Supplementary information

Environmental damages of the top ten percent consumers exceed global climate and biodiversity funding gaps

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Supplementary methods

All data and calculations can be found in the Supplementary Data Excel spreadsheet file at https://doi.org/10.5281/zenodo.19348642. Here we provide more detail on methods. Tian et al.[1] calculate per capita consumption-based carbon (CO_2) phosphorus (P), nitrogen (N), freshwater use, (terrestrial) biodiversity loss (Mean Species Abundance loss, MSA loss) and land-use (Human Appropriation of Net Primary Productivity, HANPP) footprints per expenditure decile (based on household survey data) for 168 countries and the global total based on GTAP[1]. We take the footprints for the top 10% globally and several countries as illustrations - Brazil, China, Egypt, Germany, India, and USA as the biggest economies in the world and/or of their continent - to calculate the environmental damage costs. Note that the footprints only consider consumption and attribute all emissions to consumers (government and gross fixed capital formation emissions are proportionally attributed to households), so assets and ownership are not taken into account. For the top 10% about half of emissions originate from investments[2], so the top 10% footprints and damage costs would increase when taking this into account.

To monetise the footprints, we use the Environmental Prices Handbook 2024[3] which provides estimates of prices for various of the planetary boundaries (see section Environmental Prices). They represent the social damage of environmental pollution per unit of pollutant/water meaning the loss of economic welfare for an additional unit of the pollutant/water released into or extracted from the environment. The handbook has prices for CO_2, N, P, and water consumption, with lower, central, and upper estimates. For biodiversity, the handbook has prices for Potentially Disappeared Fraction (PDF) rather than MSA loss. To our knowledge, there is no direct price for MSA loss in the literature. Therefore, we convert the PDF prices into MSA loss prices using a recent study that finds a consistent positive relationship between PDF and MSA loss[4] (see section Environmental Prices). To our knowledge there is no price for HANPP in the literature, so this is not included in our estimates.

We first calculate the environmental costs per planetary boundary. Each planetary boundary (CO_2, N, P, water, MSA loss) has its own worksheet in the accompanying Supplementary Data Excel spreadsheet file (sheets 2-6). In each sheet, Table X.1 contains the per capita environmental footprint of the top 10% consumers of the world, Brazil, China, Egypt, Germany, India, and the USA (the biggest economies in the world and/or of their continent) given by Tian et al.[1]. These consumption-based footprints are based on household survey data. Note that Tian et al.[1] use survey data to calculate the share of various consumption categories as a proportion of total consumption and then use that to split the macro-economic data on household demand in GTAP, to circumvent the limitation that surveys notoriously underrepresent the top spenders.

We then calculate the environmental costs of that footprint using various environmental prices. Each sheet's Table X.2 contains the lower, central and upper environmental price from the Environmental Prices Handbook[3] in $€_{2021}$, which we convert to $€_{2017}$ per country (see the next section). In Table X.3, we then multiply these 2017 prices with the per capita footprint to arrive at the lower, central and upper damage costs for that specific planetary boundary. We take the prices directly from the handbook, except for MSA loss for which we must convert the available price, see the section on MSA loss.

In sheet 7. *Total bill*, we sum the individual environmental per capita costs for total per capita costs. We multiply the per capita bill by 10% of the population as per the World Bank (indicator code SP.POP.TOTL[5]) (table 7.5) for the total bill of the top 10%. We show the results both in euro and dollar, using the average exchange rate in 2017 given in sheet 8. *Currency conversions* (Table 8.3). We also calculate the environmental bill as a proportion of pre-tax income and wealth. For this, we use the top 10% average national income and top 10% average net personal wealth in 2017 from the World

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[1] The authors provided us with their calculated footprints (the data displayed in their Supplementary Figures 1-6), for which we are grateful.

Inequality Database[6]. This is in 2023 currency, which we convert to 2017 using deflators as described below. Note that the group of global top 10% spenders is not necessarily identical to the top 10% income earners or top 10% wealth owners, so the percentages are not exact but illustrative.

In sheet 8, *Currency conversions*, we list the GDP series used to convert $€_{2021}$ prices to $\$_{2017}$ per country. We use the adjustment formula from the value transfer tool Benefito[8] associated with the previous Environmental Prices Handbook:

$$1) \quad Value_X = Value_E \left(\frac{Y_X}{Y_E}\right)^{\beta}$$

with $Value_X$: adjusted damage value for the country X, $Value_E$: average damage value for the EU, Y_X: income level in country X expressed as GDP per capita at PPP, Y_E: average income in the EU expressed as GDP at PPP per capita, and β: income elasticity (set at 0.85 based on literature).

Table 8.1 contains GDP per capita in PPP from the World Bank (indicator code NY.GDP.PCAP.PP.KD[7]) for each country in 2021 (the year of the environmental prices). We calculate the ratio of the respective country's/world's GDP per capita to the EU (Y_X / Y_E) to the power of the income elasticity 0.85 (β). In the respective sheet for each planetary boundary, we multiply this with the environmental price ($Value_E$), thereby scaling the environmental prices to each country/the world ($Value_X$).

Table 8.2 contains a GDP deflator series from the World Bank (indicator code NY.GDP.DEFL.KD.ZG[9]). This provides annual inflation percentages, which we convert using 2017 as a base year from which we calculate specific deflators to 2017 (the year of the footprints). In each planetary boundary sheet, we multiply these with the environmental price, to deflate $€_{2021}$ to $€_{2017}$ prices. We also use these deflators to deflate the climate and biodiversity financing targets that we use as reference values for the total environmental bill.

Finally, Table 8.3 has the average exchange rate in 2017 between euro and dollar to convert between the currencies[10].

Environmental prices

The Environmental Prices Handbook[3] calculates prices using a model that traces monetary valuations of ultimate impacts (endpoints) such as on human health and ecosystems, back through midpoints, which include climate change, eutrophication and water consumption, to specific emissions/substances like CO_2, N and P to ensure comparability between prices. Prices based on willingness-to-pay valuation methods, except for the carbon price which is based on abatement costs. See Supplementary Table 1 below for an overview of the midpoints, endpoints and type of valuations used for each planetary boundary. Please refer to the respective chapters of the handbook for more details and the references.

CO_2 prices

The handbook uses abatement costs instead of the social cost of carbon (SCC) as they find that SCC estimates in the literature have very large uncertainty, omit certain climate impacts and are highly sensitive to both the damage functions used and the discount rate. The handbook indicates that they follow Stern & Stiglitz[11] who recommend using abatement costs rather than the SCC, which is also used by OECD[12]. Most recent SCC studies have optimal reduction pathways that reach zero emissions by 2050, which aligns with the IPCC scenario used for the central estimate and European targets, so the targets used for setting the abatement costs correspond with optimal reduction pathways. The handbook therefore uses abatement costs as proxy for damage costs.

Different from the other substances, we keep the CO_2 price constant rather than scaling based on GDP per capita. We do this because climate damages are global and irrespective of where emissions take place, rather than local as with the other impacts. Having one uniform carbon price reflects this. On the other hand, one can argue that prices should be differentiated per country because of the principle of common but differentiated responsibility. The abatement costs are associated with becoming net zero in 2050, which is an EU goal and IPCC scenario. However, for instance Global South countries do not need to have this goal. In this view, each country has its own price according to its own goal. The value transfer method used for the other substances can be a proxy for this. We have also calculated the bill with differentiated prices, see the Supplementary Data sheet 2. *CO2* (Tables 2.4 and 2.5) and 7. *Total bill* (Table 7.6). As expected, the CO_2 bill for Brazil, China, Egypt, India and the world becomes lower (56-82% lower) and for Germany and USA higher (17-29% higher). The total environmental bill (central estimates) becomes 23-53% lower for Brazil, China, Egypt, India and the world, and 4-7% higher for

Germany and USA. This does not alter the main conclusions of the paper, with the world and USA estimates still surpassing biodiversity and climate financing targets, and biodiversity loss and climate change still the biggest contributors to the bill.

Supplementary Table 1: The Environmental Prices Handbook has lower, central and upper estimations for PDF (which we use for MSA loss, see section MSA loss price), CO_2, P, N and water. This table shows what midpoints and endpoints they connect these to and what valuations they base their prices on. CO_2 is about abatement costs, the rest about willingness to pay. Please refer to the respective chapters of the handbook for more details and references.

	PDF (MSA loss)	CO_2	P	N	Water
Midpoint		Climate change	Freshwater eutrophication	Marine eutrophication	
Endpoint	Ecosystems	Human health and ecosystems (but not valued explicitly)	Ecosystems	Ecosystems	Human health, ecosystems
Lower estimation	Regression analysis formula of willingness-to-pay studies on the value of land use change and biodiversity (Kuik et al., 2008), updated with prices of Costanza et al. (2014)	CE Delft (2022) study with cheap carbon capture and storage and direct air capture and storage	Dutch levy level	Housing prices study Norway translated to European average	Valuation of: decline in Net Primary Productivity due to water shortage; loss of fish species due to reduced river discharge (individualistic worldview)
Central estimation	Regression analysis formula of willingness-to-pay studies on the value of land use change and biodiversity (Kuik et al., 2008), updated with prices of Costanza et al. (2014)	IPCC (2018) central values based on 1.5-degree scenario with limited overshoot	Valuation of biodiversity loss	Dutch levy level	Valuation of: decline in Net Primary Productivity due to water shortage; loss of fish species due to reduced river discharge (hierarchical worldview)
Upper estimation	Regression analysis formula of willingness-to-pay studies on the value of land use change and biodiversity (Kuik et al., 2008), updated with prices of Costanza et al. (2014)	Upper price of France Stratégie (2019) net zero 2050 scenario	Housing prices study (in relation to water quality) Norway translated to European average	Two studies by Söderqvist & Hasselström (2008) and Gren et al. (2008)	Valuation of: malnutrition due to water shortage; decline in Net Primary Productivity due to water shortage; loss of fish species due to reduced river discharge (hierarchical worldview)

MSA loss prices

Mean Species Abundance (MSA) loss is the difference in species abundance of an ecosystem in its current versus its pristine state multiplied by the size of the ecosystem[13]. The available footprint is in an aggregate form: global MSA-loss hectares. The Environmental Prices Handbook[3] does not have prices for MSA loss, but does for another biodiversity indicator, Potentially Disappeared Fraction (PDF). Both are measured on a scale of 0 to 1, where 1 means the area is like its pristine state and 0 that all species have disappeared.

A recent study[4] investigates how MSA loss and PDF are related based on both simulated and empirical data. They find a significant ($p<0.001$) positive relationship between the two. The relationship is not linear and varies along the value of PDF (0-1). From their supplementary data file (of the version with at least 10 species sampled, n=13,968) we use the central predicted MSA loss value and the lower and upper bound per 0.01 step in PDF value (see Supplementary Data sheet 6, Table 6.a). For each point on the curve, we divide the lower, central and upper MSA loss by PDF to determine the ratios between the two (Supplementary Data table 6.b). We take the average ratios over the whole curve, excluding the data points at 0-0.05 PDF since the authors indicate the variance in MSA loss is high at such low PDF values. The handbook has prices in €/PDF.m^2.yr. We convert PDF to MSA loss using the calculated ratios and m^2 to hectares, to match the MSA loss.ha.yr footprint (Supplementary Data Table 6.c). The handbook used a 1% annual price increase in the value of biodiversity to arrive at $€_{2021}$. Therefore, we use a 1% annual price decrease to get to $€_{2017}$.

Converting PDF to MSA loss prices comes with limitations. The study relating the two finds that PDF explains about half the variance of MSA loss and MSA loss occurs before local extinctions, concluding that the two indicators are complementary[4]. The relationship between the two shows a slight s-shaped curve, so the ratio between MSA loss and PDF varies along the curve meaning that the level of MSA loss is relevant to the ratio it has with PDF. However, we only have an aggregated MSA loss footprint, so we cannot determine at what level the MSA loss occurs. We use the average ratio of the curve, but use lower, central and upper estimates of MSA loss at each point along the curve, giving a range.

The PDF price is based on European ecosystems and land use. Since the handbook indicates valuation depends among others on type, size and species richness of ecosystems and (human) population density, which vary greatly around the world, only using GDP per capita ratios to transfer the prices from EU27 to other regions is a rough estimation and it would be better to establish valuations per region. For a full pricing of biodiversity, the MSA loss footprint also needs to be disaggregated.

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