TITLE:
Biodiversity footprint of public procurement in Finland

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ABSTRACT
Halting biodiversity loss requires systematic action from all sectors of society. The public sector is a significant actor globally in creating markets for goods and services, public procurement representing on average 13 – 20% of national gross domestic product. In this study, we assessed the biodiversity footprint of public procurement in Finland for years 2021 and 2022. We applied the consumption-based hybrid-LCA biodiversity footprint model BIOVALENT, where EXIOBASE and LC-IMPACT databases are combined to connect the economic activities in the value chains of procured goods and services with the resulting biodiversity impact. Our results indicate that (i) largest contributors to the biodiversity footprint of public procurement in Finland in 2022 were construction and maintenance (20%), energy consumption (14%), health and social services (10%), and medication and care supplies (10%); (ii) the greatest potential in mitigating the biodiversity footprint of public procurement lies in construction and maintenance, medication and care supplies, energy consumption, and in food and accommodation services; and (iii) according to the model on average over 90% of the biodiversity footprint was located overseas. These insights from our analysis can be used for guiding mitigation actions towards potentially most impactful procurement categories. The considerable role of the value chain in the harmful biodiversity impacts call for significant changes in the public procurement practices, given their influence throughout production systems and consumption patterns.

KEYWORDS
biodiversity footprint, biodiversity impact, public procurement, value chain, industrial ecology, consumption

1. INTRODUCTION

The prosperity and wellbeing of societies is highly dependent on the state of the environment (Diaz et al., 2019; Dasgupta, 2021). According to World Economic Forum (2026) biodiversity loss and ecosystem collapse are among the largest risks to society ranked by severity within the next 10 years. Despite the interconnectedness of human societies and the environment, human activities have caused and continue to cause significant losses of biological diversity globally (Tilman et al., 2017; Cordella et al., 2022). Biodiversity loss occurs through five main direct drivers, which are land and sea use changes, direct exploitation of organisms, climate change, pollution, and invasion of alien species (Diaz et al., 2019; Jaureguiberry, 2022). Over 47,000 species are known to be threatened with extinction (IUCN, 2025) and approximately 1 million is estimated to be when the number of undiscovered species is accounted for (IPBES, 2019; Diaz et al., 2019).

Economic activity connected to the production and consumption of goods and services which are nowadays largely generated through global value chains, drive local threats to species (Lenzen et al., 2012; Wilting et al., 2017). Countries import materials and intermediate products, which they then use for the production of other goods and services, either intermediates or final products, that are then set out to be exported or consumed (Cabernard & Pfister, 2021). Each step along the value chain adds to the environmental pressures via the aforementioned drivers of biodiversity loss. Similar to the operators along the value chains, also the environmental pressures are spread out to various geographical locations globally (Sandström et al., 2017; Wilting et al., 2017). The link between economic activities and environmental degradation has been shown to have implications on the transboundary dynamics of biodiversity loss, where countries do effectively import or export ecological impacts (Lenzen et al., 2012; Bjelle et al., 2021).

One approach for investigating the relationship between human activities and biodiversity loss is biodiversity footprint assessment. In biodiversity footprinting life cycle impacts of consumed goods and services are quantified combining environmentally extended input-output (EEIO) techniques with Life Cycle Assessment (LCA) modelling or other similar approaches (reviewed by Marques et al., 2017, Crenna et al., 2020, and Damiani et al., 2023). EEIO databases connect international economic flows between different sectors to the environmental pressures that arise from the activities in each country (Kitzes, 2013; Moran et al., 2016). LCA models track the environmental impacts of value chains generally in more specific contexts, such as individual products or services (Teillard et al., 2016; Winter et al., 2017).

The public sector is a significant actor in global markets. Public procurement of goods and services account for on average 13 - 20% of world gross domestic product (GDP) (The World Bank, 2020). In Finland, public procurement amounts to approximately 30 billion euros annually when also in-house procurement is considered (Kivistö & Virolainen, 2019), which is around 13% of the Finnish GDP. Hence, the public sector has power when it comes to influencing sustainability and green initiatives by demand as well as drive innovation in companies and industries (Morley et al., 2021). The actions of the government also influence consumer behavior and serve as an example for other countries and the general public (Ma et al., 2020). The interest towards more sustainable practices in the public sector has initiated various projects. In Finland, for instance, impacts from resource use and carbon emissions have been studied (Seppälä et al., 2011; Nissinen & Savolainen, 2019; Kalimo et al., 2021, Pulkki et al., 2023). In the EU, research has covered public procurement sustainability topics in high-impact sectors such as food production (Casonato et al., 2024) and construction (Ahmed et al., 2024) focusing mainly on carbon footprint, land use impacts, circular economy, and ecolabels while assessments on biodiversity impacts are still rare.

In this study, we build on the previous work but focus on the value chain biodiversity impacts resulting from public procurement in Finland. More specifically, we quantify the global biodiversity impacts of procurement made by the state, municipalities, and joint municipal authorities in Finland in years 2021 and 2022. We further analyse the results to identify where action should be targeted to efficiently reduce the adverse biodiversity impacts. Finally, we discuss the implications of the results for public procurement practices in Finland and more widely around the world.

2. METHODS

To assess the biodiversity impacts of public procurement of Finland, we utilized the Biodiversity Equivalent Impact Assessment method BIOVALENT (El Geneidy et al., 2025). BIOVALENT is based on the EEIO database EXIOBASE (Stadler et al., 2018) and the life cycle impact assessment (LCIA) database LC-IMPACT (Verones et al., 2020). Next, we cover the steps that were needed to collect the data for the biodiversity impact assessment. We also explain in more detail how the assessment works and how it is related to other similar methods. In addition, we introduce a method for analysing the opportunities for impact mitigation based on the assessment results.

2.1 Collection of data

The consumption data for this biodiversity footprint assessment was collated from an open public procurement database (exploreadministration.fi) where data on public expenditure is available. The data reported in the database and extracted for this study was based on the state's central accounting and quarterly accounting reports from municipalities and joint municipal authorities. Procurement expenditure data from years 2021 and 2022 was collected. Data was available in total for 64 governmental procurement organizations, 306 and 283 municipalities, and 132 and 124 joint municipal authorities, in 2021 and 2022 respectively. The expenditure accounts were categorized into broader procurement categories based on the categorization done in a previous study by Kalimo and colleagues (2021) and adapting it according to the product categories in the EXIOBASE 3 database (Stadler et al., 2018). The categorization framework is provided in the Supporting information (Table S1).

Some accounts were excluded from the assessment due to being deemed as irrelevant in terms of methodologically quantifiable biodiversity impacts or containing insufficient information. Such excluded accounts were purchases and rents of land and water areas, purchases of buildings, per diem allowances, reimbursement of other costs, and patent, licence, and access fees. Also, procurements from other public entities (i.e. in-house procurements), which contained mainly health care and social services, were excluded from the calculations to avoid double counting the biodiversity impacts along the value chains.

2.2 Assessing the amount of the drivers of biodiversity loss

EEIO databases contain information on the relationship between economic activities and environmental impacts (Kitzes et al., 2013). Various EEIO databases, such as EXIOBASE (Stadler et al, 2018), Eora (Lenzen et al., 2013), WIOD (Timmer et al., 2015), and GTAP (Aguiar et al., 2022) have been developed to model the connections of financial flows through global supply chains to the physical accounts of environmental pressures. Although the databases adhere to the same principles for modelling global sectoral inputs, outputs, and the associated environmental pressures, they differ in terms of the time periods covered, the level of geographical detail, and the granularity of sector-specific data (Moran & Wood, 2014). In this study, we used EXIOBASE 3.8.2 (Stadler et al., 2018) for connecting the monetary consumption of products and services in the public procurement dataset to the environmental pressures, which can be referred to as the drivers of biodiversity loss, such as land use and pollution. We used EXIOBASE due to its relatively high sectorial detail and open access format. EXIOBASE 3 is a publicly available database covering 163 industries and 200 product categories (Stadler et al., 2018).

The financial accounts in the public procurement data were harmonized with EXIOBASE by selecting the appropriate match for each account from the 200 available product categories from the database. Due to the unavailability of more accurate open access data on the content of the accounts in the financial reporting, averages of two or more EXIOBASE categories were used for some accounts to achieve a more accurate match. For example, half of the monetary value of property rent costs were allocated as heating costs while the other half was allocated as other property management costs. The account allocations to EXIOBASE product categories are provided in Supporting information (Table S1).

Due to the data in EXIOBASE being based on the year 2019, while the financial account data used in this study was from the years 2021 and 2022, price adjustments were needed. Prices were adjusted according to the Consumer Price Index from Statistics Finland (2023a). In addition, the prices were converted from the financial account prices (i.e., purchaser prices) into basic prices, that are often used for the calculation of impact factors in the EEIO data accounting for taxes, subsidies, trade and transport margins, and value-added tax if required by the financial data. This basic price conversion was done by applying basic price conversion factors calculated in the publication of El

Geneidy et al. (2025). In this study, value-added tax adjustments were deemed irrelevant since those are invoiced separately from the financial account data reported in the public procurement database and utilized in this study.

2.3 Assessing the biodiversity impacts caused by the drivers of biodiversity loss

There are also various databases that model biodiversity impacts resulting from environmental pressures (Curran et al., 2011). Different LCIA databases such as LC-IMPACT (Verones et al., 2016), ImpactWorld+ (Bulle et al., 2019), ReCiPe 2016 (Huijbregts et al., 2016), and Stepwise2006 (Weidema et al., 2009) utilize LCIA models in the impact assessment phase. In other words, they quantify the biodiversity impacts of the drivers of biodiversity loss. Other alternative or complementary approaches to LCIA include methods incorporating for example ecosystem service accounting or models such as GLOBIO (Alkemade et al., 2009; Schipper et al., 2020). In this study, we used regionalized global LCIA data from LC-IMPACT (Verones et al., 2020) to assess the biodiversity impact of the drivers of biodiversity loss that were quantified with EXIOBASE. The full BIOVALENT method is described in more detail in El Geneidy et al. (2025).

Before assessing the biodiversity impact generated from the drivers of biodiversity loss, we require information on the geographical locations of the drivers. Here we identified the locations of the drivers with the open access tool Pymrio (Stadler, 2021). The full regionalization process along with the harmonization of country classification of EXIOBASE and LC-IMPACT is covered in the BIOVALENT method paper by El Geneidy et al. (2025). Regionalized biodiversity impacts were assessed for different drivers of biodiversity loss, namely land use, climate change, pollution, and water stress. More specifically land use types accounted for in the method included different annual and permanent crops, fodder crops, pasture, forestry, and other land use. Climate change includes impacts from greenhouse gases such as carbon dioxide, methane and nitrogen dioxide in terrestrial and freshwater ecosystems. LC-IMPACT version 1.3 does not contain regionalized information about the impacts of climate change, which is why impacts of climate change were not regionalized in this study. Pollution impacts were modelled from photochemical ozone formation and terrestrial acidification for terrestrial ecosystems, from eutrophication via phosphorus for freshwater ecosystems, and from eutrophication via nitrogen for marine ecosystems. Water stress was modelled from the consumption of blue water, i.e. freshwater from surface waters. A detailed description of pressure categories accounted for in this study can be found in the publication of El Geneidy et al. (2025).

Several different indicators exist for measuring biodiversity footprints (Curran et al., 2011). In LC-IMPACT biodiversity loss is measured as potentially disappeared fraction of species (PDF) which indicates global species extinction risk (i.e., risk of irreversible extinction of species) in three ecosystem types: terrestrial, freshwater, and marine. As these relative changes in the risk for extinction for species within the considered taxonomic groups in each ecosystem type are not recommended to be combined as they are (Verones et al., 2020), we calculated a weighted average of the ecosystem-specific PDF values across the three ecosystem types. Weights for ecosystem types were allocated using the respective estimated shares of global plant and animal species richness (Román-Palacios et al., 2022). The merged biodiversity footprint represents global species extinction risk as a single indicator, the biodiversity equivalent (BDe), introduced originally by El Geneidy et al. (2025). Biodiversity equivalent is calculated according to the equation below:

$$\mathrm{BDe} = \mathrm{PDF}_{\mathrm{terrestrial}} \times 0.801 + \mathrm{PDF}_{\mathrm{freshwater}} \times 0.096 + \mathrm{PDF}_{\mathrm{marine}} \times 0.102$$

2.4 Assessing the total biodiversity footprint of public procurement

In the calculation of the total biodiversity footprint of public procurement, the harmonized prices (€) were multiplied by the ecosystem specific impact factors (PDF/€) for terrestrial, freshwater, and marine ecosystems. Ecosystem-specific footprints (PDF) were then aggregated into the biodiversity equivalent (BDe).

The results reported as biodiversity equivalents describe the extinction risk for global species across all three ecosystem types. When calculating biodiversity footprints of organizations or other individual actors, the number representing the resulting extinction risk is bound to be small, especially when the total footprint results are further disaggregated into results for different consumption categories. In order to allow for better understanding of the

differences between the biodiversity footprint of different categories, we used multiplication and prefixes. The prefix used for biodiversity footprints throughout this paper is nano (n = 10^{-9}) and for the impact factors femto (f = 10^{-15}).

Furthermore, geographical distribution of the biodiversity footprint was modelled using an open access tool Pymrio (Stadler, 2021) and results were visualized using QGIS version 3.22.9 (QGIS Development Team, 2022).

2.5 Quadrant of opportunities

Results from the biodiversity footprint assessment were utilized in identifying priority procurement categories for targeted mitigation efforts in public procurement practices in the future. Priority procurement categories were identified by constructing a prioritization quadrant analysis. The "Quadrant of opportunities" is illustrated in Figure 1, and each of the four factors included in the priority identification are detailed below. It is good to note that the results illustrated by the quadrant of opportunities are always relative to the data in question.

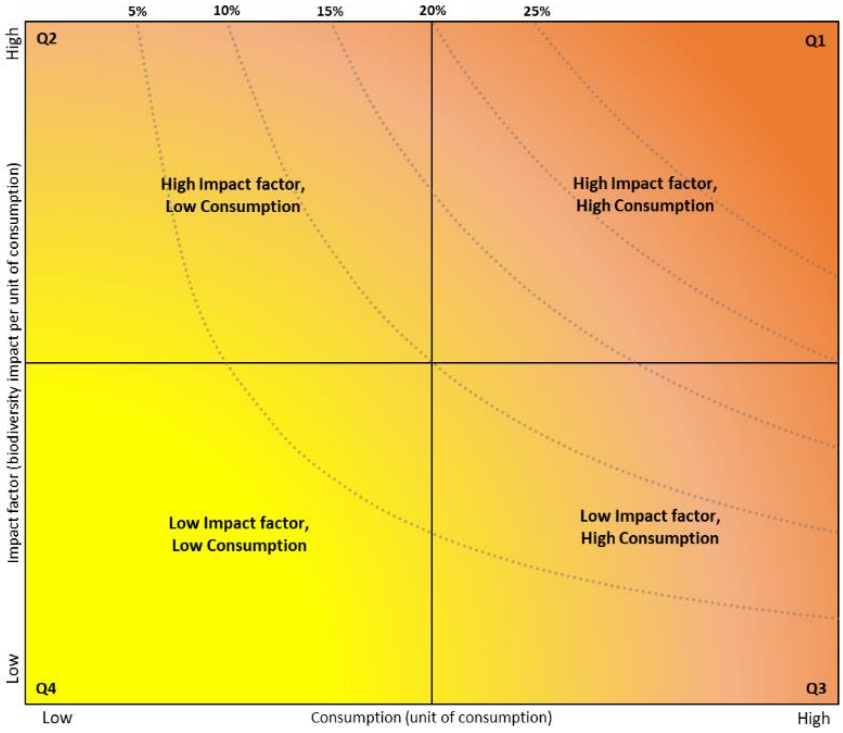

Figure 1. Example illustration of the quadrant of opportunities. Data points are placed in the graph based on the respective impact factor (biodiversity impact per unit of consumption) and consumption (unit of consumption). Sections Q1 – Q4 are divided by solid lines on each axis representing the median values for the data for both axes and numbered in the order of relevance to the opportunity to mitigate impacts. Dashed lines illustrate the shares of 5, 10, 15, 20, and 25 per cent from the total biodiversity footprint.

The quadrant of opportunities includes factors which can be used for analysing the priorities in impact mitigation. First, the procurement categories were placed in the graph based on the impact factor and consumption values. The value on the vertical axis represents the impact factor as biodiversity impact (femtoBDe, BDe*10^{15}) per unit of consumption (€). On the horizontal axis of the graph is the consumption as expenditure in billions of euros (bn €). The figure is divided into four sections, Q1 – Q4, by placing a line according to the median values in the data for both axes. These lines separate the categories into four sections, which enables the differentiations to categories of priority. In the context of biodiversity impact mitigation, the sections are numbered in the order of priority, starting from Q1 (highest priority) with high impact factor and high consumption. In these categories, impact mitigation can be achieved both by replacing products or services with a more sustainable alternatives which have lower impact per

euro of expenditure, and by reducing overall consumption, for example. The second section ranked by priority (Q2) includes categories which have high impact factors but low expenditure value. Here, the second highest priority ranking is based on the effectiveness of choosing alternative low impact products and services in mitigating impacts. Perhaps, here the underlying assumption is that public procurements are based on requirements for functioning societies and public welfare in the current socio-economic system, which means that switching products and services to alternative options is more feasible and effective in this context than reducing consumption. The third section (Q3) includes categories which have low impact factors but high expenditure. These are categories in which mitigation of impacts is most effective when consumption is reduced. With the categories grouped in Q4, the opportunities to mitigate impacts are relatively low since both the impact factor and expenditure are small. However, as was stated above, the results illustrated by the quadrant of opportunities are always relative to the data in question and depending on the data, it is possible that in some cases even the Q4 quadrant may have significant mitigation potential in terms of reducing the absolute biodiversity loss.

In addition, included in the figure as functions of the impact factor and the expenditure are the dashed lines indicating the areas of placement for shares of the total biodiversity footprint aiding the interpretation. For instance, the 5% dashed line indicates that all data points on the left side of the line represent less than 5% of the total biodiversity footprint while the data points on the right side represent a larger than 5% share. All the functions are calculated based on the assessment data.

It is worth noting, that priority analyses such as this, which are based on monetary value are sensitive to the changes of the prices of the goods and services. If the price is reduced it would show as a mitigated impact even if the same number of the same goods and services are purchased. This would not represent true impact mitigation outcome which is why the results based on reducing expenditure should be interpreted with caution. However, the framework can be utilized with any metric such as consumption in kilograms or megawatthours in which case similar sensitivity would be less likely to occur. In any case the quadrant of opportunities provides an overall useful outline for priority mitigation efforts for the public sector but also for businesses and organizations in general.

3. RESULTS

In 2021, the public sector procured goods and services worth 26.9 billion euros and the biodiversity footprint was 26 171 nBDe. In other words, the potential extinction risk for global species was 0.00026. In 2022, despite the expenditure being higher at 29.1 billion euros, the biodiversity footprint was smaller at 25 048 nBDe. From the biodiversity footprint as well as the expenditure of the public sector, over a quarter came from the state, less than a half from the municipalities, and over a quarter from the joint municipal authorities (Table 1).

Table 1. The absolute (nBDe) and relative (%) biodiversity footprint and the expenditure of public procurement of the government, municipalities, joint municipal authorities and in total in 2021 and 2022.

	Biodiversity footprint (nBDe)		***Share from biodiversity footprint (%)***		***Expenditure (bn. €)***		***Share from expenditure (%)***	
Year	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Government	7 260	7 799	28	31	6.5	7.9	24	27
Municipalities	12 025	10 656	46	43	12.8	13.2	48	45
Joint municipal authorities	6 886	6 593	26	26	7.6	8.1	28	28
In total	26 171	25 048			26.9	29.1		

The largest contributor to the biodiversity footprint of public procurement was construction and maintenance services, which contributed 19% to the biodiversity footprint in 2021 and 20% in 2022 while the share of the total expenditure was 12% both years (Figure 2). The second largest contributor was the consumption of utilities, i.e.

electricity, heating, water, and rent, was 18% in 2021 and 14% in 2022, while the share of the total expenditure was 12% and 11%, respectively. The third and fourth largest contributors were health and social services and medical and care supplies, both with a share of 10% of the total biodiversity footprint in both years. Although the biodiversity footprint was similar in those categories, the share of the total expenditure of health and social services (20% in 2021 and 18% in 2022) was nearly triple the share of medical and care supplies (7% in both years).

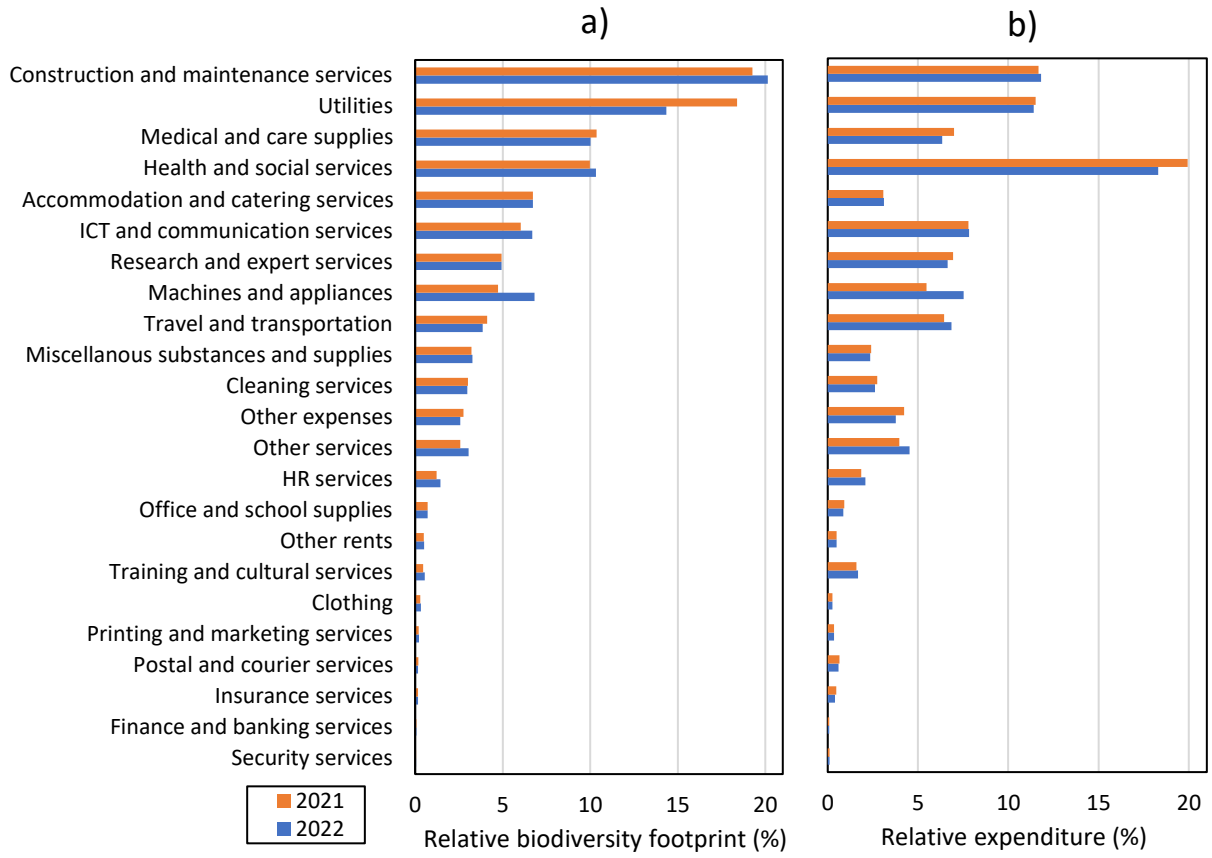

Figure 2. The relative contribution of consumption categories to a) biodiversity footprint and b) expenditure of public procurement in years 2021 and 2022. Categories have been arranged in the order of largest to smallest contribution to biodiversity footprint in 2021.

3.1 Biodiversity footprint of public procurement in terrestrial ecosystems

The terrestrial biodiversity footprint of public procurement in Finland was 29 449 nPDF in 2022. This means that the potential extinction risk for terrestrial species globally is 0.0029. According to the model, 53% of the impacts on terrestrial ecosystems were caused by climate change (carbon dioxide, methane, and nitrogen oxide), 42% by land use, and 5% by pollution (photochemical ozone formation and soil acidification) (Figure 3a). The impact of climate change in terrestrial ecosystems was largest from procurement of construction and maintenance services, utilities, medical and care supplies, and health and social services (Figure 4a). The impact of land use was largest from construction and maintenance services, health and social services, medical and care supplies, and accommodation and catering services. The impact of pollution in terrestrial ecosystems was largest from accommodation and catering services, health and social services, miscellaneous substances and supplies, and ICT and communication services.

3.2 Biodiversity footprint of public procurement in freshwater ecosystems

The biodiversity footprint of public procurement in Finland directed to freshwater ecosystems was 9 568 nPDF in 2022. This means that the potential extinction risk for global freshwater species was 0.00096. According to the

model, 51% of the impacts on freshwater ecosystems were caused by climate change (carbon dioxide, methane, and nitrogen oxide), 47% by water consumption, and 2% by pollution (eutrophication in freshwater habitats due to phosphorus emissions) (Figure 3b). The impact of climate change in freshwater ecosystems was largest from procurements of construction and maintenance services, utilities, medical and care supplies, and health and social services (Figure 4b). The impact of water consumption was largest from medical and care supplies, health and social services, construction and maintenance services, and ICT and communication services. The impact of pollution in freshwater ecosystems was largest from health and social services, accommodation and catering services, ICT and communication services, and medical and care supplies.

3.3 Biodiversity footprint of public procurement in marine ecosystems

The biodiversity footprint of public procurement in Finland in marine ecosystems was 5 381 nPDF in 2022. This means that the potential extinction risk for global marine species was 0.00054. The impacts assessed for marine ecosystems consisted of the impacts of pollution (eutrophication in marine habitats due to nitrogen emissions) (Figure 3c).

The largest impact to marine ecosystems from pollution (including eutrophication in marine habitats due to nitrogen emissions) comes from accommodation and catering services, covering nearly half of the total impacts of pollution on marine ecosystems. The characterization factor in the LC-IMPACT database for Estonia is significantly higher than for any other country. This affects the results and could be an error in the database. Although it might be well justified to remove this value as an outlier, we decided to report the original results nevertheless to indicate the existing potential uncertainties in the current assessment methodologies. The largest impacts from pollution to marine ecosystems after accommodation and catering services come from miscellaneous substances and supplies, ICT and communication services, and construction and maintenance services (Figure 4c).

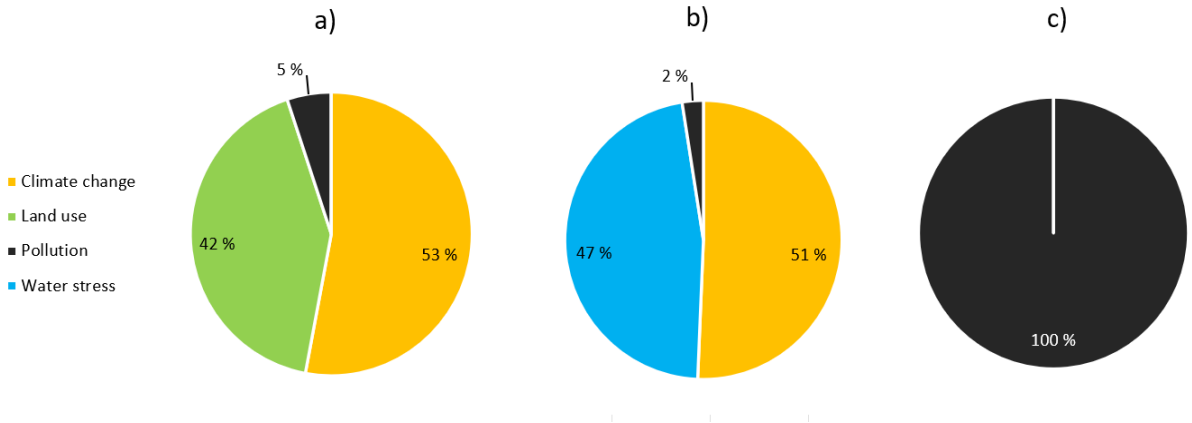

Figure 3. Distribution of biodiversity impacts (%) for drivers of biodiversity loss in a) terrestrial ecosystems, b) freshwater ecosystems, and c) marine ecosystems.

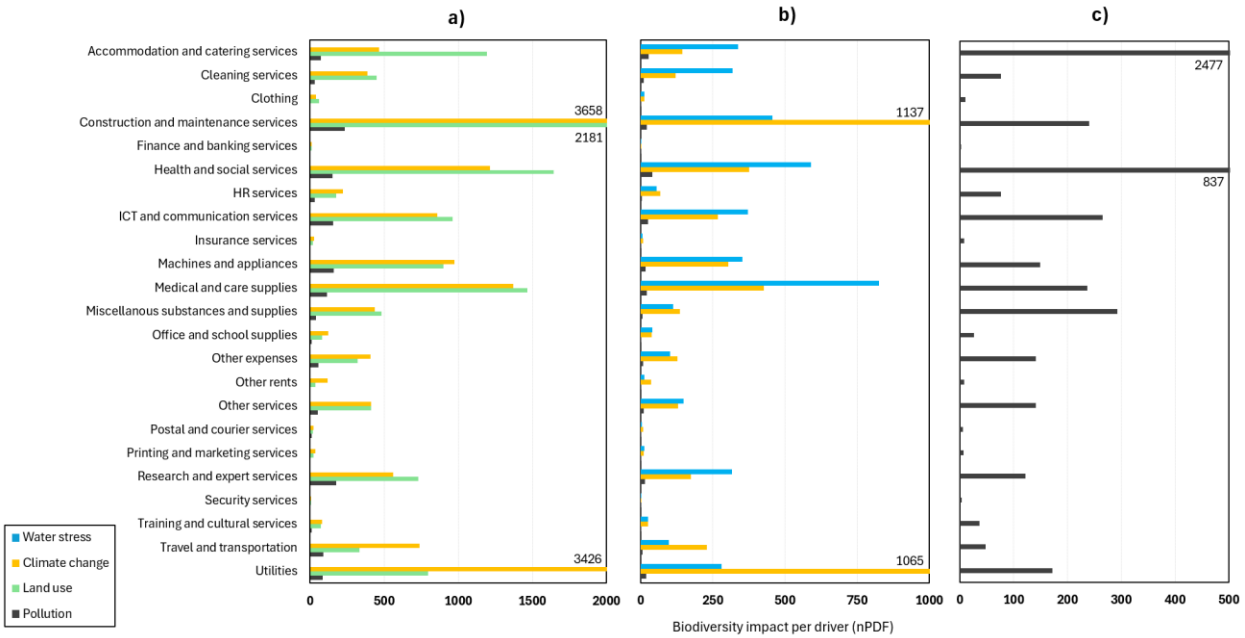

Figure 4. Biodiversity footprint of public procurement for a) terrestrial ecosystems, b) freshwater ecosystems, and c) marine ecosystems. Footprints represent the relative potential loss of species as a potentially disappeared fraction of species within each ecosystem type as nPDF (1 nPDF = 0.000000001%). Bars exceeding the plotted range are truncated for visualization clarity and their numerical values are displayed next to each bar.

3.4 Geographical distribution of impacts

Figure 5 illustrates the geographical distribution of the impacts for each driver of biodiversity loss specific to the ecosystem type. The impacts from land use to terrestrial ecosystems were highest in small island nations close to the equator. The largest shares from the land use impacts occurred in Guam, São Tomé and Príncipe, Seychelles, North Mariana Islands, and New Caledonia, covering together 24 per cent of the land use impacts. A share of 3.5 per cent of the impacts was distributed to Finland, while Russia and Indonesia had shares of 3.1 and 2.4 per cent, respectively.

The impact of pollution to terrestrial ecosystems was largest in Arab Emirates with a share of 18.8 per cent of the impacts. The second largest share from the impacts was for Palestinian Territories (12.7%), Italy (10.8%), Lebanon (9.6%), and Papua New Guinea (8.3%). Only 1.1 per cent of the impacts of terrestrial pollution was distributed to Finland.

The impacts from water consumption to freshwater ecosystems were highest in the United States with a share of 21.4 per cent. The second largest share from the impacts of water consumption was for Australia (6.2%) followed by Brazil (2.9%), China (2.3%), Russia (1.9%), and Botswana (1.9%). Only 0.1 per cent of the impacts from water consumption was distributed to Finland.

The impact of pollution to freshwater ecosystems was largest in India with a share of 19.7 per cent. Brazil had the second largest share (6.1%), followed by China (5.1%), Finland (4%), Sri Lanka (3.8%), and Taiwan (3.2%).

The impact of pollution to marine ecosystems was largest in China with a share of 38.3 per cent. Germany had the second largest share (32.6%), followed by The Netherlands (7.9%), Finland (6.5%), Sweden (6.3%), and United States (6%). Estonia was removed from the geographical visualization of marine impacts due to a disproportionately large share from pollution which indicated that there is a potential mistake in the characterization factor in LC-IMPACT database.

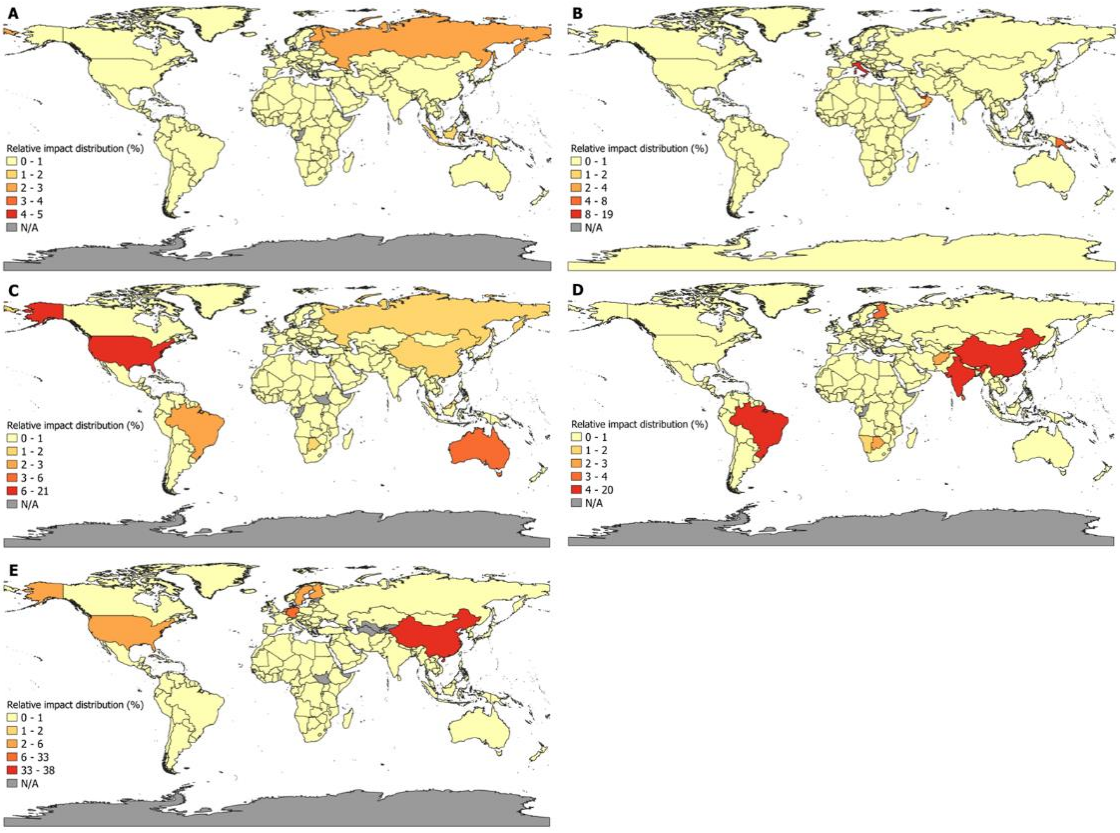

Figure 5. The geographical distribution of the driver- and ecosystem type-specific relative impacts (%) from a) land use, b) terrestrial pollution, c) water consumption, d) freshwater pollution, and e) marine pollution. N/A: No data available. Symbology is based on the Jenks natural breaks classification method.

3.5 Options for mitigating impacts: the quadrant of opportunities

Opportunities for mitigating biodiversity impacts from public procurement in Finland are illustrated in the quadrant of opportunities in Figure 6. The highest potential lies in the categories placed in the upper right section of Q1 based on data from the year 2022. The highest priority categories, for which impact mitigation strategies should be implemented include construction and maintenance services, utilities, medical and care supplies, machines and appliances, ICT and communication services, and accommodation and catering services illustrated in

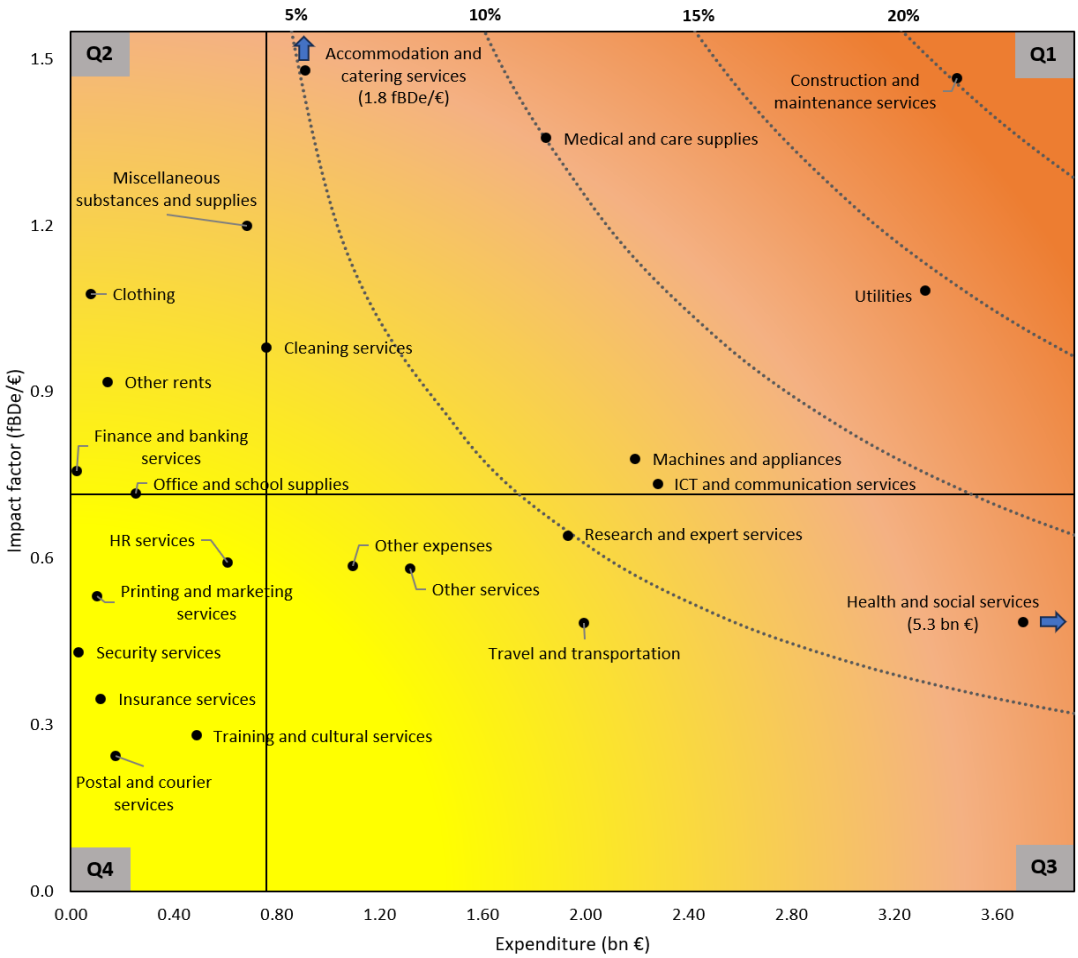

Figure 6. Quadrant of opportunities of the biodiversity footprint of public procurement in Finland in 2022. Each procurement category is placed in the graph based on the respective impact factor (in femtoBDe 10^{-15}, of impact per euro of expenditure) and expenditure (in billions of euros). Sections Q1 – Q4 were divided by solid lines on each axis representing the median values for procurement categories and numbered in the order of relevance to the opportunity to mitigate impacts. Dashed lines illustrate the shares of 5, 10, 15, and 20 per cent from the total biodiversity footprint of public procurement. Both axes in the figure are truncated to better represent the distribution of data. Top-end values outside the axis range are indicated with a blue arrow and the numerical values are displayed below the category label.

4. DISCUSSION

In this study we assessed the biodiversity footprint of public procurement in Finland from years 2021 and 2022. The results indicate that the impacts on biodiversity are widespread considering the distribution of impacts originating from different procurement categories but also considering how the impacts are spread geographically on a global scale. Construction and maintenance services, energy consumption, medical and care supplies, and health and social services inflicted the largest impacts from the procurements made by the public sector in Finland. According to the results, from the pressures included in this assessment, climate change poses the largest threat to global terrestrial and freshwater biodiversity. However, land use is a significant pressure to the terrestrial ecosystems as well and it might well be that the relative significance of the different drivers of biodiversity loss might change based on the LCIA model used (Bromwich et al., 2025).

The results of this study further enforce the earlier findings of interconnectedness of global value chains and the effects on biodiversity (Lenzen et al., 2012; Marques et al., 2019; Sandström et al., 2017). According to the results

of this study, over 90 per cent of the impacts on biodiversity are situated outside of Finland. This relatively high proportion may reflect the value choices made in the modelling frameworks in general and also for the specific impact pathways modelled for each pressure category. As an example, the relatively low proportion of the impact directed to Finland may stem from the assignation of vulnerability scores according to the threat status and range size of different taxonomic groups in the LC-IMPACT database (Verones et al., 2020). As Finland hosts a relatively low number of endemic or globally threatened species, the modelling frameworks give lower emphasis on risks of species extinction in Finland compared to those countries with high endemism and high number of globally threatened species (Huais et al., 2025). This also reflects the nature of the indicator: it prioritizes the permanent, irreversible extinction of species, rather than regional disappearance of species (El Geneidy et al., 2025; Verones et al., 2020).

The coverage of impacts on marine ecosystems in this method is limited. Only impacts of marine eutrophication could be included in the assessment although there are significant known impacts from pressures such as climate change, sea use, other types of pollution (e.g., plastic), overexploitation of natural resources, and invasive species that adversely affect marine biodiversity (Herbert-Read et al., 2022; Lincoln et al., 2022). Other impacts, at this point missing from the methodology but recognized as having significant impact on biodiversity, include those from invasive alien species (Early et al., 2016; Pyšek et al., 2020) and direct exploitation of natural resources (Egenolf et al., 2022; Stanford-Clark et al., 2024) in terrestrial and freshwater ecosystems. Incorporating these forementioned impacts requires further research on the operationalization of existing research into the biodiversity footprint methodology. In practice, this would entail scientifically robust modelling of impact pathways from which midpoint and endpoint characterization factors can be derived. Some work has already been done, for example, to broaden the scope of climate change impacts (Iordan et al., 2023) and the impact of invasive alien species in global trade (Borgelt et al., 2024).

Large scale biodiversity footprint assessments include multiple parts including modelled trade flows, caused environmental pressures, and arising biodiversity impacts. Each part adds a level of uncertainty to the assessment (Bromwich et al., 2025). Impact modelling based on financial data and EEIO databases is dependent on the granularity of the accounting data provided and the granularity and amount of the product categories available in the chosen database (Moran et al., 2016). Financial data for a large entity, such as the public sector of a country, contains a large volume of data, which in this study was on a relatively coarse scale of financial accounts containing highly variable products and services. Therefore, some subjective choices were required in order to match accounts with appropriate product categories in the EEIO database. Until widely accepted and standardized systems for environmental accounting and methodologies for biodiversity footprint assessments become available, open discussion about modelling methods and implications of subjective choices are key in creating such systems.

Although an aggregated value across ecosystem types, the biodiversity equivalent, is calculated and provided in this study, the ecosystem-specific disaggregated values are vital in retaining more information for further use of the information in practical settings. For example, a public procurement specialist might be interested in the specific actions that can be taken to reduce impacts on freshwater ecosystems across the value chain. Further disaggregation of biodiversity impacts by consumption categories, individual financial accounts, and different levels of organization in the public sector are also provided in the Supporting information S1, to support the identification of the relevant impacts and implementation of effective action towards mitigating such impacts.

As the public sector has a central role in the global economy contributing to 13 - 20% of world GDP (The World Bank, 2020), it is likely that public procurement is also a major driver of biodiversity loss due to human consumption. The model and results of this study can be used for a high-level assessment of public procurement in any country. The associated biodiversity impact factors will be published alongside another study (El Geneidy et al., 2025) and a Biodiversity Footprint Database (https://doi.org/10.5281/zenodo.8369650), and can be used to assess public procurement biodiversity footprints. The public sector has great responsibility and opportunity to initiate collective action for transformative changes across value chains (Booth et al., 2024) and can play a key role in achieving the goals of the Global Biodiversity Framework and nature positive (Nature Positive Initiative, 2023; zu Ermgassen et al., 2022). The quadrant of opportunities provides practitioners with a readily approachable tool to prioritize efforts in reducing biodiversity loss across value chains to reach a nature positive world.

STATEMENTS AND DECLARATIONS

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

The data that supports the findings of this study are available in the supporting information of this article. The data for the public procurement expenditure is available publicly (in Finnish) at: https://www.exploreadministration.fi/

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Funding was acquired by J.S.K. and S.E. Material preparation, data collection and analysis were performed by E.P. The first draft of the manuscript was written by E.P. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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SUPPORTING INFORMATION

Supporting Information

Supporting Information S1: This table provides accounts in public procurement data for the biodiversity footprint calculations for years 2021 and 2022, and their allocation to product and service categories available in EXIOBASE in the present study.

Supporting Information S2: This table provides merged EXIOBASE 3 product categories used for creating impact factors better suited for procurement accounts that could not be directly matched with a single suitable product category.

Table S1. Allocation of public procurement accounts to broad procurements categories and the product and service categories available in EXIOBASE 3 database. Merged categories are italicized and explained in detail in Supporting Information Table S2.

Broad procurement category	Account (data only available in Finnish)	Account (translation to English by Microsoft Copilot)	EXIOBASE product category
HR services	Muut henkilöstöpalvelut	Other personnel services	Other business services (74)
	Talous- ja henkilöstöhallinnon palvelujen ostot, sisäiset	Internal purchases of financial and HR administration services	Other business services (74)
	Työvoiman vuokraus	Temporary staffing / leased workforce	Other business services (74)
ICT and communication services	ICT käyttöpalvelut	ICT operating services	Computer and related services (72)
	ICT-laitteet	ICT equipment	Office machinery and computers (30)
	ICT-laitteiden vuokrat	Rental of ICT equipment	Renting services of machinery and equipment without operator and of personal and household goods (71)
	ICT-palvelujen ostot, sisäiset	Internal purchases of ICT services	Computer and related services (72)
	ICT-palvelut	ICT services	Computer and related services (72)
	Itse valmistetut ja teetetyt tietojärjestelmät	Self-produced and outsourced information systems	Computer and related services (72)

	Keskeneräiset aineettomat käyttöomaisuushankinnat	Intangible assets under construction	Computer and related services (72)
	Liittymismaksut	Connection fees	Computer and related services (72)
	Muut aineettomat oikeudet	Other intangible rights	Computer and related services (72)
	Muut pitkävaikutteiset menot	Other long-term expenditures	Computer and related services (72)
	Ostetut valmisohjelmistot ja tietojärjestelmät	Purchased software and information systems	Computer and related services (72)
	Puhelinkeskukset ja muut viestintälaitteet	Telephone exchanges and other communication equipment	Radio, television and communication equipment and apparatus (32)
	Sovelluspalvelut	Application services	Computer and related services (72)
	Toimistokoneet ja laitteet	Office machines and equipment	Office machinery and computers (30)
Machines and appliances	Arvoltaan vähäiset koneet, kalusteet ja kuljetusvälineet	Low-value machinery, furniture, and vehicles	Machinery and equipment n.e.c. (29)
	Audiovisuaaliset koneet ja laitteet	Audiovisual equipment	Radio, television and communication equipment and apparatus (32)
	Kalusto	Equipment / furnishings	Machinery and equipment n.e.c. (29)
	Kevyet työkoneet	Light work machines	Machinery and equipment n.e.c. (29)
	Koneiden ja laitteiden vuokrat	Rental of machinery and equipment	Renting services of machinery and equipment without operator and of personal and household goods (71)
	Koneiden, kaluston ja laitteiden rakentamis- ja kunnossapitopalvelut	Construction and maintenance of machinery, equipment, and furnishings	Machinery and equipment n.e.c. (29)
	Laboratoriolaitteet ja -kalusteet	Laboratory equipment and furnishings	Machinery and equipment n.e.c. (29)
	Maanpuolustuskalusto	Defence equipment	Machinery and equipment n.e.c. (29)
	Muiden koneiden ja laitteiden korjaus- ja kunnossapitopalvelut	Repair and maintenance of other machinery and equipment	Computer and related services (72)
	Muiden koneiden ja laitteiden vuokrat	Rental of other machinery and equipment	Renting services of machinery and equipment without operator and of personal and household goods (71)
	Muut koneet ja laitteet	Other machinery and equipment	Machinery and equipment n.e.c. (29)

	Muut korjaus- ja kunnossapitopalvelut	Other repair and maintenance services	*Building work and material* (See Table S2)
	Muut tutkimuslaitteet	Other research equipment	Machinery and equipment n.e.c. (29)
	Raskaat työkoneet	Heavy work machines	Machinery and equipment n.e.c. (29)
	Vesirakenteiden laitteet	Water construction equipment	Machinery and equipment n.e.c. (29)
Training and cultural services	Koulutus- ja kulttuuripalvelut	Education and cultural services	Education services (80)
	Koulutuskorvaukset työnantajille	Training compensation to employers	Education services (80)
	Koulutuspalvelut	Training services	Education services (80)
	Muut koulutuspalvelut	Other training services	Education services (80)
	Virkistyspalvelut	Recreation services	Recreational, cultural and sporting services (92)
	Asiakaspalvelut (Kuntien julkisten toimijoiden ulkopuolelta ostetuista palveluista 8%)	Client services (8% of all purchased client services by municipalities)	Education services (80)
Medical and care supplies	Hoitotarvikkeet	Medical supplies	Furniture; other manufactured goods n.e.c. (36)
	Lääkkeet	Medicines	Chemicals nec
Travel and transportation	Autot ja muut maakuljetusvälineet	Cars and other land transport vehicles	Motor vehicles, trailers and semi-trailers (34)
	Kilometrikorvaukset	Mileage allowances	Calculated based on travelled kilometers as data was provided in the form of paid kilometre allowances.
	Kuljetusvälineiden korjaus- ja kunnossapitopalvelut	Repair and maintenance of transport vehicles	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries
	Kuljetusvälineiden vuokrat	Rental of transport vehicles	Renting services of machinery and equipment without operator and of personal and household goods (71)
	Laivat ja muut vesikuljetusvälineet	Ships and other water transport vehicles	Other transport equipment (35)
	Lentokoneet ja muut ilmakuljetusvälineet	Aircraft and other air transport vehicles	Other transport equipment (35)
	Matkustus- ja kuljetuspalvelut	Travel and transport services	Other land transportation services
	Matkustuspalvelut	Travel services	Other land transportation services
	Poltto- ja voiteluaineet	Fuels and lubricants	Gas/Diesel Oil
Other services	Muut palvelut	Other services	Other services (93)
Other expenses	Jäsenmaksut kotimaahan	Membership fees (domestic)	Membership organisation services n.e.c. (91)

	Jäsenmaksut ulkomaille	Membership fees (foreign)	Membership organisation services n.e.c. (91)
	Muut kulut	Other expenses	Other business services (74)
	Muut pakolliset maksut	Other mandatory fees	Other business services (74)
	Muut toimintakulut	Other operating expenses	Other business services (74)
	Muut yhteistoimintaosuudet	Other cooperation contributions	Other business services (74)
	Ympäristönhoito- ja ylläpitopalvelut	Environmental management and maintenance services	Other business services (74)
Other rents	Muut vuokrat	Other rents	*Rent* (See Table S2)
Printing and marketing services	Ilmoitus-, mainos- ja markkinointipalvelut	Advertising and marketing services	Other business services (74)
	Painatukset, ilmoitukset, markkinointi	Printing, notices, and marketing	Printed matter and recorded media (22)
	Painatuspalvelut	Printing services	Printed matter and recorded media (22)
Postal and courier services	Posti	Postal services	Post and telecommunication services (64)
	Posti- ja kuriiripalvelut	Postal and courier services	Post and telecommunication services (64)
Finance and banking services	Pankkipalvelut	Banking services	Financial intermediation services, except insurance and pension funding services (65)
	Rahoitus- ja pankkipalvelut	Financial and banking services	Financial intermediation services, except insurance and pension funding services (65)
Utilities	Asuntojen vuokrat	Housing rentals	*Rent* (See Table S2)
	Lämmitys	Heating	*Heating (municipalities and joint municipal authorities)* (See Table S2)
	Lämmitys, sähkö ja vesi	Heating, electricity, and water	Account expenditure of the state divided into heating, electricity, and water based on detailed information on the shares of those categories in the aggregated account. For each expenditure respective *Heating (State), Elecricity (State),* and Collected and purified water, distribution services of water (41) impact factors were used (See Table S2)
	Muiden rakennusten vuokrat	Rent of other buildings	*Rent* (See Table S2)
	Rakennusten ja huoneistojen vuokrat	Rent of buildings and premises	*Rent* (See Table S2)
	Sähkö ja kaasu	Electricity and gas	*Electricity (Municipalities and joint municipal authorities)* (See Table S2)

	Vesi	Water	Collected and purified water, distribution services of water (41)
Construction and maintenance services	Asuinrakennusten korjaus- ja kunnossapitopalvelut	Repair and maintenance of residential buildings	*Building work and material* (See Table S2)
	Asuinrakennusten rakentamispalvelut	Construction of residential buildings	*Building work and material* (See Table S2)
	Keskeneräiset muut rakennukset	Other buildings under construction	*Building work and material* (See Table S2)
	Keskeneräiset rakenteet	Structures under construction	*Building material* (See Table S2)
	Maa- ja vesirakenteiden korjaus- ja kunnossapitopalvelut	Repair and maintenance of land and water structures	*Building work and material* (See Table S2)
	Maa- ja vesirakenteiden rakentamispalvelut	Construction of land and water structures	*Building work and material* (See Table S2)
	Muiden rakennusten korjaus- ja kunnossapitopalvelut	Repair and maintenance of other buildings	*Building work and material* (See Table S2)
	Muiden rakennusten rakentamispalvelut	Construction of other buildings	*Building work and material* (See Table S2)
	Muut ennakkomaksut	Other advance payments	*Building work and material* (See Table S2)
	Muut rakentamispalvelut	Other construction services	*Building work and material* (See Table S2)
	Muut rakenteet	Other structures	*Building material* (See Table S2)
	Rakennelmat	Constructions (built structures)	*Structures* (See Table S2)
	Rakennusmateriaali	Building materials	*Building material* (See Table S2)
	Rakennusten ja alueiden rakentamis- ja kunnossapitopalvelut	Construction and maintenance of buildings and areas	*Building work and material* (See Table S2)
	Rautatiepohjat, Väylävirasto	Railway foundations (Finnish Transport Infrastructure Agency)	Stone
	Rautatierakenteet	Railway structures	*Building material* (See Table S2)
	Tiepohjat, Väylävirasto	Road bases (Finnish Transport Infrastructure Agency)	*Asphalt* (See Table S2)
Accommodation and catering services	Elintarvikkeet	Foodstuffs	Food products nec
	Elintarvikkeet, juomat ja tupakka	Food, beverages, and tobacco	Food products nec
	Majoitus- ja ravitsemispalvelut	Accommodation and catering services	Hotel and restaurant services (55)
	Ravitsemispalvelut	Catering services	Hotel and restaurant services (55)
Miscellanous substances and supplies	Asuinhuoneisto- ja toimistokalusteet	Residential and office furniture	Furniture; other manufactured goods n.e.c. (36)
	Muu materiaali	Other materials	*Structures* (See Table S2)

	Muut aineelliset hyödykkeet	Other tangible assets	Furniture; other manufactured goods n.e.c. (36)
	Muut aineet, tarvikkeet ja tavarat	Other materials, supplies, and goods	Furniture; other manufactured goods n.e.c. (36)
	Muut kalusteet	Other furniture	Furniture; other manufactured goods n.e.c. (36)
	Muut keskeneräiset aineelliset käyttöomaisuushankinnat	Tangible fixed assets under construction	*Building work and material* (See Table S2)
	Taide-esineet	Art objects	Furniture; other manufactured goods n.e.c. (36)
Cleaning services	Pesulapalvelut	Laundry services	*Cleaning services* (See Table S2)
	Puhdistusaineet ja -tarvikkeet	Cleaning agents and supplies	Chemicals nec
	Puhtaanapito- ja pesulapalvelut	Cleaning and laundry services	*Cleaning services* (See Table S2)
	Siivouspalvelut	Cleaning services	*Cleaning services* (See Table S2)
Health and social services	Muut terveyspalvelut	Other health services	Health and social work services (85)
	Sosiaali- ja terveyspalvelut	Social and healthcare services	Health and social work services (85)
	Työterveyspalvelut	Occupational health services	Health and social work services (85)
	Asiakaspalvelut (Kuntien julkisten toimijoiden ulkopuolelta ostetuista palveluista 92 % ja kuntayhtymien vastaavat hankinnan kokonaisuudessaan)	Client services (92% of all client services purchased by municipalities & all client services for joint municipal authorities)	Health and social work services (85)
Office and school supplies	Kirjallisuus	Literature	Printed matter and recorded media (22)
	Kirjat, lehdet ja muut painotuotteet	Books, periodicals, and other printed materials	Printed matter and recorded media (22)
	Toimisto- ja koulutarvikkeet	Office and school supplies	Paper and paper products
	Toimistotarvikkeet	Office supplies	Paper and paper products
Research and expert services	Asiantuntija- ja tutkimuspalvelut	Expert and research services	Research and development services (73)
	Asiantuntijapalvelut	Expert services	Research and development services (73)
	Muut toimistopalvelut	Other office services	Other business services (74)
	Muut tutkimus- ja kehittämismenot	Other research and development expenses	Research and development services (73)
	Toimistopalvelut	Office services	Computer and related services (72)
Clothing	Vaatteisto	Clothing	Wearing apparel; furs (18)
	Vaatteisto, virka-, työ- ja suojapuvut	Uniforms, workwear, and protective clothing	Wearing apparel; furs (18)

Insurance services	Liikennevahinkomaksut	Traffic damage charges	Insurance and pension funding services, except compulsory social security services (66)
	Muut vahinkovakuutusmaksut	Other non-life insurance premiums	Insurance and pension funding services, except compulsory social security services (66)
	Vakuutukset	Insurance	Insurance and pension funding services, except compulsory social security services (66)
Security services	Vartiointi- ja turvallisuuspalvelut	Security services	Public administration and defence services; compulsory social security services (75)

Table S2. Merged EXIOBASE product categories for product categories to procurement accounts.	
Merged category	**EXIOBASE product categories with weightings used for weighted average calculation of impact factor**
Building material	1/3 Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20) 1/3 Bricks, tiles and construction products, in baked clay 1/3 Basic iron and steel and of ferro-alloys and first products thereof
Building work and material	1/2 **Building material***, 1/2 Construction work (45)
Structures	1/4 Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20), 1/4 Rubber and plastic products (25), 1/4 Glass and glass products, 1/4 Basic iron and steel and of ferro-alloys and first products thereof
Asphalt	1/4 Stone, 1/4 Sand and clay, 2/4 Bitumen
Rent	1/2 Other services, 1/2 **Heating*** (calculated based on EXIOBASE product categories for different electricity types according to heating consumption distribution for years 2021 and 2022 in Finland)
Cleaning services	3/4 Other services, 1/4 Chemicals nec
Electricity (State)	According to consumption distribution in 2021/2022: 32.9% / 11.9% Electricity by hydro 66% / 49.3% Electricity by biomass and waste 1.2% / 38.8% Electricity by wind
Electricity (Municipalities & Joint municipal authorities)	According to consumption distribution in 2021/2022*: 26% / 30% Electricity by nuclear 18% / 16% Electricity by hydro 20% / 15% Net import = Electricity by petroleum and other oil derivatives 14% / 14% Electricity by biomass and waste 9% /14% Electricity by wind + Others with less than 5% shares
Heating (State)	According to consumption distribution statistics in 2022 received from the Senate Properties Finland in 2023: 77% district heating (calculated based on statistics of the types of production methods for each year) 20% Electricity by biomass and waste 3% Electricity by petroleum and other oil derivatives
Heating (Municipalities & Joint municipal authorities)	According to consumption distribution statistics for the year 2021 retrieved from the Municipalities' and regions' usage-based greenhouse gas emissions data provided by the Finnish Environment Institute**: 39% Electricity by petroleum and other oil derivatives 30% district heating (calculated based on statistics of the types of production methods for 2021) 16% Electricity by biomass and waste (mainly wood burning) 12% **Electricity** (calculated based on electricity impact factor calculated for Municipalities & Joint municipal authorities above)

	*Statistics Finland (2023). 12sv -- Supplies and total consumption of electricity, 1960-2024. Available from: https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/StatFin__ehk/statfin_ehk_pxt_12sv.px/ ** Finnish Environment Institute (2023). Municipalities' and regions' usage-based greenhouse gas emissions. Available from: https://paastot.hiilineutraalisuomi.fi/#en