Supplemental materials

of the article

“Reducing plastic production: Economic loss or environmental gain?”

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S1. Methods used to design graphs from Figures 1, 2, 3 in the article and Figure S4

S1.1. Figure 1 (displayed in the article).

Global cumulative discard of plastic waste inadequately managed over 1950-2060 in million metric tons (MMT) – BAU scenario

The curves in Figure 1 (in the article) are obtained summing global annual discard of plastic waste inadequately managed (displayed in Figure S1 here below) over the period 1950-2060 under business-as-usual scenarios simulated by Lebreton and Andrady (2019), Yan et al. (2022), Cordier et al. (2021), and Lau et al. (2020).

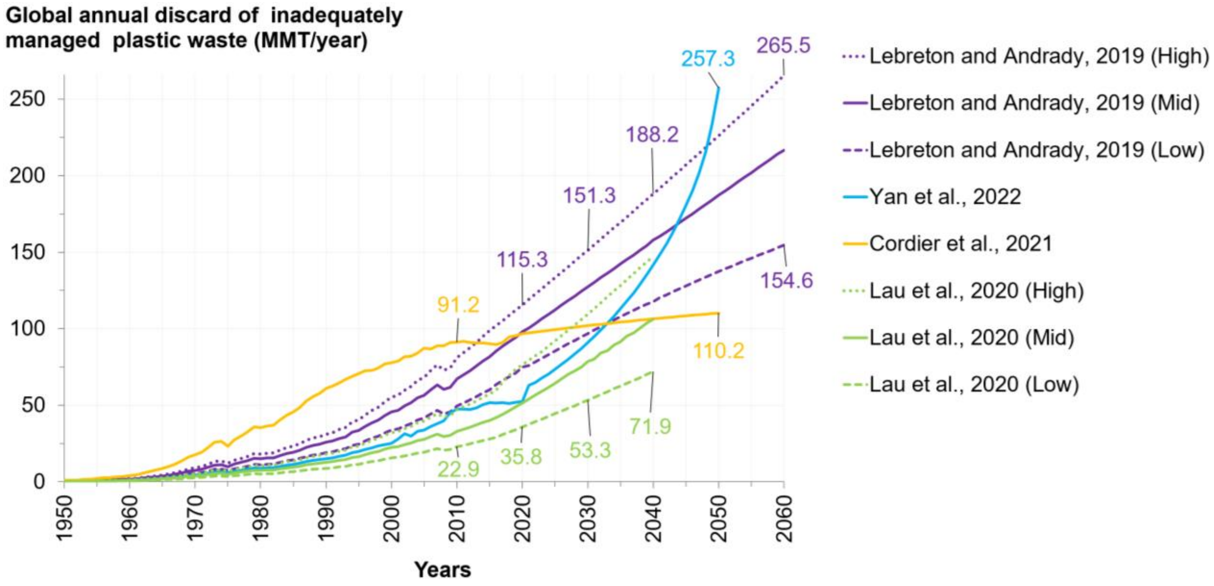

Figure S1. Global annual discard of plastic waste inadequately managed likely to reach the ecosystems (terrestrial and aquatic) – or having reached already – in million metric tons per year (MMT/year). Note: numbers displayed along the curves show the lowest and highest estimations across all models. The curves are based on data found in Lebreton and Andrady (2019) over the simulation period 2015-2060, Yan et al. (2022) over 1996-2050, Cordier et al. (2021) over 1990-2050, and Lau et al. (2020) over 2016-2040. All curves simulate a business-as-usual scenario. For the computation of the curve before the simulation period, we made an extrapolation assuming that annual discard of plastic waste inadequately managed followed the annual growth rate of global plastic production (based on data from Geyer et al. (2017)’s supplementary materials).

S1.2. Figure 2 (displayed in the article).

Global plastic debris accumulated over time in terrestrial (upper graph) and aquatic (lower graph) ecosystems over 1950-2060 – BAU scenario.

The curves in Figure 2 (in the article) are obtained summing over time annual emissions of plastic waste into the ecosystems (Figure S2 here below) provided by Lau et al. (2020), Borrelle et al. (2020), and OECD (2022). The OECD (2022) also provides accumulated values in 2019 and 2060. We used them to cross-check our computation method and make sure we did not make any mistake.

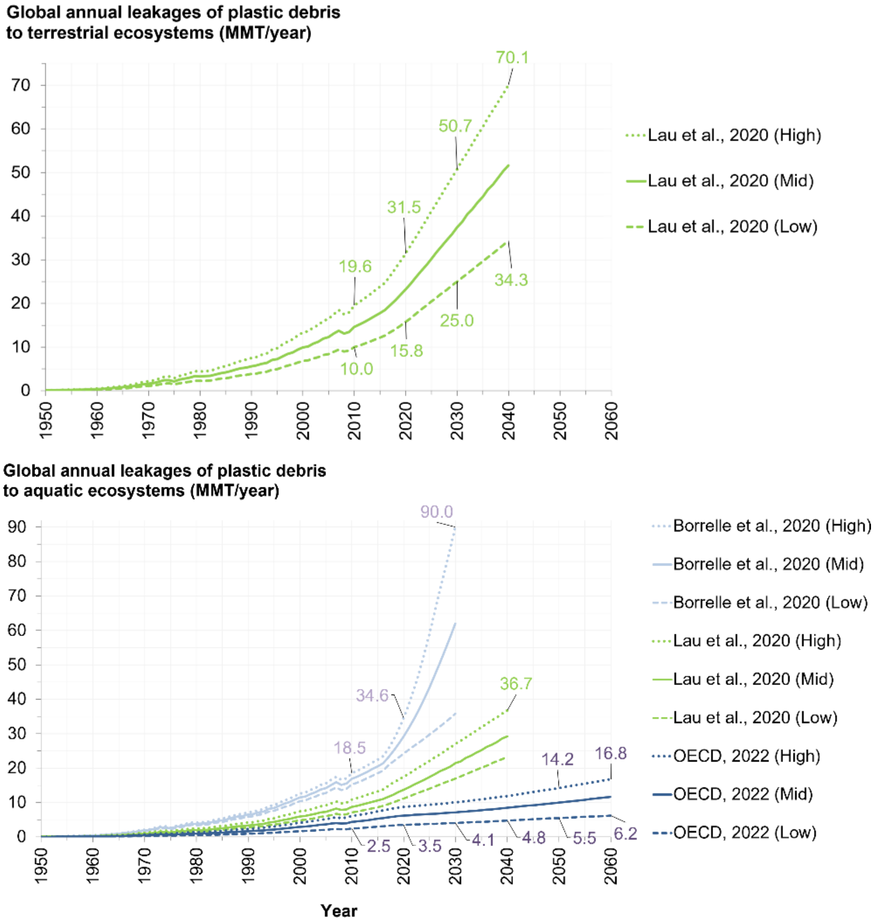

Figure S2. Global annual leakages of plastic debris to terrestrial (upper graph) and aquatic ecosystems (lower graph). Note: aquatic ecosystems include lakes, rivers and oceans. The curves are based on data found in Lau et al. (2020) over the simulation period 2016-2040, Borrelle et al. (2020) over 2016-2030, and OECD (2022, based on Lebreton and Andrady, 2019) over 2019-2060. All curves on the graph simulate a Business-as-usual scenario. For the computation of the curves before the simulation period, we made the same extrapolation as explained below Figure S1. Regarding data from Lau et al. (2020), values over the period 2016-1940 where not available for each year in the article. We requested them to the authors and they were sent by email in an Excel file the 5th of January 2023 by J.E. Palardy (one of the co-authors and project director at The Pew Charitable Trusts)". Note that they are also publicly available in Zenodo and can be downloaded from this link: https://zenodo.org/record/3929470)".

In Figure 2 and S2, our calculations omit the share of floating plastics that sink on riverbeds and lakebeds after several years or decades spent in freshwater ecosystems (van Emmerik et al., 2022). Therefore, it probably leads us to overestimate floating plastics in rivers and underestimate sinking plastic on river and lakebeds. However, improving the accuracy of our estimations will require further research since fragmentation, degradation and transport of plastics through different river compartments (e.g., river surface, riverbeds, river floodplains, etc.) remains largely unknown (Ford et al., 2022). This probably led us to overestimating costs of plastic pollution reduction strategies for floating plastics, that is, *River cleanup (floating plastics)* in Table 1.

S1.3. Figure 3 (displayed in the article)

Global plastic debris accumulated over time in aquatic ecosystems disaggregated into oceans (upper graph), plastics floating in rivers (middle graph), and plastics sinking on riverbeds and lakebeds (lower graph) – BAU scenario.

The curves in Figure 3 (in the article) are obtained summing over time estimations of annual emissions of plastic waste (Figure S3, here below) provided by Lebreton et al. (2019). The other models directly provided accumulated values (Jambeck et al., 2015; Cordier and Uehara, 2019; and OECD, 2022). For the computation of accumulated plastic floating in rivers (Figure 3 middle graph), we subtracted from annual leakages of plastics floating into rivers (Figure S3 middle graph based on data provided in OECD, 2022, p.124) the annual amounts transported via rivers to the oceans (data provided in OECD, 2022, p. 126). The subtraction provided annual results that were summed year by ear over 1950-2060 to obtain accumulated value over time. For the computation of accumulated plastics sinking on riverbeds and lakebeds, we subtracted from accumulated leakages of plastics into freshwater ecosystems (computed based on data on plastic leakages floating into rivers and sinking on riverbeds and lakebeds provided in OECD, 2022, p.125) the accumulated plastic floating in rivers (estimated in Figure 3 middle graph). The subtraction provided accumulated results year by year over the period 1950-2060. Such a calculation presents, however, one drawback: it omits the share of floating plastics that sink on riverbeds and lakebeds after several decades spent in freshwater ecosystems. Therefore, it probably leads to overestimate floating plastics in rivers and underestimate sinking plastic on river and lakebeds. For the computation of plastics accumulated into oceans (Figure 3 upper graph) based on OECD (2022), accumulated data were provided for the year 2019 and 2060 in OECD (2022, p. 125). We estimated the annual emissions in between assuming a linear growth over 2019-2060. In all graphs of Figure 3, low and high estimations around the middle estimation from OECD (2022) are extrapolated from low and high margins provided in OECD (2022, p. 120) for emissions into all aquatic ecosystems (lakes, rivers and oceans), which are based on Lebreton and Andrady (2019), Lebreton et al. (2019) and Cottom et al. (2022).

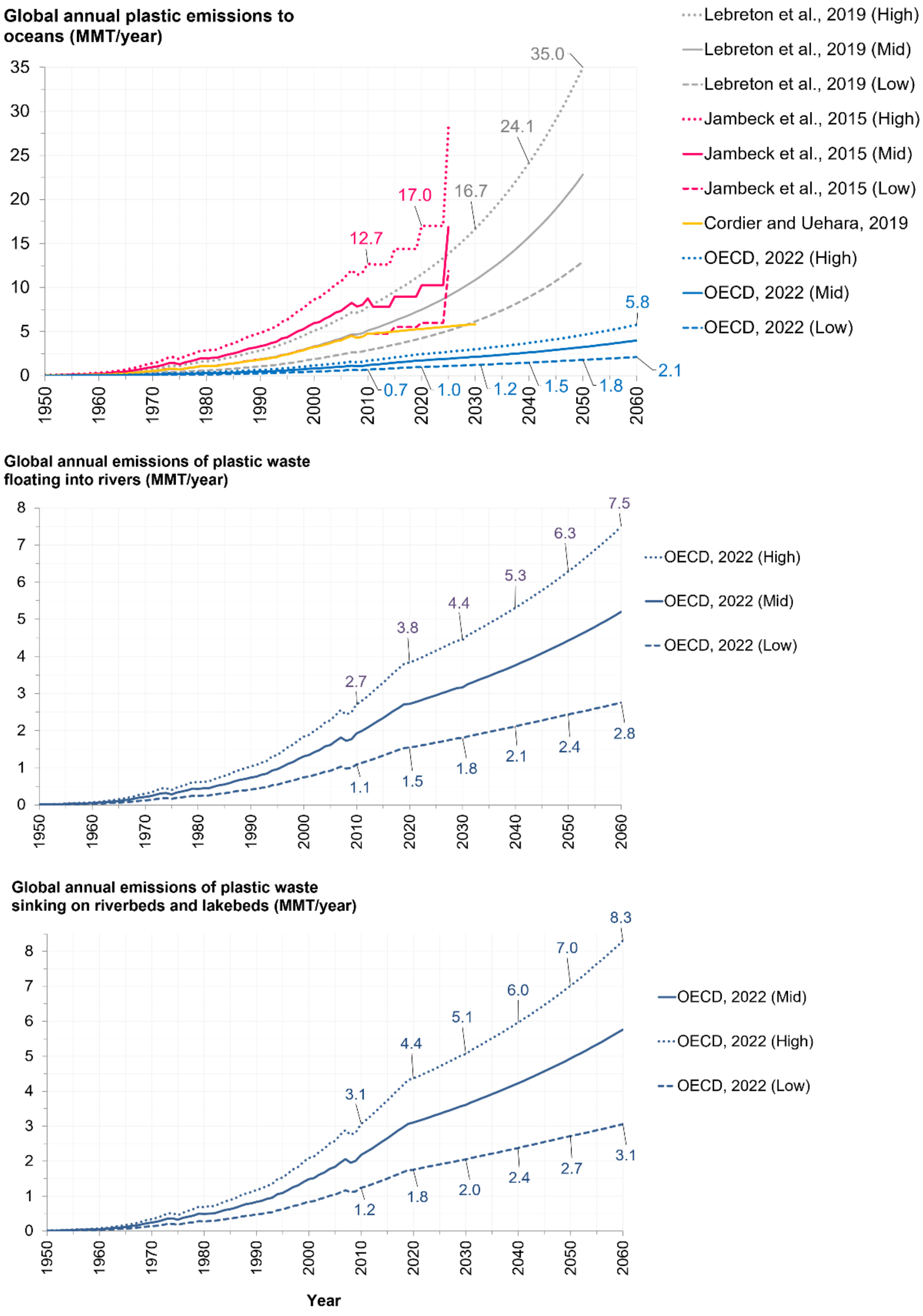

Figure S3. Global annual leakages of plastic waste to oceans (upper graph), rivers where plastics are floating (middle graph) and riverbeds and lakebeds where plastics are sinking (lower graph).

Note: The curves are based on data found in Lebreton et al. (2019) over the simulation period 1950-2050, Jambeck et al. (2015) over 2010-2025, Cordier and Uehara (2019) over 2010-2030, and OECD (2022) over 2019-2060. Values over the period 1950-2050 where not available in Lebreton et al. (2019). We requested them to the authors and they were sent by email in an Excel file the 10th of January 2023 by Laurent Lebreton. All curves on the graphs simulate a Business-as-usual scenario. For the computation of the curves before the simulation period, we made the same extrapolation as explained below Figure S1. In OECD (2022, p. 126), annual emissions of plastic waste to the ocean (upper graph) were provided for the year 2019 and 2060 only. We estimated the annual emissions in between assuming a linear growth over 2019-2060. The same for the middle and lower graph: annual emissions were provided in OECD (2022, p. 124) for the years 2019, 2030 and 2060 only. We used an exponential regression to estimate the values in between. The mathematical functions (linear and exponential) used for the statistical regressions were selected because they best fitted the observed values. In all graphs of Figure S3, low and high estimations around the middle estimation from OECD (2022) are extrapolated from low and high margins provided in OECD (2022, p. 120) for emissions into all aquatic ecosystems (lakes, rivers and oceans), which are based on Lebreton and Andrady (2019), Lebreton et al. (2019) and Cottom et al. (2022).

S1.4. Figure S.4 to compute costs of damages to marine cosystems in the "Action scenario"

The impact of the "Action scenario" towards zero plastic pollution by 2040 is displayed here below in Figure S.4 for the marine ecosystem. We used this figure to calculate the cost of damages caused to marine ecosystems by plastic pollutants in the "Action scenario" on a year-by-year basis as explained in Section 3 of the article.

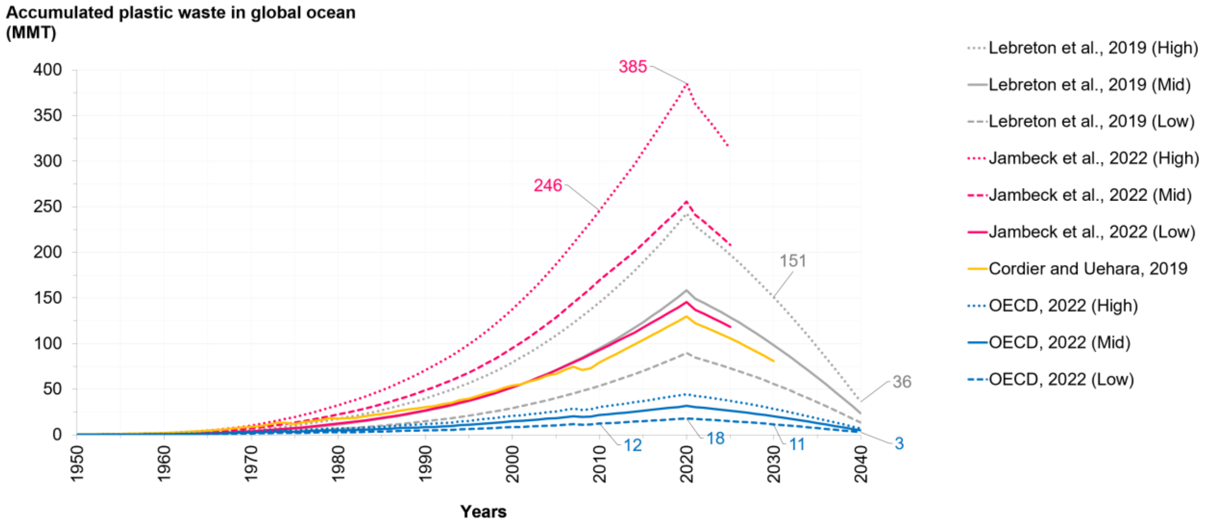

Figure S4. Global plastic debris accumulated over time into the oceans – "Action scenario" towards zero plastic pollutants. Note: The curves are based on data found in Lebreton et al. (2019), Jambeck et al. (2015), Cordier and Uehara (2019), and OECD (2022), which we transformed to take into account the reduction of plastic emissions into aquatic ecosystems as estimated in the *System Change Scenario* designed by Lau et al. (2020) and the ocean clean-up operations as estimated in our "Action scenario" (Section 2 of the article).

S2. World input-output table and value added of plastic industry

Our own calculation is based on the world input-output table 2014 (Timmer et al., 2015) and estimates the global value added annually produced by the plastic and rubber sector to US$ 667 billion in 2021 (this estimation is in US$ at prices of the year 2021). This estimation is based on the value added produced in 2014 by the plastic and rubber sector provided in the World IO table (Timmer et al., 2015): US$ 453 billion in 2014 (at prices of the year 2014). We estimated the 2021 value added assuming that the 2014 value would follow the average annual growth rate of the global plastic production calculated over 2006-2015 (based on data from Geyer et al. (2017)'s supplementary materials). Then, we updated the result for inflation to 2021 prices based on inflation rates over 2014-2021 provided in https://www.usinflationcalculator.com/, which gave a value added of US$ 667 billion (at 2021 prices). The UNEP (2023, p. 5) estimates this amount to US$ 713.9 billion in 2021, which is close to our own estimation.

S3. Input-output equations and stopping plastic production scenario

Leontief's input-output equations (Leontief, 1936 and 1970; Miller and Blair, 2009, p. 21; Uehara et al., 2018, p. 4) provide further economic details reflecting inter-industrial sales of intermediate inputs between economic sectors (intermediate consumers), in addition to sales to final consumers. We simulated direct and indirect costs of stopping plastic production in the world input-output table (Timmer et al., 2015), which is an inter-country table showing domestic sales as well as foreign sales (that is, imports and exports of commodities between countries). Before running the input-output equations described below, we aggregated the table summing the rows and the columns of each country in order to have a global table made of one "big country" – that is, the world – and 56 economic sectors. (This aggregated World Input-Output table is named, hereinafter, WIO table).

The WIO table (synthetized in Table S1 here below) comprises two matrices: **X**, the intermediate sales matrix, and **F**, the final demand matrix. It also comprises four vectors: **x**, **x**′, **t** and **v**, representing total industry output per economic sector, its transpose, taxes less subsidies on products paid by each economic sector, and value added payments per economic sector.

Table S1. The WIO table: industry-by-industry input-output table (adapted from Miller and Blair, 2009)

	Buying Sector $(j = 1, \dots, n; n = 56)$	Final Demand $(k = 1, \dots, b; b = 5)$	Total Output
Selling Sector $(i = 1, \dots, n; n = 56)$	$\mathbf{X}$ x_{ij}	$\mathbf{F}$ f_{ik}	$\mathbf{x}$ x_i
Taxes	$\mathbf{t}$ t_j		
Value Added	$\mathbf{v}$ v_j		
Total Inputs	$\mathbf{x}'$ x_j		

We can derive the following input-output equation (Eq. 1) from the industry-by-industry IO table (Table S1), which calculates sectoral output (**x**) based on static technical coefficients:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf} \quad \textbf{(1)}$$

I is an identity matrix (in which all components are zero except on the diagonal where all components are 1); **f** is the final demand vector (**f** = **Fi**, where i is a column vector of 1's known as a summation vector), which includes 5 final demand categories (households, non-profit organizations, government, investors (gross fixed capital formation), and change in inventories and valuables); $(\mathbf{I} - \mathbf{A})^{-1}$ is known as the Leontief inverse (or total requirement matrix) and is renamed **L** for conciseness; and **A** is the matrix of technical (or direct input) coefficients made of elements $a_{ij} = x_{ij}/x_{\mathrm{j}} = x_{ij}/x_{\mathrm{i}}$ (Miller and Blair, 2009). Eq. (1) calculates the direct and indirect impacts of changes in the final demand (**F**) on the industry outputs (**x**). Full mathematical developments and explanations are provided in Miller and Blair (2009, p. 21).

The calculation of the economic loss that would occur if plastic production would entirely stop from one day to another is calculated as follows. $GDP_{2021}^{Zero\ plastic}$ is the global GDP in 2021 in an economic system where the plastics industry would have been eliminated. Its calculation is operated in four steps:

- In the first step, we calculate the global GDP as it was observed in 2014, which is the reference year of the WIO (Table S1) as provided by Timmer et al. (2015). The calculation is made by summing in the WIO sectoral value added ($v_j^{observed}$) and taxes less subsidies on products ($t_j^{observed}$) observed in 2014 as follows:

  $$GDP_{2014}^{observed} = \sum_{j=1}^{n=56} v_j^{observed} + t_j^{observed}$$

  (All mathematical symbols are explained in Table S1).

- In the second step we calculate $GDP_{2014}^{Zero\ plastic}$ as follows:
  - First, we set to zero the sales of goods and services from plastic and rubber industries (row i = 13) to intermediate consumers ($x_{13,j}$) and final consumers ($f_{13,k}$) as well as the purchases of goods and services by plastic and rubber industries (column j = 13) to other economic sectors ($x_{i,13}$).
  - Second, we run Eq. (1) with a WIO table where the row of elements $x_{13,j}$ and $f_{13,k} = 0$ and the column of elements $x_{i,13} = 0$ to obtain the total input of each sector j ($x_j^{Zero\ plastic}$) – which equals the total output ($x_i^{Zero\ plastic}$) as in all input-output models – in a virtual global economy where the plastic industry has been removed from the economic system.
  - Third, we calculate $GDP_{2014}^{Zero\ plastic}$with technical coefficients of value added ($v_j^{Zero\ plastic}$) and taxes less subsidies on products ($t_j^{Zero\ plastic}$) as follows: $GDP_{2014}^{Zero\ plastic} = \sum_{j=1}^{n=56} v_j^{Zero\ plastic} + t_j^{Zero\ plastic}$, where $v_j^{Zero\ plastic} = \frac{v_j^{2014}}{x_j^{2014}} x_j^{Zero\ plastic}$ and $t_j^{Zero\ plastic} = \frac{t_j^{2014}}{t_j^{2014}} x_j^{Zero\ plastic}$. The technical coefiicients $\frac{v_j^{2014}}{x_j^{2014}}$ and $\frac{t_j^{2014}}{x_j^{2014}}$ are directly calculated in the WIO table (Table S1) in the reference year 2014; $x_j^{Zero\ plastic}$ is the total input of sector j calculated with the input-output equation (eq. 1) after reducing to zero the sales of plastics to economic sectors (intermediate demand $x_{13,j}$) and to final consumers (final demand ($f_{13,k}$)) in the WIO table (Table S1).

- In the third step we calculate the percentage loss due to the cancelation of the plastic sector $\left(\frac{GDP_{2014}^{observed} - GDP_{2014}^{Zero\ plastic}}{GDP_{2014}^{observed}}\right)$.
- In the fourth step, we convert $GDP_{2014}^{Zero\ plastic}$ into the year 2021 to obtain $GDP_{2021}^{Zero\ plastic}$ by applying the percentage loss to the global GDP observed in 2021 (GDP_{2021}^{BAU}) provided by the World Bank (2023):

  $$GDP_{2021}^{Zero\ plastic} = GDP_{2021}^{BAU}\left(1 - \frac{GDP_{2014}^{observed} - GDP_{2014}^{Zero\ plastic}}{GDP_{2014}^{observed}}\right),$$

where GDP_{2021}^{BAU}= US$ 96527 billion, which is the global GDP (national GDPs observed in 2021 and summed across all countries in the world) provided by the World Bank (2023) at prices of the year 2021 in US$.

S4. Annual emissions in *BAU* and *system change scenarios* from Lau et al. (2020)

Results from Lau et al. (2020) show that annual plastic emissions into the global ecosystem (terrestrial and aquatic together) could be reduced by 75-84% in 2040 with the *"system change scenario"* relative to the annual emission levels that would be achieved if no plastic pollution abatement strategies were undertaken, that is, if the *business-as-usual* scenario (BAU) would occur. In the BAU scenario, annual emissions into aquatic and terrestrial ecosystems in 2040 would reach 23-37 MMT/year and 34-70 MMT/year, respectively. Under the *"system change scenario"*, annual global emissions of plastics in 2040 will reach 3.8-7.0 MMT/year into aquatic ecosystems and 7.8-17.8 MMT/year into terrestrial ecosystems, that is a total annual leakage into ecosystem of 11.6-24.8 MMT/year.

S5. Human health cost

The plastic-related health costs mentioned in the article (Sections 3 and Table 1) are obtained summing the costs listed in the *Endocrine Society*'s table available here: https://www.endocrine.org/-/media/endocrine/files/advocacy/society-letters/2023/may/paris-1-pager.pdf). The table has been computed by the *Endocrine Society* based on Trasande et al. (2015 and 2016), Gore et al. (2015), Attina et al. (2016), Malits et al. (2022), and Obsekov et al. (2022). The Endocrine Society considers the estimates displayed in the table are conservative because they are limited to a subset of chemicals in plastic materials that contribute to disease and disability, they are limited to a subset of diseases due to the few chemicals they studied, and the cost estimates represent a subset of the entire costs due to the disease studied. The chemicals present in plastic materials that have been considered are the following: brominated flame retardants, phthalates, bisphenol A, and per- and polyfluoroalkyl substances (PFAS).

S6. Calculations of benefits from Table 2 in the article

We replicate here below Table 2 (displayed in the article). The explanations on the way each cell is calculated are developed right below the table. The coloured text in Table 2 helps to identify the related paragraphs where the calculation is developed.

Table 2. Global benefits earned from plastic production in case of "Inaction" and "Action" scenarios (scenarios described in Table 1 in the article). Note: all benefits are in billion US$ at prices of the year 2021 and are total values calculated over 2016-2040 with a discount rate of 3.5%. Negative values are a cost. This table is based on data from Sections 2, 3 and 4 in the article.

	Benefits (US$ billion) (Obtained from plastic incomes: (taxes, wages & salaries, dividends, rents, etc.)		**Net benefit (US$ billion)** (Benefits minus costs calculated in table 1)	
	Low estimate	**High estimate**	**Low estimate**	**High estimate**
Action scenario	32668	33138	-120433	19667
Inaction scenario	37985	37985	-243817	24274
Comparison action/inaction	Action reduces incomes generated by plastic industries by 14% compared to inaction	Action reduces incomes generated by plastic industries by 13 % compared to inaction	The net benefits in the "Action" and "Inaction" scenarios are both negative, which means an economic loss (that is, a cost). For the "Inaction scenario", this means that the benefits obtained from the plastic industry are not sufficient to offset costs of plastic pollution impacts caused by inaction. For the "Action scenario", the economic loss (that is, the negative net benefit) is 2 times lower than in the "Inaction scenario". This is because every year, actions are implemented to reduce plastic pollution to approach the zero level in the ecosystems by 2040.	Net benefits earned in the "Action" and "Inaction" scenarios are both positive, which represents an economic gain. For the "Action scenario", this suggests that actions towards zero plastics pollution by 2040 is profitable for society because reduced cost of damages resulting from plastic pollution reduction strategies are sufficient to offset costs of actions. However, the net benefit in the "Inaction scenario" is 1.2 times greater than in the "Action scenario", which means inaction is slightly more beneficial than action. This is because in the "Inaction scenario", production is not reduced and, hence, benefits obtained from the plastic industry more than compensate costs of plastic pollution impacts caused by inaction.

S6.1. Calculation of benefits : "Action scenario"

- ***Low estimate of benefits: US$ 32668 billion:***

The low estimate of benefits earned as direct and indirect incomes generated by plastic industry activities in the "Action scenario" (e.g., wages and salaries earned by workers, dividends earned by shareholders, rents earned by owners, taxes earned by governments, etc.) is calculated running the input-output equation (eq. 1) after gradually reducing the sales of plastics to economic sectors (intermediate demand) and to final consumers (final demand matrix **F**) in the WIO table (Table S1) by an additional 2.35 percentage points each year compared to BAU level in 2021. This means that in 2021, the first year of the transition period, plastic sales are reduced by 2.35%, in 2022 they are reduced by 4.70%, …, in 2039 by 44.65%, and in 2040, the last year of the transition period, they are reduced by 47% compared to the BAU production level in 2021. This calculation takes into account the value added generated by the manufacturing of substitute materials that are expected to replace plastic products. The low estimate of the production of substitutes provided by Lau et al. (2020) ranges from 2.0 million tons/year in 2021 to 62.1 million tons/year in 2040 (low estimates available here: https://zenodo.org/record/3929470). We calculated that each million tons of plastic substitutes would generate a direct and indirect GDP increase by 4.1 billion US$ (at 2021 prices). This estimation is based on the ratio of the amount of plastic production in 2021 (459.2 million tons)[1] to the $GDP_{Plastic}^{Bau}$ in 2021 (which is the part of the global GDP directly and indirectly generated by the plastic industry in 2021; $GDP_{Plastic}^{Bau}$ = US$ 1875 billion in 2021, that is 1.9 % of the global GDP). The low estimate of the benefit obtained from plastics ($Benefit_{Plastic}^{Action}$) is computed as follows :

$$Benefit_{Plastic}^{Action} = Total\ GDP_{Plastic}^{BAU} - Total\ transition\ _{low}^{2.35\%-47\%} = US\$\ 32668\ billion \quad \textbf{(2)}$$

where:

$GDP_{Plastic}^{BAU} = GDP_{2021}^{BAU} - GDP_{2021}^{Zero\ plastic}$ = the annual contribution of plastic sales to GDP production in 2021.

GDP_{2021}^{BAU}= US$ 96527 billion, which is the global GDP (national GDPs observed in 2021 and summed across all countries in the world) provided by the World Bank (2023) at prices of the year 2021 in US$.

$GDP_{2021}^{Zero\ plastic}$ is the global GDP in 2021 in an economic system where the plastics industry would have been eliminated. Its calculation is developed in Section S3 and leads to this equation: $GDP_{2021}^{Zero\ plastic} = GDP_{2021}^{BAU}\left(1 - \frac{GDP_{2014}^{observed} - GDP_{2014}^{Zero\ plastic}}{GDP_{2014}^{observed}}\right)$.

To obtain $Total\ GDP_{Plastic}^{BAU}$ in eq. (2), we sum $GDP_{Plastic}^{BAU}$ across the 25 years of the 2016-2040 period as follows:
$Total\ GDP_{Plastic}^{BAU} = \sum_{year=\ 2016}^{Year=2040} \frac{GDP_{year}^{BAU} - GDP_{year}^{Zero\ plastic}}{(1+3.5/100)^{(year-2021)}}$, where $GDP_{year}^{BAU} = GDP_{2021}^{BAU}$ and $GDP_{year}^{Zero\ plastic} = GDP_{2021}^{Zero\ plastic}$, which means we assume there is no GDP growth across 2021-2040. This is unlikely and explains our estimation is conservative. The denominator introduces the discounting rate of 3.5% to convert future amounts into present value at prices of the year 2021.

In equation eq. (2), $Transition_{low}^{2.35-47\%} = GDP_{year}^{BAU} - GDP_{year}^{Action}$. It yields the benefit lost (estimated in terms of GDP loss) in each year over the 2016-2040 period in the "Action

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[1] We estimated plastic production in 2021 through a quadratic regression appplied to annual plastic production values estimated over 1950-2015 by Geyer et al. (2017). Plastic production includes polymer resin and fiber production.

scenario” compared to the BAU scenario, where GDP_{year}^{Action} is the global GDP in the “Action scenario” calculated year by year with the WIO table after reducing by an additional 2.35% percentage points the sales of plastics to economic sectors (intermediate demand) and to final consumers. This means that in 2021, the reduction of plastic sales is of 2.35% compared to BAU level in 2021, in 2022 the reduction is two times 2.35% (that is, 4.70%) compared to BAU level in 2021, …, and in 2040 it is 20 times 2.35% (that is, 47%) compared to BAU level in 2021. Regarding GDP_{year}^{BAU}, we assumed it constant over years and it is calculated as GDP_{2021}^{BAU} (see above), and GDP_{year}^{Action} is calculated in four steps similarly to $GDP_{2021}^{Zero\ plastic}$:

- In the first step, we calculate $GDP_{2014}^{observed}$, the global GDP observed in 2014, as described above (Section S3).
- In the second step, GDP_{2014}^{Action} is calculated similarly to $GDP_{2014}^{Zero\ plastic}$ except that:
  - First, instead of reducing to zero $x_{13,j}$, $f_{13,k}$ and $x_{i,13}$ in the WIO table (Table S1), we reduce by 2.35% the sales of plastics to economic sectors (intermediate demand $x_{13,j}$) and to final consumers (final demand ($f_{13,k}$)), which gives GDP_{2014}^{Action}.
  - Second, we run Eq. (1) with a WIO table where the row of elements $x_{13,j}$ and $f_{13,k}$ are reduced by 2.35% to obtain the total input of each sector j (x_j^{Action}) – which equals the total output (x_i^{Action}).
  - Third, we calculate GDP_{2014}^{Action} with technical coefficients of value added (v_j^{Action}) and taxes less subsidies on products (t_j^{Action}) as follows: $GDP_{2014}^{Action} = \sum_{j=1}^{n=56} v_j^{Action} + t_j^{Action}$, where $v_j^{Action} = \frac{v_j^{2014}}{x_j^{2014}} x_j^{Action}$ and $t_j^{Action} = \frac{t_j^{2014}}{t_j^{2014}} x_j^{Action}$; x_j^{Action} is the total input of sector j calculated with the input-output equation (eq. 1) after reducing by 2.35% the sales of plastics to economic sectors (intermediate demand $x_{13,j}$) and to final consumers (final demand ($f_{13,k}$)) in the WIO table (Table S1).
- In the third step we calculate the percentage loss due to reduction by 2.35 % of plastic sales: $\left(\frac{GDP_{2014}^{observed} - GDP_{2014}^{Action}}{GDP_{2014}^{observed}}\right)$.
- In the fourth step, we convert GDP_{2014}^{Action} into the year 2021 to obtain GDP_{2021}^{Action} by applying the percentage loss to the global GDP observed in 2021 (GDP_{2021}^{BAU}) provided by the World Bank (2023): $GDP_{year\,=\,2021}^{Action} = GDP_{2021}^{BAU}\left(1 - \frac{GDP_{2014}^{observed} - GDP_{2014}^{Action}}{GDP_{2014}^{observed}}\right)$. And we add to that result the direct and indirect effect of plastic substitutes on GDP: each million tons of plastic substitutes increase global GDP by US$ 4.1 billion at prices of the year 2021 (for example, in the first year of the simulation, 2021, Lau et al. (2020) estimate that 2 million tons of plastic substitutes are produced in their *System change scenario.* Hence, we add US$ 8.2 billion (= 2 Million tons * US$ 4.1 billion)).
- Then, we repeat the four steps to calculate the effect of a reduction by an additional 2.35%, which means a 4.70% reduction compared to the BAU level of production in 2021. And then, we repeat again the four steps to calculate the effect of an additional 2.35%, which means a 7.05% reduction compared to the BAU level of production in 2021, etc. In total we repeat the four steps 20 times to reach a 47% reduction. This gives GDP_{2021}^{Action}, $GDP_{2022}^{Action}, GDP_{2023}^{Action}, \ldots, GDP_{2040}^{Action}$, that is each of the GDP_{year}^{Action} over the simulation period. The equation of the fourth step presented above is the same for each year, except that the value of GDP_{2014}^{Action} varies due to: (*i*) the variation of the production reduction

percentage increased from 2.35% in 2021 up to 47% in 2040 and (*ii*) the amount of plastic substitute productions which increases from 2.0 million tons/year in 2021 to 62.1 million tons/year in 2040 (low estimates).

To obtain $Total\ GDP^{Action}$, that is, the total amount over the period 2016-2040 in constant US$ at prices of the year 2021, we proceed as follows: $Total\ GDP^{Action} = \sum_{year=2016}^{Year=2040} \frac{GDP_{year}^{Action}}{(1+3.5/100)^{(year-2021)}}$. Regarding $Total\ transition\ _{low}^{2.35-47\%}$ in eq. (2), it is obtained as follows: $Transition_{low}^{2.35-47\%} = \sum_{year=2016}^{Year=2040} \frac{GDP_{year}^{BAU}-GDP_{year}^{Action}}{(1+3.5/100)^{(year-2021)}}$, where $GDP_{year}^{BAU} = GDP_{2021}^{BAU}$ and GDP_{year}^{Action} is calculated for each year using the multiplier GDP_{2021}^{BAU} in the equation of the fourth step, which means we assume there is no GDP growth across 2021-2040. This is unlikely and explains our estimation is conservative. The denominator introduces the discounting rate of 3.5% to convert future amounts into present value at prices of the year 2021.

- ***High estimate of benefits: US$ 33138 billion:***

The high estimate of benefits earned as direct and indirect incomes generated by plastic industry activities in the “Action scenario” is calculated in the following equation exactly the same way as the low estimate computed with eq. (2) except that we use the high estimate of the production of plastic substitutes provided by Lau et al. (2020): 2.6 million tons/year in 2021 to 81.1 million tons/year in 2040 (high estimates, available here: https://zenodo.org/record/3929470). The Benefit obtained from plastics (high estimate) is computed as follows:

$$Benefit_{Plastic}^{Action} = Total\ GDP_{Plastic}^{BAU} - Total\ transition_{high}^{2.35-47\%} = US\$\ 33138\ billion \qquad \textbf{(3)}$$

S6.2. Calculation of benefits : “Inaction scenario”

- ***Low and high estimate of benefits: US$ 37985 billion:***

The benefits earned as direct and indirect incomes generated by plastic industry activities in the “Inaction scenario” (e.g., wages and salaries earned by workers, dividends earned by shareholders, rents earned by owners, taxes earned by governments, etc.) are computed assuming that the contribution of the plastic industry to global GDP can be estimated by the difference between global GDP as observed in 2021 (GDP_{2021}^{BAU}) and the GDP that would be produced if the plastic industry would be removed from the global economic system ($GDP_{2021}^{Zero\ plastic}$). This gives the annual contribution of plastic sales to GDP production in 2021, which is computed as follows :

$$GDP_{Plastic}^{BAU} = GDP_{2021}^{BAU} - GDP_{2021}^{Zero\ plastic} \qquad \textbf{(4)}$$

To obtain $Total\ GDP_{Plastic}^{BAU}$ (which is computed as in eq. (2)), we sum $GDP_{Plastic}^{BAU}$ across the 25 years of the 2016-2040 period as follows:

$$Benefit_{Plastic}^{Inaction} = Total\ GDP_{Plastic}^{BAU} = \sum_{year=2016}^{Year=2040} \frac{GDP_{year}^{BAU} - GDP_{year}^{Zero\ plastic}}{\left(1+\frac{3.5}{100}\right)^{(year-2021)}}$$
$$= \text{US\$ 37985 billion} \qquad \textbf{(5)}$$

S6.3. Calculation of net benefits: “Action scenario”

Net benefits are calculated subtracting the costs shown in Table 1 (in the article) from the benefits shown in Table 2 (in the article and Supplemental materials). The calculations are developed below.

- ***Low estimate of net benefits: US$ –120433 billion:***

For the low estimate, the net benefit is calculated subtracting from $Benefit_{Plastic}^{Inaction}$ (calculated in eq. (5)) the cost shown in Table 1 corresponding to the high estimate. The calculation is as follows:

$$Net\ benefit^{Action} = Benefit_{Plastic}^{Inaction} - Total\ transition_{high}^{2.35-47\%} - Waste\ management\ costs - Terrestrial\ cleanup - Ocean\ cleanup\ (plastics\ floating\ offshore) - Ocean\ cleanup\ (plastics\ floating\ close\ to\ the\ shoreline) - River\ cleanup\ (floating\ plastics) - Damages\ to\ marine\ ecosystems - Human\ health\ in\ USA, EU\ and\ Canada = 37985 - 5317 - 1335 - 1739 - 248 - 3895 - 1373 - 132819 - 11692 = US\$ - 120433\ billion$$

- ***High estimate of net benefits: US$ 19667 billion:***

For the high estimate of the net benefit, the calculation is the same as above except that the cost subtracted from the $Benefit_{Plastic}^{Inaction}$ correspond to the low estimate in Table 1. The calculation is as follows:

$$Net\ benefit^{Action} = Benefit_{Plastic}^{Inaction} - Total\ transition_{low}^{2.35-47\%} - Waste\ management\ costs - Terrestrial\ cleanup - Ocean\ cleanup\ (plastics\ floating\ offshore) - Ocean\ cleanup\ (plastics\ floating\ close\ to\ the\ shoreline) - River\ cleanup\ (floating\ plastics) - Damages\ to\ marine\ ecosystems - Human\ health\ in\ USA, EU\ and\ Canada = 37985 - 4847 - 470 - 507 - 11 - 251 - 23 - 1003 - 11206 = US\$\ 19667 billion.$$

S6.4. Calculation of net benefits: “Inaction scenario”

In the “Inaction scenario”, the cost of action is zero and plastic pollution is not reduced to zero (differently to the “Action scenario” which aims to approach zero plastic pollution by 2040). As a result, the net benefit is computed by subtracting from the benefits displayed in Table 2 for the “Inaction scenario”, the cost of plastic pollution impact displayed in Table 1.

- ***Low estimate: US$ –243817 billion:***

For the low estimate, the net benefit is calculated by subtracting from the benefit shown in Table 2, the cost shown in Table 1 corresponding to the high estimate. The calculation is as follows:

$$Net\ benefit^{Inaction} = Benefit_{Plastic}^{Inaction} - Waste\ management\ costs - Damages\ to\ marine\ ecosystems - Human\ health\ in\ USA, EU\ and\ Canada = 37985 - 1612 - 268498 - 11692 = US\$\ -243817\ billion$$

- ***High estimate: US$ 24274 billion:***

For the high estimate, the net benefit is calculated by subtracting from the benefit shown in Table 2, the cost shown in Table 1 corresponding to the low estimate. The calculation is as follows:

$$Net\ benefit^{Inaction} = Benefit_{Plastic}^{Inaction} - Waste\ management\ costs - Damages\ to\ marine\ ecosystems - Human\ health\ in\ USA, EU\ and\ Canada = 37985 - 643 - 1862 - 11206 = US\$\ 24274\ billion$$

S7. Discussion and conclusion

Three reasons explain the underestimation of the cost of global environmental damages in case of inaction (Table 1 and Figure 4 in the article). First, because the cost of global damages caused by plastics cover marine ecosystems exclusively and completely omits terrestrial ecosystems. And yet, the costs of global damages caused to terrestrial ecosystems is likely to be important and even higher than marine ecosystems. In 2040, plastic pollution is forecasted to be 1.8 to 5.1 times greater in terrestrial ecosystems than in aquatic ecosystems, with 830-1664 MMT of plastic debris accumulated in terrestrial ecosystems and 164-900 MMT in aquatic ecosystems (Figure2).

Second, the cost of plastics on human health is underestimated since we considered only the health impact in the USA, the European Union and Canada due to the lack of study in other countries.

Third, because of lacking knowledge, except for model's results from Lau et al. (2020), the models displayed in Figures 2 and 3 (and Figures S2 and S3 in supplemental materials) do not consider emissions of primary microplastics into the environment (e.g., synthetic textile fibers from washing machines). And given the lack of technologies to clean up microplastics (and nanoplastics) in the ecosystems, we could not apply removal cost estimations to microplastic debris estimations from Lau et al. (2020) since such estimations do not exist. Microplastics are divided into primary and secondary microplastics. Primary microplastics are pieces of plastic between 0.1 mm and 5 mm in size that enter the environment as such. They may be found in personal care products (microbeads), in the form of plastic pellets used in industrial plastic manufacturing, in the form of plastic fibers used in synthetic textiles, from tire abrasion on roads, etc. These particles directly enter natural ecosystems from different sources. Secondary microplastics are broken down from macroplastic particles (≥ 5mm in size) through natural weathering processes in the ecosystem (Lau et al., 2020 – in supplementary materials; Bajt, 2021); those are included in all model's results displayed on Figures 2, S2, 3 and S3. Further studies should study primary microplastic emission to the ecosystem since they are likely to be significant. For example, tire wear may contribute 5–10% of global ocean plastics loading (Kole et al., 2017; Hale et al., 2020).

References

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., ... & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science*, *369*(6510), 1515-1518.

Cordier M. and Uehara T., 2019. How much innovation is needed to protect the ocean from plastic contamination? Science of the total environment 670 (2019) 789–799.

Cordier, M., Uehara, T., Baztan, J., Jorgensen, B., & Yan, H. (2021). Plastic pollution and economic growth: The influence of corruption and lack of education. *Ecological economics*, *182*, 106930.

Cottom, J. et al. (2022), "Spatio-temporal quantification of plastic pollution origins and transportation (SPOT)" University of Leeds, UK. Available at: https://plasticpollution.leeds.ac.uk/toolkits/spot/.

Ford, H. V., Jones, N. H., Davies, A. J., Godley, B. J., Jambeck, J. R., Napper, I. E., et al. (2022). The fundamental links between climate change and marine plastic pollution. Sci. Total Environ.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3 (7), e1700782.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771.

Lau, W. W., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., ... & Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. *Science*, *369*(6510), 1455-1461.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), 1-11.

Lebreton, L., Egger, M., & Slat, B. (2019). A global mass budget for positively buoyant macroplastic debris in the ocean. *Scientific reports*, *9*(1), 1-10.

Miller R. E., Blair P. D., 2009. *Input-output analysis: foundations and extensions*. Cambridge university press.

OECD, 2022. Global Plastics Outlook: Policy Scenarios to 2060. OECD Publishing, Paris, 283 pp. https://doi.org/10.1787/aa1edf33-en

Timmer M. P., Dietzenbacher E., Los B., Stehrer R., de Vries G. J., 2015. An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production. Review of International Economics 23, 575–605. Available at: http://www.wiod.org/database/wiots16.

Uehara, T., Cordier, M., & Hamaide, B. (2018). Fully dynamic input-output/system dynamics modeling for ecological-economic system analysis. Sustainability, 10(6), 1765.

van Emmerik, T., Mellink, Y., Hauk, R., Waldschläger, K., & Schreyers, L. (2022). Rivers as plastic reservoirs. Frontiers in Water, 3, 212.

World Bank, 2023. GDP (current US$). World Development Indicators. Available here: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Yan H., Cordier M., & Uehara T., 2022. Demographic Factors and the Environmental Kuznets Curve: Global Plastic Pollution by 2050 Could Be 2 to 4 Times Worse than Projected. SSRN preprint *available at*: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4231443