that are driven by consumption (in this case Finnish consumption), the countries of origin where the land use and pollution occur need to be identified. The open-source tool Pymrio can be used to assess the country of origin in the EEIO databases(72).
Following the code provided in Pymrio, we first calculated a global matrix for the country of origin of a driver of biodiversity loss (DR_{origin}):

$$DR_{origin} = \begin{matrix} DR_{1,1,1} & DR_{1,2,2} & \dots & DR_{1,j,k} \\ DR_{2,1,1} & DR_{2,2,2} & \dots & DR_{2,j,k} \\ \vdots & \vdots & \ddots & \vdots \\ DR_{i,1,1} & DR_{i,2,2} & \dots & DR_{i,j,k} \end{matrix}$$

Each cell of the matrix describes the amount of the driver of biodiversity loss (DR) that occurs in region *i* (referred to as impact region) and is driven by consumption in region *j* (referred to as consumption region), product sector *k* (for further clarification see SI Appendix Table S6). The data is from 2011 because running the analysis on data from more recent years, for example 2019, provided non-sensible results, especially in terms of pollution. This might be due to errors in the EXIOBASE satellite account datasets. However, impact factors (impact/euro) from 2019 were used. For the biodiversity footprint assessment, we do not identify the country of origin for climate change because there is no regionalized biodiversity impact data in LC-IMPACT for climate change(42). However, we do assess the country of origin for carbon dioxide emissions in the carbon footprint assessment. The several blue water consumption (water stress) accounts in EXIOBASE were aggregated using the aggregation function in Pymrio. We use the general version of EXIOBASE, with limited land use types and country resolution, rather than the higher-resolution data as it allowed us to include climate change and pollution as biodiversity pressures alongside land use. This somewhat limits the accuracy of the analyses, since it increases the use of averages when connecting EXIOBASE with LC-IMPACT, especially in terms of regional level of detail. In any case it seems the level of detail is sufficient for the purpose of providing a means to influence decision-making in organizations.

As we know the impact and consumption region (in this case Finland) of each driver of biodiversity loss, we can then identify the share of a driver of biodiversity loss in each region (DR_{share}):

$$DR_{share} = \frac{DR_{origin}}{\sum_{i=1}^{n} DR_{i,j,k}}$$

The cells of the new matrix contain the share of the driver of biodiversity loss (*DR*) in impact region *i* from the total amount of the driver that is driven by consumption in consumption region *j*, product sector *k*.

Then we need to harmonize the regional classification between EXIOBASE and LC-IMPACT. EXIOBASE contains 44 countries and five 'rest of the world' regions(50), while LC-IMPACT contains a highly detailed list of the world's countries. The missing countries from EXIOBASE can be harmonized by using the five 'rest of the world' regions. Once the harmonization was done, we allocated the share of the driver of biodiversity loss (DR_{share}) to each respective region. Then we looked into how one unit of a driver of biodiversity loss (DR_{unit}, e.g., 1 kg or 1 m^2) is divided between each impact region *i*:

$$DR_{unit} = DR_{share,i,j,k} / R_i$$

Here *R* represents the frequency of the impact region *i* after harmonization with LC-IMPACT (e.g. EXIOBASE region 'Rest of the World Europe' has been allocated to 23 countries in LC-IMPACT). Given the lack of information on 'rest of the world' regions, we were forced to assume that the drivers of biodiversity loss were shared equally between all countries representing those regions.

At this stage we calculated the impact factors of the driver of biodiversity loss (DR_{factor}) for each impact region *i* driven by consumption in consumption region *j*, product sector *k*:

$$DR_{factor,i,j,k} = DR_{unit,i,j,k} \times DR_{exiobase,j,k}$$

$DR_{exiobase}$ represents the monetary impact factors of the driver of biodiversity loss (impact per euro) from EXIOBASE for consumption region *j*, product sector *k*. Finally, we calculated the biodiversity equivalent factors for the driver of biodiversity loss (*BDe*) for each impact region *i*, driven by consumption in consumption region *j* and product sector *k*, by combining the previous matrix with the biodiversity equivalent factors for each driver of biodiversity loss ($DR_{lc\text{-}impact}$) for each impact region *i* from LC-IMPACT(42, 76):

$$BDe_{i,j,k} = DR_{factor,i,j,k} \times DR_{lc\text{-}impact,i}$$

Total biodiversity equivalent factors (BDe_{factor}) for each consumption region *j* and product sector *k* were derived by summing up the biodiversity equivalent factors of each impact region *i* in consumption region *j*, product sector *k*:

$$BDe_{factor,j,k} = \sum_{i=1}^{n} BDe_{i,j,k}$$

The biodiversity footprint of each financial account was then calculated by simply multiplying the biodiversity equivalent factor (*BDe/euro*) with the harmonized financial accounts (see Step 3). In terms of the biodiversity impacts of climate change, we take into account carbon dioxide, methane, fossil methane and nitrous oxide. We chose impact factors that take all effects into account for a period of 100 years for both terrestrial and aquatic ecosystems(42). With the spatial component missing from the climate change biodiversity impact analyses, we then multiplied the biodiversity impact factor of each gas with its respective counterpart factor in EXIOBASE. Then we summed the results to derive a total biodiversity footprint factor of climate change for both terrestrial and aquatic ecosystems.

We calculated biodiversity footprint results for each pressure individually first and then merged the results into three impacted ecosystem types: terrestrial, freshwater and marine ecosystems. We then combined the biodiversity footprints of the three ecosystem types by taking a weighted average of biodiversity footprints over ecosystem types. As weights we used the estimated share of all plant and animal species that exist in each habitat type(78). The merged biodiversity footprint (BF_{total}) can then be calculated with the equation:

$$BF_{total} = BF_{terrestrial} \times 0.801 + BF_{freshwater} \times 0.096 + BF_{marine} \times 0.102$$

The Biodiversity Footprint Database can be accessed in https://doi.org/10.5281/zenodo.8369650.

Step 3. Harmonize the accounts

EXIOBASE product classification is based on the Statistical Classification of Economic Activities in the European Community, the so-called NACE classification(50, 79). The financial accounts of the University of Jyväskylä were harmonized with EXIOBASE (SI Appendix Dataset S4), except in the case of two accounts that are general cost accounts ("Compensation of cooperation costs" and "Other costs"), which were considered to represent an average of other cost accounts (excluding depreciation accounts), and in the case of five accounts that were imported as external environmental accounts (heat, electricity, water, travel services and travel grants, see Step 5 for further information). In total, 123 financial accounts were analysed, out of which 12 were excluded because it was not possible to identify their environmental impacts with the current methodologies (e.g. tax-related accounts). Regarding rental accounts, we excluded some space rentals to avoid double-counting of the energy-related environmental accounts.

In the case study, price adjustment due to inflation had to be made only for the financial account data from 2020 because environmental impact multipliers for the year 2019 were used. Prices were adjusted by using the Consumer Price Index from Statistics Finland (2021). For the basic price conversion factors (SI Appendix Dataset S3), we used EXIOBASE supply and use tables(71) for the Finnish economy in the year 2019 (data is nowcasted based on 2016 data points). Value-added tax (VAT) was excluded from calculations because it is invoiced separately in the university accounts (as it is in most Finnish organizations) and thus has already been deducted from the purchaser price. However, if VAT were to be included in the financial account prices, it should be deducted as shown by the formulae in the SI Appendix Table S7.

One of the inevitable limitations of using EEIO data is that it is accumulating retroactively. Thus, inflation between the baseline year of the EEIO database and the financial account data needs to be taken into account. Prices can be adjusted by using national Consumer Price Index data, showing the relative increase of inflation in a given year in relation to a baseline year (i.e. Inflation factor):

$$IAP = FAP - (FAP \times INF)$$

where *IAP* is the inflation-adjusted price, *FAP* is the financial account price and *INF* is the inflation factor. Furthermore, in order to use the impact factors (Step 2) of the EEIO database, financial account prices (i.e. purchaser prices) need to be converted to basic prices, the general unit used in EEIO databases. The System of National Accounts(80) define producer price (*PRP*) as:

$$PRP = BP + TAX - SUB$$

where *BP* is the basic price, *TAX* is the amount of taxes on products excluding invoiced VAT, and *SUB* is the amount of subsidies on products. Consequently, purchaser price (*PUP*) is defined as:

$$PUP = PRP + TTM + VAT$$

where *TTM* refers to the trade and transport margins and *VAT* to the value-added tax not deductible by the purchaser. Finally, the purchaser price (*PUP*) can be defined as:

$$PUP = BP + TAX – SUB + TTM + VAT$$

Then a basic price conversion factor (*BPCF*) can be calculated for each product sector *i* by calculating the share of taxes less subsidies, value-added tax and trade and transport margins from the total supply (*SUP*) values per product sector *i* of the EEIO database (in basic prices):

$$BPCF_i = (TAX_i – SUB_i + VAT_i + TTM_i) / (SUP_i + TAX_i – SUB_i + VAT_i + TTM_i)$$

The required values on taxes less subsidies (excluding VAT) and *TTM*s can be found from national supply and use tables, generally contained within the EEIO database repositories. Harmonized prices (*HP*), including inflation adjustment and basic price conversion, can be calculated with the equation:

$$HP = IAP – (IAP \times BPCF)$$

The conversion formulae and their explanations are summarized in SI Appendix Table S7.

STEP 4. Calculate results

This step can be seen as an optional mid-point step to gain more in-depth insights about the environmental accounts before Step 5, where the results are condensed to meet the financial impact statement criteria. The impact factors from EEIO databases and the footprints of accounts that were calculated with non-monetary impact factors (Step 2) should be assigned to their respective financial account categories (Step 3) and multiplied with the harmonized prices, with the exception of those non-monetary accounts whose results can be directly imported into the accounting scheme.

STEP 5. Assemble the value-transforming financial-environmental impact statement

We made a rough pricing scheme for the purpose of illustrating the principle of how environmental accounts can be used to transform the financial value in the financial-environmental impact statement. To evaluate the offsetting cost of the carbon footprint we used the World Bank carbon pricing statistics for the European Union(51). We converted prices to euros with a currency converter(81). Thus, we multiply the converted pricing factor with the University of Jyväskylä’s carbon footprint.

To estimate the offsetting value of the biodiversity footprint, more assumptions were needed. We used the LC-IMPACT database to determine the biodiversity footprint of intensive forestry land use in Finland and in Brazil(42). By dividing the total biodiversity footprint of the organization (3.66E-08 BDe in 2021) with the characterization factors of intensive forestry land use in Finland (2.65E-17 BDe/m^2)(42) and in Brazil (2.24E-15 BDe/m^2)(42), we assessed how much intensive forestry land should be permanently removed from use if we were to preserve an equivalent amount of global biodiversity (BDe) in Finland. This resulted in 138 423 ha in Finland, and 1636 ha in Brazil. However, protecting an ecosystem from economic demand does not necessarily mean that the demand ends; rather, the economic activity is often shifted elsewhere. To account for this so-called leakage, we derived a correction factor from an existing biodiversity offsetting case report, which calculated the amount of additional forest biodiversity offsets that need to be done when leakage is considered(82). Multiplying this factor (4.15) with the amount of land that needs to be preserved to avoid the BDe loss, we conclude that the total amount of conserved forest land in Finland needs to be 574 455 ha. As we could not find an estimate of potential leakage for Brazil, we utilized the Finland-specific multiplier also for Brazil and conclude that the total amount of conserved forest land in Brazil needs to be 6789 ha.

Acknowledgments

We thank the Strategic Research Council at the Academy of Finland (Kotiaho 345267), Green Carbon Finland Ltd, The Finnish Innovation Fund Sitra and SOK Corporation for funding the development of the methodologies. We thank Māris Grunskis for the illustrations, Andrew Pattison and Annukka Sailo for correcting the language, the administration at the University of Jyväskylä for giving access to the consumption data, the biodiversity footprint team members Veera Vainio and Krista Pokkinen as well as Ulla Helimo, Matti Toivonen, Janne Peljo and Hanna-Leena Pesonen for feedback.

References

1. IPBES, "Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services." (2019).

2. S. Díaz, *et al.*, Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science* **366**, eaax3100 (2019).

3. I. J. Visseren-Hamakers, *et al.*, Transformative governance of biodiversity: insights for sustainable development. *Curr. Opin. Environ. Sustain.* **53**, 20–28 (2021).

4. G. M. Mace, *et al.*, Aiming higher to bend the curve of biodiversity loss. *Nat. Sustain.* **1**, 448–451 (2018).

5. D. Leclère, *et al.*, Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature* **585**, 551–556 (2020).

6. C. Hong, *et al.*, Land-use emissions embodied in international trade. *Science* **376** (2022).

7. D. Presberger, T. Bernauer, Economic and political drivers of environmental impact shifting between countries. *Glob. Environ. Change* **79**, 102637 (2023).

8. A. Marques, *et al.*, Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nat. Ecol. Evol.* **3** (2019).

9. G. P. Peters, Carbon footprints and embodied carbon at multiple scales. *Curr. Opin. Environ. Sustain.*, 245–250 (2010).

10. S. Shi, J. Yin, Global research on carbon footprint: A scientometric review. *Environ. Impact Assess. Rev.* **89**, 106571 (2021).

11. R. Chen, R. Zhang, H. Han, Where has carbon footprint research gone? *Ecol. Indic.* **120**, 106882 (2021).

12. J. W. Bull, *et al.*, Analysis: the biodiversity footprint of the University of Oxford. *Nature* **604**, 420–424 (2022).

13. S. El Geneidy, *et al.*, “Sustainability for JYU: Jyväskylän yliopiston ilmasto- ja luontohaitat” (2021).

14. J. Lammerant, K. Driesen, J. Verhelst, J. De Ryck, “ASSESSMENT OF BIODIVERSITY MEASUREMENT APPROACHES FOR BUSINESSES AND FINANCIAL INSTITUTIONS” (EU Business @ Biodiversity Platform, 2022).

15. I. Taylor, *et al.*, Nature-positive goals for an organization’s food consumption. *Nat. Food* **4**, 96–108 (2023).

16. J. A. Nicholls, Integrating financial, social and environmental accounting. *Sustain. Account. Manag. Policy J.* **11**, 745–769 (2020).

17. E. Bracci, L. Maran, Environmental management and regulation: Pitfalls of environmental accounting? *Manag. Environ. Qual. Int. J.* **24**, 538–554 (2013).

18. R. D. Hines, Financial accounting: In communicating reality, we construct reality. *Account. Organ. Soc.* **13**, 251–261 (1988).

19. K. Saravanamuthu, What is measured counts: Harmonized corporate reporting and sustainable economic development. *Crit. Perspect. Account.* **15**, 295–302 (2004).

20. S. Schaltegger, R. Burritt, *Contemporary Environmental Accounting - Issues, Concepts and Practice* (2000).

21. J. Veldman, A. Jansson, Planetary Boundaries and Corporate Reporting: The Role of the Conceptual Basis of the Corporation. *Account. Econ. Law Conviv.*, 1–18 (2020).

22. International Accounting Standards Board, Conceptual Framework for Financial Reporting (2018).

23. Alfred Endres, *Environmental Economics : Theory and Policy* (Cambridge University Press, 2011).

24. K. Maas, S. Schaltegger, N. Crutzen, Integrating corporate sustainability assessment, management accounting, control, and reporting. *J. Clean. Prod.* **136**, 237–248 (2016).

25. M. Laine, M. Scobie, M. Sorola, H. Tregidga, Special Issue Editorial: Social and Environmental Account/Ability 2020 and Beyond. *Soc. Environ. Account. J.* **2245** (2020).

26. F. Zappettini, J. Unerman, ‘Mixing’ and ‘Bending’: The recontextualisation of discourses of sustainability in integrated reporting. *Discourse Commun.* **10**, 521–542 (2016).

27. GRI, Consolidated Set of the GRI Standards (2023).

28. IFRS, Exposure Draft. IFRS Sustainability Disclosure Standard. (2022).

29. WBCSD, WRI, “The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard” (2012).

30. Capitals Coalition, “Natural Capital Protocol” (2016).

31. IIRC, International Integrated Reporting Framework (2021).

32. J. Unerman, J. Bebbington, B. O'dwyer, Corporate reporting and accounting for externalities. *Account. Bus. Res.* **48**, 497–522 (2018).

33. F. Hartmann, P. Perego, A. Young, Carbon Accounting: Challenges for Research in Management Control and Performance Measurement. *Abacus* **49**, 539–563 (2013).

34. J. Houdet, H. Ding, F. Quétier, P. Addison, P. Deshmukh, Adapting double-entry bookkeeping to renewable natural capital: An application to corporate net biodiversity impact accounting and disclosure. *Ecosyst. Serv.* **45**, 101104 (2020).

35. S. Alvarez, M. Blanquer, A. Rubio, Carbon footprint using the Compound Method based on Financial Accounts. the case of the School of Forestry Engineering, Technical University of Madrid. *J. Clean. Prod.* **66**, 224–232 (2014).

36. H. N. Larsen, J. Pettersen, C. Solli, E. G. Hertwich, Investigating the Carbon Footprint of a University - The case of NTNU. *J. Clean. Prod.* **48**, 39–47 (2013).

37. M. Thurston, M. J. Eckelman, Assessing greenhouse gas emissions from university purchases. *Int. J. Sustain. High. Educ.* **12**, 225–235 (2011).

38. T. Pajula, *et al.*, "Carbon handprint guide. V. 2.0. Applicable for environmental handprint" (VTT Technical Research Centre of Finland Ltd. LUT University., 2021).

39. R. H. Crawford, P. A. Bontinck, A. Stephan, T. Wiedmann, M. Yu, Hybrid life cycle inventory methods – A review. *J. Clean. Prod.* **172**, 1273–1288 (2018).

40. S. Nakamura, K. Nansai, "Input–Output and Hybrid LCA" in *Special Types of Life Cycle Assessment*, LCA Compendium – The Complete World of Life Cycle Assessment., M. Finkbeiner, Ed. (Springer Netherlands, 2016), pp. 219–291.

41. S. El Geneidy, S. Baumeister, V. M. Govigli, T. Orfanidou, V. Wallius, The carbon footprint of a knowledge organization and emission scenarios for a post-COVID-19 world. *Environ. Impact Assess. Rev.* **91**, 106645 (2021).

42. F. Verones, *et al.*, LC-IMPACT: A regionalized life cycle damage assessment method. *J. Ind. Ecol.* **24**, 1201–1219 (2020).

43. M. A. J. Huijbregts, *et al.*, ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* **22**, 138–147 (2017).

44. T. Wiedmann, J. Minx, A Definition of "Carbon Footprint." *Science* **1**, 1–11 (2007).

45. E. Crenna, A. Marques, A. La Notte, S. Sala, Biodiversity Assessment of Value Chains: State of the Art and Emerging Challenges. *Environ. Sci. Technol.* **54**, 9715–9728 (2020).

46. A. Marques, F. Verones, M. T. Kok, M. A. Huijbregts, H. M. Pereira, How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. *Curr. Opin. Environ. Sustain.* **29**, 75–81 (2017).

47. D. Parkes, G. Newell, D. Cheal, Assessing the quality of native vegetation: The 'habitat hectares' approach. *Ecol. Manag. Restor.* **4**, S29–S38 (2003).

48. IPCC, "Climate Change 2022: Impacts, Adaptation and Vulnerability" (Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022).

49. H.-O. Pörtner, *et al.*, "Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change" (Zenodo, 2021) https:/doi.org/10.5281/zenodo.5101125 (March 31, 2023).

50. K. Stadler, *et al.*, EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *J. Ind. Ecol.* **22**, 502–515 (2018).

51. The World Bank, Carbon Pricing Dashboard (2023).

52. A. Moilanen, J. Laitila, FORUM: Indirect leakage leads to a failure of avoided loss biodiversity offsetting. *J. Appl. Ecol.* **53**, 106–111 (2016).

53. Natural Resources Institute Finland, Implementation of the METSO Programme by the ELY Centres in 2008-2021 - land purchases by the state, private nature reserves and fixed-term nature reserves (2023).

54. F. D. F. Silva, *et al.*, The Cost of Forest Preservation in the Brazilian Amazon: The "Arc of Deforestation" (2019) https:/doi.org/10.22004/AG.ECON.292328 (May 17, 2023).

55. M. Thurston, M. J. Eckelman, Assessing greenhouse gas emissions from university purchases. *Int. J. Sustain. High. Educ.* **12**, 225–235 (2011).

56. T. Kortetmäki, *et al.*, Planetary well-being. *Humanit. Soc. Sci. Commun.* **8**, 1–8 (2021).

57. Business for Nature, Capitals Coalition, CDP, "Make It Mandatory: the case for mandatory corporate assessment and disclosure on nature" (2022).

58. E. Perrault Crawford, C. Clark Williams, Should corporate social reporting be voluntary or mandatory? Evidence from the banking sector in France and the United States. *Corp. Gov. Int. J. Bus. Soc.* **10**, 512–526 (2010).

59. J. Wu, B. A. Babcock, The Relative Efficiency of Voluntary vs Mandatory Environmental Regulations. *J. Environ. Econ. Manag.* **38**, 158–175 (1999).

60. R. Gray, Thirty years of social accounting, reporting and auditing: what (if anything) have we learnt? *Bus. Ethics Eur. Rev.* **10**, 9–15 (2001).

61. D. A. Koehler, The Effectiveness of Voluntary Environmental Programs—A Policy at a Crossroads? *Policy Stud. J.* **35**, 689–722 (2007).

62. P. Dasgupta, "The Economics of Biodiversity: The Dasgupta Review" (London: HM Treasury, 2021).

63. V. Boisvert, Conservation banking mechanisms and the economization of nature: An institutional analysis. *Ecosyst. Serv.* **15**, 134–142 (2015).

64. A. Vatn, Markets in environmental governance. From theory to practice. *Ecol. Econ.* **117**, 225–233 (2015).

65. N. S. Koh, T. Hahn, C. Ituarte-Lima, Safeguards for enhancing ecological compensation in Sweden. *Land Use Policy* **64**, 186–199 (2017).

66. H. Kujala, *et al.*, Credible biodiversity offsetting needs public national registers to confirm no net loss. *One Earth* **5**, 650–662 (2022).

67. N. S. Koh, T. Hahn, W. J. Boonstra, How much of a market is involved in a biodiversity offset? A typology of biodiversity offset policies. *J. Environ. Manage.* **232**, 679–691 (2019).

68. University of Jyväskylä, Annual report 2021 (2021).

69. J. Kitzes, An introduction to environmentally-extended input-output analysis. *Resources* **2**, 489–503 (2013).

70. W. Leontief, Environmental Repercussions and the Economic Structure : An Input-Output Approach Author (s): Wassily Leontief Source : The Review of Economics and Statistics , Vol . 52 , No . 3 (Aug ., 1970), pp . 262-271 Published by : The MIT Press Stable URL : ht. *Rev. Econ. Stat.* **52**, 262–271 (1970).

71. K. Stadler, *et al.*, EXIOBASE 3 (3.8.2) [Data set] (2021).

72. K. Stadler, pymrio – multi regional input output analysis in python (2022).

73. B. Steubing, A. de Koning, S. Merciai, A. Tukker, How do carbon footprints from LCA and EEIOA databases compare? A comparison of ecoinvent and EXIOBASE. *J. Ind. Ecol.* **26**, 1406–1422 (2022).

74. V. Vainio, S. El Geneidy, Sustainability for JYU: Jyväskylän yliopiston ilmasto- ja luontohaitat 2020. *JYU Rep.*, 1–39 (2021).

75. S. Fazio, *et al.*, “Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods” (European Commission, 2018) (June 4, 2023).

76. F. Verones, LC-IMPACT1.3 (2021) https:/doi.org/10.5281/zenodo.6200606 (June 4, 2023).

77. E. L. Bjelle, *et al.*, Adding country resolution to EXIOBASE: impacts on land use embodied in trade. *J. Econ. Struct.* **9** (2020).

78. C. Román-Palacios, D. Moraga-López, J. J. Wiens, The origins of global biodiversity on land, sea and freshwater. *Ecol. Lett.* **25**, 1376–1386 (2022).

79. eurostat, “NACE Rev. 2: Statistical classification of economic activities in the European Community” (European Communities, 2008).

80. European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank, “System of National Accounts 2008.”

81. Xe, Xe Currency Converter.

82. A. Moilanen, J. S. Kotiaho, “Vapaaehtoinen ekologinen kompensaatio AA Sakatti Mining Oy:n mahdolliselle Sakatin kaivokselle. Liite ympäristövaikutusten arviointiin.” (2020).

Supporting Information Text

Supporting Methods

Programming information:
Analyses done with Spyder IDE
* Spyder version: 5.1.5
* Python version: 3.7.6 64-bit
* Qt version: 5.9.7
* PyQt5 version: 5.9.2
* Operating System: Windows 10

Code for finding country of origin for the direct drivers of biodiversity loss, using Pymrio (1)

```
import pymrio
import pandas
exio3 = pymrio.parse_exiobase3(path="FILE LOCATION")
#Diagonalize specific stressor account, e.g. et1_diag = exio3.satellite.diag_stressor(("Cropland -– Cereal grains nec"))
et1_diag = exio3.satellite.diag_stressor(("DRIVER NAME"))
#Connect back to the system
exio3.et1_diag = et1_diag
exio3.calc_all()
#Aggregate to the source drivers
exiostressor = exio3.et1_diag.D_cba.groupby(level="region", axis=0).sum()
#Save as a csv-file to given location
exiostressor.to_csv(path_or_buf="FILE LOCATION")
```

Code for aggregating drivers (in this study, blue water consumption), using Pymrio (1)

```
import pymrio
import pandas
exio3 = pymrio.parse_exiobase3(path="FILE LOCATION")
#Forming the aggregated group(s).
groups = exio3.satellite.get_index(as_dict=True, grouping_pattern = {"Water Consumption Blue.*": "Water Consumption Blue -– Total"})
exio3.satellite_agg = exio3.satellite.copy(new_name="Aggregated blue water consumption accounts")
for df_name, df in zip(exio3.satellite_agg.get_DataFrame(data=False, with_unit=True, with_population=False),
                       exio3.satellite_agg.get_DataFrame(data=True, with_unit=True, with_population=False)):
    if df_name == "unit":
        exio3.satellite_agg.__dict__[df_name] = df.groupby(groups).apply(lambda x: " & ".join(x.unit.unique()))
    else:
        exio3.satellite_agg.__dict__[df_name] = df.groupby(groups).sum()
#Diagonalize specific stressor account, e.g. et1_diag = exio3.satellite.diag_stressor(("Cropland -– Cereal grains nec"))
et1_diag = exio3.satellite_agg.diag_stressor(("Water Consumption Blue -– Total"))
#Connect back to the system
exio3.et1_diag = et1_diag
exio3.calc_all()
```

```
#Aggregate to the source drivers
exiostressor = exio3.et1_diag.D_cba.groupby(level=''region'', axis=0).sum()
#Save as a csv-file to given location
exiostressor.to_csv(path_or_buf=''FILE LOCATION'')
```

Supporting Discussion

A challenge that remains to be solved when financial and environmental accounts are integrated, is that financial accounting entries do not always include all the relevant information for making an environmental footprint assessment. Thus, in future developments of financial accounting, it would be valuable to consider the needs of environmental accounting. Financial accounting entries should be as detailed as possible revealing the type of the product or service consumed (e.g., travel type: flight vs. train or energy type: coal vs. wind electricity). While more detailed information could be found from individual receipts of purchasing activities, analysis of such information might be cumbersome. Digitalization of receipts would already allow such detailed information to be stored. Second, financial accounting entries could be adjusted to also include physical consumption information, e.g., kilometers travelled, or kilograms of product consumed. Physical consumption information can be found, but it is generally scattered around different units of an organization. Another interesting avenue for further research in the integrated accounting system would be the use of double-entry bookkeeping in environmental accounting and reporting. Double-entry bookkeeping is a common feature of financial accounting used to track financial transactions by keeping book of where money was taken from and to what purpose it was used. In other words, every financial transaction has equal and opposite effects in two different accounts(2). In the future, environmental accounting could take up a similar practice by recording the flows of negative (footprints) and positive (handprints) impacts (impact statement) and consider their accumulation over time (balance sheet). This approach has been mainly discussed in terms of natural capital accounting(3) but could be extended to cover general environmental accounting principles. Double-entry bookkeeping combined with the presented hybrid EEIO-LCA methodology would also allow real-time and automated tracking of carbon and biodiversity footprints in organizations, if environmental accounts would be made at the point of purchasing events, rather than at the end of the year as was done in the case of the University of Jyväskylä. The integration of financial and environmental accounts is one of the important steps to transforming value in organizations. It is high time for equality of accounting. Environmental and financial accounting should be handled with the same level of rigor. To achieve this, changes are not only needed in environmental accounting, but also in financial accounting practices and policy, which play an important role in how organizations currently operate.

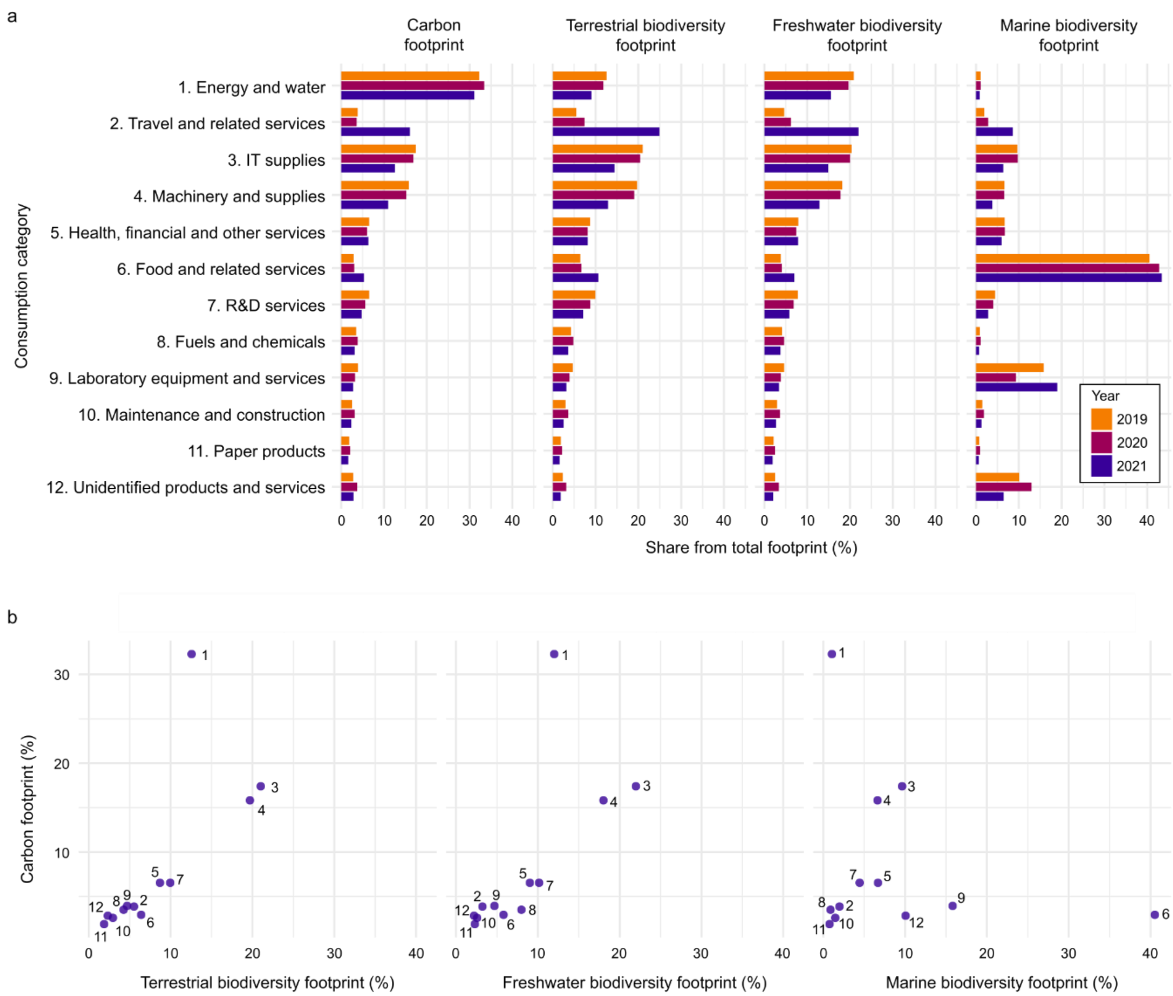

Fig. S1. The composition of the carbon and biodiversity footprints of the University divided by ecosystem types. The relative contribution (%) of different consumption categories of the University of Jyväskylän during 2019-2021 for the carbon and biodiversity footprints (**a**) and scatterplots of the relative carbon footprint of each consumption category on the relative biodiversity footprints of the corresponding consumption category in 2021 (**b**). Small numbers in the scatter plot of panel b refer to the consumption categories in panel a.

Table S1. The carbon footprint (t CO_2e) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021.

Consumption category	2019	2020	2021
Unidentified products and services	467.43	509.13	408.45
Paper products	266.49	289.87	271.44
Maintenance and construction	380.45	425.35	373.75
Laboratory equipment and services	451.65	440.28	569.07
Fuels and chemicals	505.63	522.48	506.10
R&D services	775.21	764.96	946.98
Food and related services	858.04	412.50	423.77
Health, financial and other services	1025.78	820.67	946.58
Machinery and supplies	1771.70	2062.65	2293.56
IT supplies	2025.22	2290.85	2523.55
Travel and related services	2596.25	493.49	558.56
Energy and water	5026.58	4535.46	4683.20
Total	**16150.45**	**13567.69**	**14505.01**

Table S2. The biodiversity footprint (BDe) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021.

Consumption category	2019	2020	2021
Unidentified products and services	8.49E-10	1.16E-09	9.36E-10
Paper products	6.76E-10	7.34E-10	6.86E-10
Maintenance and construction	1.07E-09	1.22E-09	1.07E-09
Laboratory equipment and services	1.57E-09	1.38E-09	1.84E-09
Fuels and chemicals	1.59E-09	1.67E-09	1.61E-09
R&D services	2.93E-09	2.87E-09	3.53E-09
Food and related services	4.97E-09	2.61E-09	2.72E-09
Health, financial and other services	3.51E-09	2.78E-09	3.20E-09
Machinery and supplies	5.40E-09	6.33E-09	7.08E-09
IT supplies	6.06E-09	6.80E-09	7.58E-09
Travel and related services	9.25E-09	2.20E-09	1.77E-09
Energy and water	3.86E-09	4.02E-09	4.62E-09
Total	**4.17E-08**	**3.38E-08**	**3.66E-08**

Table S3. The biodiversity footprint (BDe) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021 in terrestrial, freshwater and marine ecosystems.

	Terrestrial			Freshwater			Marine		
Consumption category	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Unidentified products and services	9.24E-10	1.25E-09	1.00E-09	2.88E-10	3.89E-10	3.10E-10	8.02E-10	1.15E-09	1.02E-09
Paper products	7.96E-10	8.64E-10	8.08E-10	3.16E-10	3.44E-10	3.23E-10	7.86E-11	8.37E-11	7.74E-11
Maintenance and construction	1.27E-09	1.45E-09	1.27E-09	3.65E-10	4.13E-10	3.63E-10	1.58E-10	1.64E-10	1.49E-10
Laboratory equipment and services	1.60E-09	1.56E-09	2.01E-09	5.12E-10	5.16E-10	6.60E-10	2.35E-09	8.24E-10	1.60E-09
Fuels and chemicals	1.84E-09	1.94E-09	1.86E-09	1.11E-09	1.18E-09	1.12E-09	8.91E-11	9.54E-11	9.06E-11
R&D services	3.47E-09	3.40E-09	4.18E-09	1.19E-09	1.16E-09	1.43E-09	3.51E-10	3.56E-10	4.51E-10
Food and related services	5.33E-09	2.68E-09	2.78E-09	1.60E-09	7.91E-10	8.16E-10	5.36E-09	3.78E-09	4.10E-09
Health, financial and other services	4.12E-09	3.27E-09	3.76E-09	1.40E-09	1.10E-09	1.27E-09	7.38E-10	5.95E-10	6.77E-10
Machinery and supplies	6.45E-09	7.56E-09	8.45E-09	1.99E-09	2.27E-09	2.53E-09	4.74E-10	5.83E-10	6.71E-10
IT supplies	7.18E-09	8.05E-09	8.97E-09	2.47E-09	2.77E-09	3.09E-09	7.87E-10	8.63E-10	9.75E-10
Travel and related services	1.11E-08	2.64E-09	2.13E-09	2.34E-09	5.60E-10	4.54E-10	1.06E-09	2.51E-10	2.01E-10
Energy and water	4.63E-09	4.83E-09	5.55E-09	1.41E-09	1.47E-09	1.69E-09	1.08E-10	9.67E-11	1.08E-10
Total	**4.87E-08**	**3.95E-08**	**4.28E-08**	**1.50E-08**	**1.30E-08**	**1.41E-08**	**1.24E-08**	**8.84E-09**	**1.01E-08**

Table S4. The contribution of the direct drivers of biodiversity loss to the biodiversity footprint (BDe) of the University of Jyväskylä 2019-2021 in terrestrial, freshwater and marine ecosystems.

	Terrestrial			Freshwater			Marine		
Driver type	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Land use	1.62E-08	1.52E-08	1.67E-08	-	-	-	-	-	-
Climate change	1.49E-08	1.49E-08	1.62E-08	4.64E-09	4.64E-09	5.05E-09	-	-	-
Pollution	2.28E-09	2.15E-09	2.34E-09	3.59E-10	3.18E-10	3.54E-10	1.12E-08	8.51E-09	9.82E-09
Water stress	-	-	-	6.35E-09	6.03E-09	6.56E-09	-	-	-

Table S5. Biodiversity footprint impact categories in EXIOBASE and connecting impact category in LC-IMPACT. In terms of land use, average effects from LC-IMPACT were used, instead of marginal effects.

Stressor name (EXIOBASE)	**Connecting stressor in LC-Impact**
Land use	
Cropland – Cereal grains nec Cropland – Crops nec Cropland – Oil seeds Cropland – Paddy rice Cropland – Plant-based fibers Cropland – Sugar cane, sugar beet Cropland – Vegetables, fruit, nuts Cropland – Wheat	Land stress: Annual crops, permanent crops (average)
Cropland – Fodder crops – Cattle Cropland – Fodder crops – Meat animals Cropland – Fodder crops – Pigs Cropland – Fodder crops – Poultry Cropland – Fodder crops – Raw milk	Land stress: Annual crops
Permanent pastures – Grazing-Cattle Permanent pastures – Grazing-Meat animals Permanent pastures – Grazing-Raw milk	Land stress: Pasture
Forest area – Forestry	Land stress: Intensive forestry, extensive forestry (average)
Forest area – Marginal use (excluded, no data available in EXIOBASE)	-
Infrastructure land (excluded, no data available in EXIOBASE)	-
Other land Use: Total	Average of remaining land use types in LC-Impact (Urban)
Direct exploitation of natural resources	
Water Consumption Blue – Total (aggregated 103 categories)	Water stress
Pollution	
NMVOC – combustion – air Nox – combustion – air	Photochemical ozone formation
Nox – combustion – air NH3 – combustion – air Sox – combustion – air	Terrestrial acidification
P – agriculture – water P – agriculture – soil	Freshwater eutrophication
N – agriculture – water	Marine eutrophication
Climate change	
Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	Terrestrial climate change, aquatic climate change

Table S6. Illustration of the data matrix derived from pymrio analysis of stressor (impact) sources. Regions in the column headers indicate the location of the environmental impact. Regions and sectors in row headers indicate the place of consumption.

	Region A Sector 1	**Region A Sector 2**	**Region B Sector 1**	**Region B Sector 2**
Region A	Impact in Region A driven by consumption in Region A – Sector 1	Impact in Region A driven by consumption in Region A – Sector 2	Impact in Region A driven by consumption in Region B – Sector 1	Impact in Region A driven by consumption in Region B – Sector 2
Region B	Impact in Region B driven by consumption in Region A – Sector 1	Impact in Region B driven by consumption in Region A – Sector 2	Impact in Region B driven by consumption in Region B – Sector 1	Impact in Region B driven by consumption in Region B – Sector 2
Region C	Impact in Region C driven by consumption in Region A – Sector 1	Impact in Region C driven by consumption in Region A – Sector 2	Impact in Region C driven by consumption in Region B – Sector 1	Impact in Region C driven by consumption in Region B – Sector 2

Table S7. Summary of the different operations needed to harmonize purchaser prices (financial account prices) with basic prices (EEIO database prices).

Description	Equation	Legend
Harmonizing financial account prices to take into account inflation between EEIO database baseline year and financial accounting year.	$IAP = FAP - (FAP \times IF)$	IAP = Inflation adjusted price FAP = Financial account price IF = Inflation factor
Definition of producer price.	$PRP = BP + TAX - SUB$	PRP = Producer price BP = Basic price TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products
Definition of purchaser price.	$PUP = PRP + TTM + VAT$	PUP = Purchaser price PRP= Producer price TTM = Trade and transport margins VAT = VAT not deductible by the purchaser
Definition of purchaser price when producer price is dismantled according to the definition of producer price.	$PUP = BP + TAX - SUB + TTM + VAT$	PUP = Purchaser price BP = Basic price TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products TTM = Trade and transport margins VAT = VAT not deductible by the purchaser
Basic price conversion factor that can be used to estimate the difference between purchaser price (financial account price) and basic price.	$BPCF = \frac{TAX - SUB + VAT + TTM}{SUP + TAX - SUB + VAT + TTM}$	BPCF = Basic price conversion factor TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products VAT = VAT not deductible by the purchaser TTM = Trade and transport margins SUP = Total supply per sector
Final harmonization of financial accounting prices including inflation and basic price adjustments.	$HP = IAP - (IAP \times BPCF)$	HP = Harmonized price IAP = Inflation adjusted price FAP = Financial account price BPCF = Basic price conversion factor

Dataset

The full dataset can be accessed in https://doi.org/10.5281/zenodo.8369650.

SI References

1. K. Stadler, pymrio – multi regional input output analysis in python (2022).
2. A. Hayes, Double Entry: What It Means in Accounting and How It's Used (2021).
3. J. Houdet, H. Ding, F. Quétier, P. Addison, P. Deshmukh, Adapting double-entry bookkeeping to renewable natural capital: An application to corporate net biodiversity impact accounting and disclosure. *Ecosyst. Serv.* **45**, 101104 (2020).