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Trading Responsibility: navigating national burdens in a globalized world

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Citation
Navarre, N. H. (2024, June 6). *Trading Responsibility: navigating national burdens in a globalized world*. Retrieved from https://hdl.handle.net/1887/3761727

Version:	Publisher's Version
License:	Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden
Downloaded from:	https://hdl.handle.net/1887/3761727

Note: To cite this publication please use the final published version (if applicable).

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Curriculum Vitae

Nicolas Navarre was born on April 2nd, 1992, in Syracuse, New York, United States of America. After spending his childhood between France and the United States, he graduated from Upper St. Clair High School in the United States in 2009. Nicolas then obtained a bachelor's degree in civil and environmental engineering from the Pennsylvania State University, followed by a Master of Environmental Engineering from the Pennsylvania State University where he studied biological and chemical treatment processes of polluted waters (supervised by Prof. Dr. John Regan). After working as an engineer at an environmental and geotechnical consulting firm (Landau Associates) in Seattle, Washington, Nicolas moved to the Netherlands where he completed a Master of Science in Industrial Ecology from TU Delft and Leiden University (supervised by Dr. José Mogollón and Prof. Dr. Martina Vijver). For his PhD, he worked on the modeling of anthropogenic systems and their interactions with the natural environment (supervised by Dr. Valerio Barbarossa, Dr. José Mogollón, and Prof. Dr. Arnold Tukker), with an emphasis on the food and plastic waste systems. He currently holds a postdoc position at Leiden University.

List of Publications

Navarre, N., Schrama, M., de Vos, C., & Mogollón, J. M. (2023). Interventions for sourcing EAT-Lancet diets within national agricultural areas: A global analysis. *One Earth*, *6*(1), 31-40.

Navarre, N., Mogollón, J. M., Tukker, A., & Barbarossa, V. (2022). Recycled plastic packaging from the Dutch food sector pollutes Asian oceans. *Resources, Conservation and Recycling*, *185*, 106508

Cucurachi, S., et al. "Prospective LCA methodology for Novel and Emerging Technologies for BIO-based products." *Publications Office of the European Union: Luxembourg* (2022).

Adrianto, Lugas Raka, et al. "How can LCA include prospective elements to assess emerging technologies and system transitions? The 76th LCA Discussion Forum on Life Cycle Assessment, 19 November 2020." *The International Journal of Life Cycle Assessment* 26 (2021): 1541-1544.

Acknowledgments

Unfortunately, I am not enough of a wordsmith to properly convey the importance and influence the many people who have helped me along the way, so, as my mentor said in his own dissertation, this will only be an attempt at acknowledgments.

I would like to start by thanking the members of the reading committee: Prof. dr. ing. J.W. Erisman, Prof. dr. ing. M.G. Vijver, Prof. dr. E van Sebille, Dr. R. Wang, Dr. ir. T.H.M. van Emmerik for taking time out of their schedules to review this dissertation. Your feedback has been invaluable to improving the quality of this dissertation.

Next, I'd like to thank Arnold Tukker. You've balanced a stay in Paris, new appointments, and other Ph.D.s, but not once did I feel like my work was secondary to anything else. Not only were you an amazing resource on the research side of the Ph.D., but you also went above and beyond to make sure I even had a Ph.D. to work on. After everything you've done for me, I was thrilled to share a few drinks (in front of the Arles colosseum no less!) in the closing stages of the Ph.D.

To Valerio Barbarossa, this is quite the achievement for the both of us! My first Ph.D. (hopefully the only one) and your first supervised Ph.D. (hopefully not the only one). You managed to find the perfect balance between making sure working was fun and enjoyable but that the work was rigorous. Thank you for ensuring such an enjoyable working environment. There's no doubt that the reason I rave about my Ph.D. so much is because you were a central figure of it.

To José Mogollón, I wouldn't hesitate to call you my mentor, but I would hesitate to say that mentor comes close to capturing everything you've been to me. A teacher, a supervisor, a colleague, a friend, you've worn many hats since we've met, and worn them all better than I could have hoped for. My sincerest hope is that when we look back on all we've done together in our careers, these past years will have only been the beginning.

To Stefano Cucurachi and Laura Scherer, you've been great education mentors. Thank you for giving me my initial teaching opportunities, I

enjoyed and learned so much from you in our time co-teaching together. To my students, you've taught me many things, brought me newfound energy year after year, and most importantly, become friends and colleagues as the years have gone by.

Speaking of friends and colleagues, there is no better place to start than with Emilie, my beloved officemate through the years. Most people know the importance of enjoying the company of those sitting by your side day after day. In my case, I'll be lucky if I enjoy the company of my future officemates even half as much as yours. Of course, Kaushar, Laura (close enough!), Angela, Berend, Dirk, Xinpeng, you have been wonderful officemates as well.

To Stephanie, Levon, Jaime, Philipp, Matthieu, Clay, among many more, thank you for the lunches, dinners, drinks, coffee breaks, games, laughs, holidays, and more. You've made my days a little bit better, and sharing these moments day after day, year after year, went further than you can imagine in making these past years as amazing as they were.

To Nina, Pablo, Catrin, Eva, Martijn, and Evelien. I'd like you to know that I could have added your names to the list of family members below. I could list out all the things we have done together, but that wouldn't be very useful. In the end it never mattered what we were up to. As long as you were there, I was going to have great time.

A ma famille, Guillaume, Jeanne, Cécile, Aloïs, Paul B., Laetitia, Bertrand, Maxime, Paul N., Emma, Marilys, Arnaud, Charles, Emric, et le reste de mes tantes, oncles, et cousins. Je ne cesse de raconteur à mes amis le bonheur qu'est ma grande famille. A mon père, qui m'a toujours dit que 'j'avais de l'or dans les doigts'. Faire un doctorat est principalement de la confiance en soit, et je me dois te remercier de m'avoir rendue aussi confiant, même si certains diront que ma confiance déborde un peu parfois.

To Martijn, first a classmate, later a colleague, but always a friend. To call you levelheaded would be an understatement, and in a Ph.D. filled with highs and lows, having you as a tether has been instrumental. Once again, I am relying on that by having you by my side as a paranymph. Evelien, sometimes here, sometimes elsewhere, in your own world, but always there for me. And once again, there, standing by my side as paranymph. You have been wonderful to me. Sharing these past few years has truly been a gift.

Finally, to Chloé. Even history's greatest poets would struggle to describe everything you have been for me in just a few lines. Et même si nous parlons deux langues, je suis désolé d'avoir si peu de mots à t'offrir. Tu as été à mes côtés pour des hauts, plus hauts, et des bas, plus bas, que personne d'autre ne puisse imaginer, et pour ça, je t'aimerai toujours

Appendix A – Appendix to Chapter 2

Appendix A includes the following supporting information for chapter 2:

- Figure A1

The remaining supplementary materials for chapter 2 can be found at https://github.com/nicolas-navarre/National-EAT-Lancet-diets and includes the following:

- Table A1-5

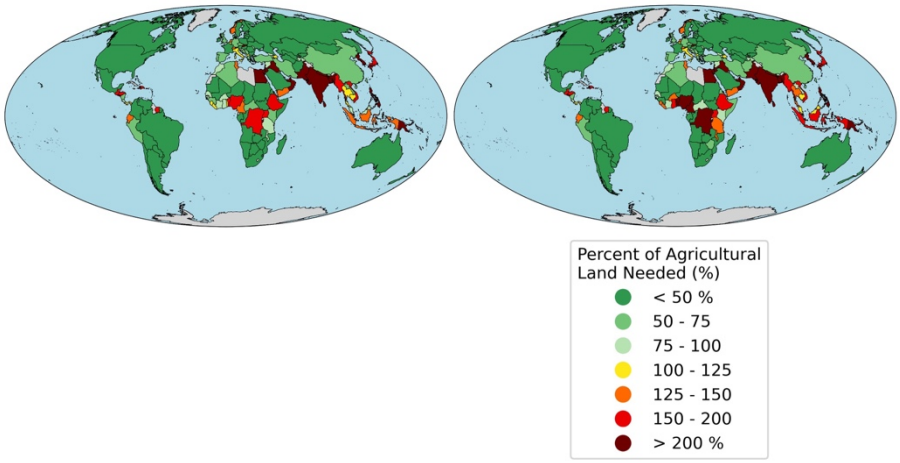

Figure A1. EAT-Lancet Diet national agricultural land use of **A.** Improving livestock yields and feed yields to global averages in sub-Saharan Africa and South & Southeast Asia and **B.** Improving crop yields to global averages in sub-Saharan Africa and South & Southeast Asia.

Appendix B – Appendix to Chapter 3

Appendix B includes the following supporting information for chapter 3:

- Figure B1 & B2
- Supplementary Table B1-9

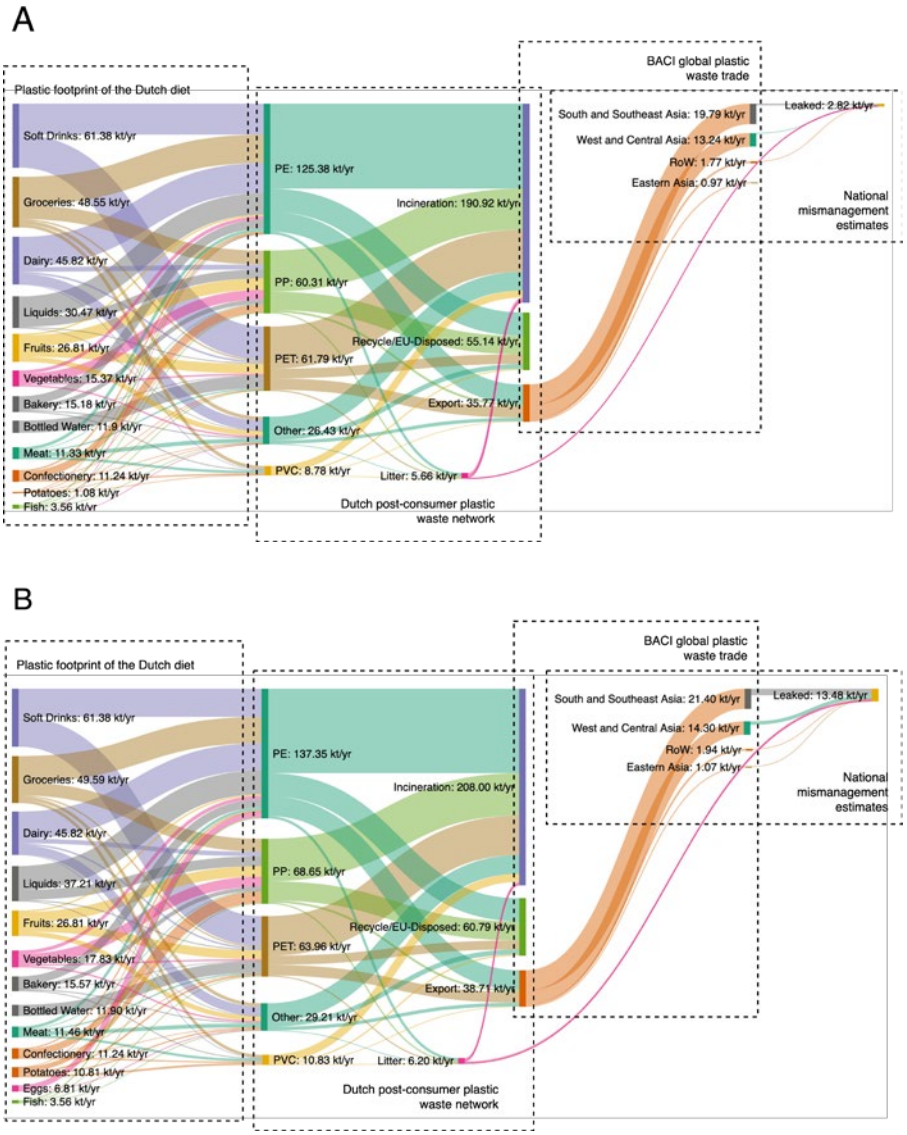

Figure B1. A. Minimum and B. Maximum fate of post-consumer plastic food packaging by plastic type in the Netherlands. All values are presented in kt/yr. Leaked values indicate the quantities of plastic leaked to the marine environment only. The nations composing the macro-geographical regions presented are classified in accordance with the United Nations UN M49 area code standard (The United Nations Statistics Division, 2018).

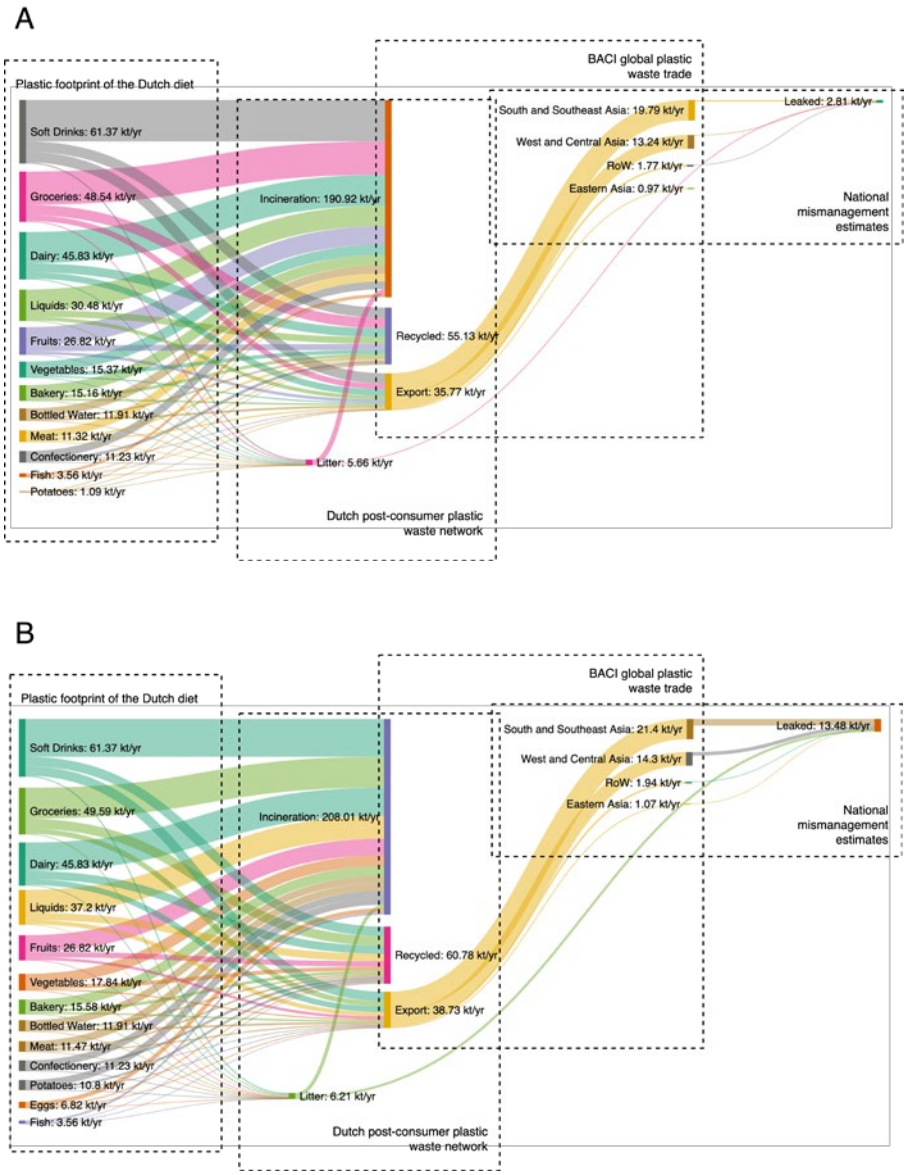

Figure B2. A. Minimum and B. Maximum relationship of food items to fate of plastic packaging waste in the Netherlands. All values are presented in kt/yr. Leaked values indicate the quantities of plastic leaked to the marine environment only. The nations composing the macro-geographical regions presented are classified in accordance with the United Nations UN M49 area code standard (The United Nations Statistics Division, 2018).

Table B1. Daily food consumption data collected by the Dutch National food Consumption Survey conducted by the Dutch National Institute for Public Health and the Environment between 2012 and 2016 (RIVM; van Rossum et al., 2020). The daily purchased fraction includes household waste, and the packaged fraction includes household and retail waste fractions. Household waste factions were acquired from van Dooren et al. (2019) and retail waste fractions from four sources combining Dutch, UK, and Swedish retail food waste and a meta-analysis of 16 studies quantifying retail food waste (see Table B2). Ref 1 and 2 are direct references to the CONCITO (2021) dataset and their reported plastic packaging quantities.

Waste Group	Food Items	Household Waste Fraction	Retail Waste Fraction*	Consumed (g/d/capita)	Purchased (g/d/capita)	Packaged (g/d/capita)	Ref 1	Ref 2	Plastic 1	Plastic 2
Potatoes	0100. Unclassified and other tubers	0.143	0.000646	0.5	0.6	0.6	Ra00256	Ra00358	0.002	0.02
Potatoes	0101. Potatoes	0.143	0.000646	71.6	83.5	85.0	Ra00256	Ra00358	0.002	0.02
Vegetables	0200. Unclass., Mixed salads / vegetables	0.189	0.002618	11.8	14.5	15.1	Ra00389		0.032	
Vegetables	0201. Leafy vegetables (exc. Cabbages)	0.189	0.002618	19.2	23.7	24.5	Ra00164		0.002	
Vegetables	0202. Fruiting vegetables	0.189	0.002618	48.4	59.7	61.8	Ra00002		0.027	
Vegetables	0203. Root vegetables	0.189	0.002618	12.3	15.2	15.7	Ra00259		0.002	
Vegetables	0204. Cabbages	0.189	0.002618	19.4	23.9	24.8	Ra00157		0.002	

Vegetables	0205. Mushrooms	0.189	0.002618	2.9	3.6	3.7	Ra00207	Ra00408	0.05	0.027
Vegetables	0206. Grain and pod vegetables	0.189	0.002618	2.5	3.1	3.2	Ra00176	Ra00173	0.027	0.002
Vegetables	0207. Leek, onion, garlic	0.189	0.002618	11.8	14.5	15.1	Ra00136		0.002	
Vegetables	0208. Stalk vegetables, sprouts	0.189	0.002618	2.6	3.2	3.3	Ra00178	Ra00155	0.027	0.002
Vegetables	0301. Legumes	0.189	0.002618	4.5	5.5	5.7	Ra00176	Ra00408	0.027	0.002
Fruits	0400. Unclass., Mixed fruit and others	0.165	0.002635	0.4	0.5	0.5	Ra00141		0.05	
Fruits	040101. Fruits	0.165	0.002635	113.4	135.8	141.4	Ra00282		0.027	
Fruits	040102. Fruit compote	0.165	0.002635	5.7	6.8	7.1	Ra00117		0.0572	
Groceries	040201. Nuts, peanuts, seeds	0.12	0.00085	5.7	6.5	6.5	Ra00140		0.05	
Confectionery	040202. Peanut butter, nut / seeds spread	0.046	0.00017	4	4.2	4.2	Ra00347		0.08	
Fruits	0403. Olives	0.165	0.002635	0.6	0.7	0.7	Ra00119		0	
Dairy	0500. Unclass. and mixed dairy products	0.0833	0.00204	1.7	1.9	1.9	Ra00496		0.015	

Dairy	050101. Non-fermented milk and milk bev.	0.0833	0.00204	147.4	160.8	162.7	Ra00341	0.003
Dairy	050102. Milk (fermented and bev), yogh.	0.0833	0.00204	53.2	58.0	58.7	Ra00076	0.04075
Dairy	0502. Milk substitutes and subst. prod.	0.0833	0.00204	8.4	9.2	9.3	Ra00209	0.003
Dairy	0503. Yogurt	0.0833	0.00204	53.7	58.6	59.3	Ra00075	0.04075
Dairy	0504. Fromage blanc, petits suisses	0.0833	0.00204	11.4	12.4	12.6	Ra00078	0.015
Dairy	0505. Cheeses (incl. Spread cheeses)	0.0833	0.00204	32.6	35.6	36.0	Ra00078	0.015
Dairy	0506. Cream desserts, puddings (milk)	0.0833	0.00204	26.3	28.7	29.0	Ra00042	0.015
Dairy	050700. Unclassified creams	0.0833	0.00204	4.3	4.7	4.7	Ra00345	0.003
Dairy	050701. Dairy creams and creamers	0.0833	0.00204	2.3	2.5	2.5	Ra00076	0.04075

Dairy	050702. Non-dairy creams and creamers	0.0833	0.00204	0.6	0.7	0.7	Ra00076		0.04075	
Confectionery	050800. Unclass., Combined ice cream / sorbet	0.046	0.00017	0.2	0.2	0.2	Ra000148		0.0822	
Confectionery	050801. Ice cream (milk based)	0.046	0.00017	7.8	8.2	8.2	Ra00147		0.0822	
Confectionery	050802. Ice cream substitutes	0.046	0.00017	0	0.0	0.0	Ra00472		0.0822	
Confectionery	050803. Sorbet / water ice	0.046	0.00017	1.7	1.8	1.8	Ra00149		0.0822	
Groceries	0601. Flour, starches, flakes, semolina	0.12	0.00085	2	2.3	2.3	Ra00102		0.014	
Groceries	0602. Pasta, rice, other grain	0.12	0.00085	47.1	53.5	53.9	Ra00234		0.021	
Bakery	060301. Bread	0.304	0.005355	125.6	180.5	189.5	Ra00029		0.0086	
Groceries	060302. Crispbread, rusks	0.12	0.00085	5.3	6.0	6.1	Ra00027		0.0086	
Groceries	0604. Breakfast cereals	0.12	0.00085	7.4	8.4	8.5	Ra00034		0.02	
Bakery	0605. Dough and pastry	0.304	0.005355	6.5	9.3	9.8	Ra00040	Ra00042	0.0086	0.015

Meat	0700. Unclass. and combined meat prod.	0.102	0.000765	2.2	2.4	2.5	Ra00010	0.027
Meat	070100. Unclass., Mixed and oth. mammals	0.102	0.000765	3.8	4.2	4.3	Ra00010	0.027
Meat	070101. Tremble	0.102	0.000765	12.2	13.6	13.8	Ra00010	0.027
Meat	070102. Veal	0.102	0.000765	0.4	0.4	0.5	Ra00230	0.027
Meat	070103. Pork	0.102	0.000765	13	14.5	14.7	Ra00230	0.027
Meat	070104. Mutton / Lamb	0.102	0.000765	0.6	0.7	0.7	Ra00273	0.027
Meat	070105. Horse	0.102	0.000765	0.1	0.1	0.1	Ra00010	0.027
Meat	070107. Rabbit	0.102	0.000765	0.1	0.1	0.1	Ra00128	0.027
Meat	070200. Unclassified and other poultry	0.102	0.000765	0	0.0	0.0	Ra00070	0.027
Meat	070201. Chicken, hen	0.102	0.000765	15.9	17.7	18.0	Ra00055	0.027
Meat	070202. Turkey, young turkey	0.102	0.000765	0.4	0.4	0.5	Ra00339	0.027
Meat	070203. Duck	0.102	0.000765	0.3	0.3	0.3	Ra00069	0.027

Meat	0703. Game	0.102	0.000765	0.1	0.1	0.1	Ra00129		0.027	
Meat	070401. Hot processed meat	0.102	0.000765	26	29.0	29.4	Ra00063		0.004	
Meat	070402. Cold processed meat	0.102	0.000765	21.1	23.5	23.9	Ra00063		0.004	
Meat	0705. Offals	0.102	0.000765	0.3	0.3	0.3	Ra00490		0.004	
Meat	070601. Hot meal substitutes	0.102	0.000765	1.4	1.6	1.6	Ra00457	Ra00474	0.05	0.061
Meat	070602. Cold meal substitutes	0.102	0.000765	0.1	0.1	0.1	Ra00475	Ra00460	0.00399	0.061
Fish	0800. Unclass and combined fish products	0.071	0.00051	0	0.0	0.0	Ra00109		0.027	
Fish	0801. Fish	0.071	0.00051	11.5	12.4	13.2	Ra00109		0.027	
Fish	0802. Crustaceans, molluscs	0.071	0.00051	1.4	1.5	1.6	Ra00204		0.015	
Fish	0803. Fish products, fish in crumbs	0.071	0.00051	3.2	3.4	3.7	Ra00195		0.05	
Fish	0804. Amphibians and reptiles	0.071	0.00051	0	0.0	0.0	Ra00204		0.015	
Eggs	0901. Eggs	0.049	0.000221	12.7	13.4	13.7	Ra00108		0	0.07875 **

Liquids	1000. Unclassified and combined fat	0.101	0.0005355	1.5	1.7	1.7	Ra00350	0.05888
Liquids	1001. Vegetable oils	0.101	0.0005355	3.5	3.9	3.9	Ra00350	0.05888
Dairy	1002. Butter	0.0833	0.00204	2.2	2.4	2.4	Ra00037	0.032
Dairy	1003. Margarines and cooking fats	0.0833	0.00204	14.9	16.3	16.4	Ra00477	0.032
Liquids	1004. Other animal fats (incl fish oil)	0.101	0.0005355	0.1	0.1	0.1	Ra00350	0.05888
Confectionery	1100. Unclass or combined confectionery	0.046	0.00017	0.4	0.4	0.4	Ra00319	0.014
Confectionery	110100. Unclassified and other types	0.046	0.00017	0	0.0	0.0	Ra00319	0.014
Confectionery	110101. Sugar	0.046	0.00017	4.7	4.9	5.0	Ra00318	0.014
Confectionery	110102. Jam, jelly, marmalade	0.046	0.00017	4	4.2	4.2	Ra00126	0
Confectionery	110103. Honey	0.046	0.00017	0.9	0.9	1.0	Ra00146	0.031
Confectionery	110104. Other sweet spreads	0.046	0.00017	1.1	1.2	1.2	Ra00121	0.08

Liquids	110105. Sweet sauce, sweet toppings	0.101	0.0005355	0.2	0.2	0.2	Ra00146	0.031
Liquids	110106. Syrups (incl. Can and beverages)	0.101	0.0005355	0.5	0.6	0.6	Ra00233	0.08
Confectionery	110200. Unclassified and other types	0.046	0.00017	3.2	3.4	3.4	Ra0498	0.0071
Confectionery	110201. Chocolate tablet	0.046	0.00017	3.2	3.4	3.4	Ra0498	0.0071
Confectionery	110202. Chocolate candy bars	0.046	0.00017	1.5	1.6	1.6	Ra0498	0.0071
Confectionery	110203. Chocolate spread and choc.powder	0.046	0.00017	3.4	3.6	3.6	Ra00499	0.08
Confectionery	110204. Chocolate confectionary	0.046	0.00017	1	1.0	1.1	Ra00498	0.0071
Confectionery	1103. Confectionary non-chocolate	0.046	0.00017	5.8	6.1	6.1	Ra00323	0.0072
Bakery	1201. Cakes, pies, pastries, puddings	0.304	0.005355	24.1	34.6	36.4	Ra00041	0.015

Groceries	1202. Dry cakes, sweet biscuits	0.12	0.00085	17.1	19.4	19.6	Ra00020		0.05	
Liquids	1300. Unclass and combined non-alcoholic	0.101	0.0005355	5.8	6.5	6.5	Ra00183		0.0259413	
Liquids	1301. Fruit and vegetable juices	0.101	0.0005355	55.4	61.6	61.9	Ra00184		0.0572	
Soft Drinks	1302. Carbonated / soft / isotonic drinks	0.065	0.0006545	349.3	373.6	375.1	Ra00183		0.0259413	
Groceries	130300. Unclass. and combined coffee / tea	0.12	0.00085	1.6	1.8	1.8	Ra00059		0.015	
Groceries	130301. Coffee	0.12	0.00085	21.98	25.0	25.2	Ra00059	Ra00060	0.015	0.017
Groceries	130302. Tea	0.12	0.00085	1.3542	1.5	1.6	Ra00058		0.0358	
Groceries	130303. Herbal tea	0.12	0.00085	88.4	100.5	101.2	Ra00058		0.038	
Groceries	130304. Chicory Substitutes	0.12	0.00085	0.1	0.1	0.1	Ra00060		0.017	
Bottled Water	1304. Waters	0.065	0.0006545	76.41326	81.7	83.2	Ra00182	Afra water	0.022666667***	
Liquids	1400. Unclassified	0.101	0.0005355	2.3	2.6	2.6	Ra00117		0.0572	

	, cocktails, punches									
Liquids	1401. Wine, cider, fruit wines	0.101	0.0005355	38.4	42.7	42.9	Ra00375	Ra00399	0.00122	0.02594 13
Liquids	1402. Fortified wines	0.101	0.0005355	1.6	1.8	1.8	Ra00375		0.00122	
Liquids	1403. Beer	0.101	0.0005355	92.3	102.7	103.1			0	
Liquids	1404. Spirits, brandy	0.101	0.0005355	3.3	3.7	3.7	Ra00306		0.0009	
Liquids	1405. Aniseed drinks	0.101	0.0005355	0	0.0	0.0	Ra00399		0.025941 3	
Liquids	1406. Liqueurs	0.101	0.0005355	0.9	1.0	1.0	Ra00186		0.0009	
Liquids	1500. Unclassified or combined sauces	0.101	0.0005355	0.6	0.7	0.7	Ra00373	Ra00374	0.014	0.0049
Liquids	150100. Other and mixed sauces	0.101	0.0005355	13.4	14.9	15.0	Ra00067		0.0049	
Liquids	150101. Tomato sauces	0.101	0.0005355	6.7	7.5	7.5	Ra00368		0.0049	
Liquids	150102. Dressings, mayonnaises and sim.	0.101	0.0005355	7.9	8.8	8.8	Ra00066		0.0049	
Eggs	150103. Mayonnaise	0.049	0.000221	4.5	4.7	4.9	Ra00202		0	

	based spreads									
Groceries	1503. Spices, herbs and flavorings	0.12	0.00085	0	0.0	0.0	Ra00487			
Groceries	150400. Unclass. and combined condiments	0.12	0.00085	2	2.3	2.3	Ra0074		0.088	
Liquids	150401. Vinegar	0.101	0.0005355	0.2	0.2	0.2	Ra00150		0.0049	
Liquids	1601. Stocks in soup recipes	0.101	0.0005355	18.6	20.7	20.8	Ra00213		0.00111	
Liquids	1602. Stocks	0.101	0.0005355	24	26.7	26.8	Ra00215		0.0079	
Groceries	1701. Vegetarian products / dishes	0.12	0.00085	0.1	0.1	0.1	Ra00383		0.0079	
Confectionery	170201. Artificial sweeteners	0.046	0.00017	0.3	0.3	0.3	Ra00318		0.061	
Groceries	170202. Meal substitutes	0.12	0.00085	4.4	5.0	5.0	Ra00457	Ra00458	0.014	
Groceries	1703. Insects	0.12	0.00085	0	0.0	0.0			0.05	0.027
Groceries	1800. Unclassified or combined snacks	0.12	0.00085	0	0.0	0.0	Ra00364		0	
Groceries	1801. Savory	0.12	0.00085	9.4	10.7	10.8	Ra00020		0.05	
									0.05	

Bakery	snacks, biscuits, crisps 1802. Savory filled buns, croissants	0.304	0.005355	11.2	16.1	16.9	Ra00040	0.0086

*Fraction of 1.7% total losses. Further detailed in Sup. Table 2
**Assuming a 1 ounce package of six eggs containing 60 gram eggs
*** Assuming a 34 gram bottle to package 1.5L of water

Table B2. The fraction of total retail waste disaggregated by food groups. The estimates of this study rely first on the data presented by Vollebregt (2020) where possible and disaggregates compound food groups using supporting information from WRAP, 2016; Cicatiello et al., 2017; and Eriksson, Strid and Hansson, 2012, 2014.

Reference	Food Group	Retail Waste*
Eriksson, Strid and Hansson, 2012, 2014; Vollebregt, 2020	Retail Waste	0.017
	Meat and Fish	0.075
	Dairy, eggs, chilled conv products	0.133
	Bread, bakery, pastry	0.315
	Potatoes, veggies, fruit	0.345
	Other fresh products and shelf-stable products	0.132
WRAP, 2016	Bakery	0.320
	Fresh produce	0.260
	Dairy and eggs	0.130
	pre-prepared meals	0.090
	meat and fish	0.060
	ambient	0.040
	soft drinks	0.030
	frozen	0.030
	alcoholic drinks	0.020
	confectionery	0.010
Cicatiello et al., 2017	Groceries	0.050
	Liquids	0.070
	Fruits and vegetables	0.340
	Fresh meat	0.040
	Deli	0.040
	Fresh seafood	0.040
	Bakery	0.310
	Confectionery	0.000
	Prepared meat	0.020

	Dairy	0.090
	Frozen	0.010
	Meat	0.045
	Fish	0.030
	Dairy	0.120
	Eggs	0.013
	Bakery	0.315
This study	Potatoes	0.038
	Veggies	0.154
	Fruit	0.155
	Groceries	0.050
	Liquids	0.0315
	Confectionery	0.010
	Soft Beverages**	0.0385

*Reported as fraction of total waste.

**Includes bottled water

Table B3. Ratio of plastic types disaggregated by food groups derived from Bouma et al. (2003) and Duffy et al. (2007). This table was used to disaggregate total plastic packaging as reported by 2.0 LCA data into the five major plastic categories.

	Bakery	Confect -ionery	Dairy	Eggs	Fish	Fruits	Groceries	Liquids	Meat	Potatoes	Veget -ables	Soft Drinks	Bottled Water
PE	56	13	63	86	36	6	56	68	25.5	2	20	48.5	0
PP	27.5	65	10.5	0	24	41	27.5	28	5	47	60	0	0
PVC	6.5	13	1	0		0	6.5	0	22	20	0	0	0
PET	3	3	4	0	23	35	3	3	12	17	10	51.5	100
Other	7	6	21.5	14	17	18	7	1	35.5	14	10	0	0

Table B4. Fate fractions for each plastic type in the Dutch plastic post-consumer waste network. Values derived from Brouwer et al., 2019, Heestin et al., 2017, and Jambeck et al., 2015. Rates for proper recycling and export are reported as the fraction of waste not sent to incineration.

	Proper Sorting	Export	Incineration	Litter
PE	0.95	0.536	0.65	0.02
PP	0.94	0.153	0.65	0.02
PVC	0.56	0.631	0.65	0.02
PET	0.94	0.631	0.65	0.02
Other	0.87	0.631	0.65	0.02

Table B5. Packaging results derived from 2.0 LCA data, plastic type disaggregation, and total food packaged in the Netherlands.

		ton/year														
Waste group	**Food packaged (g/d/cap)**	**min PE**	**max PE**	**mean PE**	**min PP**	**max PP**	**mean PP**	**min PVC**	**max PVC**	**mean PVC**	**min PET**	**max PET**	**mean PET**	**min Other**	**max Other**	**mean Other**
Bakery	252.6	1.3	1.4	1.4	0.7	0.7	0.7	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Bottled Water	83.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.9	1.9	0.0	0.0	0.0
Confectionery	45.7	0.2	0.2	0.2	1.2	1.2	1.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Dairy	396.2	4.6	4.6	4.6	0.8	0.8	0.8	0.1	0.1	0.1	0.3	0.3	0.3	1.6	1.6	1.6
Eggs	18.6	0.0	0.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Fish	18.5	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Fruits	149.8	0.3	0.3	0.3	1.7	1.7	1.7	0.0	0.0	0.0	1.5	1.5	1.5	0.8	0.8	0.8
Groceries	245.0	4.3	4.4	4.4	2.1	2.2	2.1	0.5	0.5	0.5	0.2	0.2	0.2	0.5	0.6	0.5
Liquids	309.6	3.3	4.0	3.6	1.4	1.7	1.5	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.1	0.1
Meat	110.9	0.5	0.5	0.5	0.1	0.1	0.1	0.4	0.4	0.4	0.2	0.2	0.2	0.6	0.6	0.6
Potatoes	85.6	0.0	0.0	0.0	0.1	0.8	0.4	0.0	0.3	0.2	0.0	0.3	0.2	0.0	0.2	0.1
Soft Drinks	375.1	4.7	4.7	4.7	0.0	0.0	0.0	0.0	0.0	0.0	5.0	5.0	5.0	0.0	0.0	0.0
Vegetables	172.9	0.5	0.6	0.5	1.5	1.7	1.6	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.3	0.3
Total	2263.6	19.9	21.8	20.8	9.6	10.9	10.2	1.4	1.7	1.6	9.8	10.1	10.0	4.2	4.6	4.4

Table B6. Model results linking food categories to final waste management fate by plastic type. Source data used to develop Figure 3A, S1, and S2. All calculations are available from the model source code upon request.

Source	Min	Max	Mean	Target
Bakery	8.4	8.7	8.6	PE
Confectionery	1.5	1.5	1.5	PE
Dairy	28.7	28.7	28.7	PE
Eggs	0.0	5.8	2.9	PE
Fish	1.3	1.3	1.3	PE
Fruits	1.6	1.6	1.6	PE
Groceries	27.0	27.6	27.3	PE
Liquids	20.6	25.1	22.9	PE
Meat	2.9	2.9	2.9	PE
Potatoes	0.0	0.2	0.1	PE
Soft Drinks	29.6	29.6	29.6	PE
Vegetables	3.1	3.5	3.3	PE
Bakery	4.1	4.3	4.2	PP
Confectionery	7.3	7.3	7.3	PP
Dairy	4.8	4.8	4.8	PP
Fish	0.8	0.8	0.8	PP
Fruits	10.9	10.9	10.9	PP
Groceries	13.3	13.6	13.4	PP
Liquids	8.5	10.4	9.4	PP
Meat	0.6	0.6	0.6	PP
Potatoes	0.5	5.0	2.8	PP
Vegetables	9.2	10.6	9.9	PP
Bakery	1.0	1.0	1.0	PVC
Confectionery	1.5	1.5	1.5	PVC
Dairy	0.5	0.5	0.5	PVC
Groceries	3.1	3.2	3.2	PVC
Meat	2.5	2.5	2.5	PVC
Potatoes	0.2	2.1	1.2	PVC
Bakery	0.5	0.5	0.5	PET

Bottled Water	11.8	11.8	11.8	PET
Confectionery	0.3	0.3	0.3	PET
Dairy	1.8	1.8	1.8	PET
Fish	0.8	0.8	0.8	PET
Fruits	9.3	9.3	9.3	PET
Groceries	1.4	1.5	1.5	PET
Liquids	0.9	1.1	1.0	PET
Meat	1.3	1.4	1.4	PET
Potatoes	0.2	1.8	1.0	PET
Soft Drinks	31.4	31.4	31.4	PET
Vegetables	1.5	1.8	1.6	PET
Bakery	1.1	1.1	1.1	Other
Confectionery	0.7	0.7	0.7	Other
Dairy	9.8	9.8	9.8	Other
Eggs	0.0	0.9	0.5	Other
Fish	0.6	0.6	0.6	Other
Fruits	4.8	4.8	4.8	Other
Groceries	3.4	3.4	3.4	Other
Liquids	0.3	0.4	0.3	Other
Meat	4.0	4.0	4.0	Other
Potatoes	0.2	1.5	0.8	Other
Vegetables	1.5	1.8	1.6	Other
PE	22.0	24.1	23.1	Export
PE	81.0	88.7	84.9	Incineration
PE	2.5	2.7	2.6	Litter
PE	19.1	20.9	20.0	
Litter	2.1	1.6	2.0	Incineration
Litter	0.4	1.1	0.7	Leaked
PP	3.0	3.4	3.2	Export
PP	39.2	44.6	41.9	Incineration
PP	1.2	1.4	1.3	Litter
PP	16.6	18.9	17.7	
Litter	1.0	0.8	1.0	Incineration

Litter	0.2	0.5	0.3	Leaked
PVC	1.1	1.3	1.2	Export
PVC	6.8	8.5	7.7	Incineration
PVC	0.2	0.2	0.2	Litter
PVC	0.6	0.8	0.7	
Litter	0.1	0.1	0.1	Incineration
Litter	0.0	0.1	0.0	Leaked
PET	12.6	13.1	12.9	Export
PET	40.1	41.5	40.8	Incineration
PET	1.2	1.3	1.2	Litter
PET	7.4	7.7	7.5	
Litter	1.0	0.8	0.9	Incineration
Litter	0.2	0.5	0.3	Leaked
Other	5.0	5.5	5.3	Export
Other	17.8	19.7	18.7	Incineration
Other	0.5	0.6	0.6	Litter
Other	2.9	3.2	3.1	
Litter	0.4	0.3	0.4	Incineration
Litter	0.1	0.2	0.1	Leaked
Export	0.0	1.1	1.0	Eastern Asia
Export	8.2	9.0	8.6	Europe
Export	19.7	21.3	20.5	
Export	13.2	14.2	13.7	
Export	2.7	1.9	1.8	RoW
Eastern Asia	0.0	0.1	0.1	Leaked
South and Southeast Asia	1.5	6.9	3.4	Leaked
West and Central Asia	0.3	3.8	1.4	Leaked
RoW	0.1	0.2	0.1	Leaked
Europe	8.2	9.0	8.6	

Table B7. Model results linking food categories to final waste management fate. Source data used to develop Figure 3B, S3, and S4. All calculations are available from the model source code upon request.

Source	Min	Max	Mean	Target
Bakery	1.7	1.7	1.7	Export
Bottled Water	2.1	2.1	2.1	Export
Confectionery	0.7	0.7	0.7	Export
Dairy	6.1	6.1	6.1	Export
Eggs	0.0	1.0	0.5	Export
Fish	0.4	0.4	0.4	Export
Fruits	2.9	2.9	2.9	Export
Groceries	5.4	5.5	5.5	Export
Liquids	3.6	4.4	4.0	Export
Meat	1.4	1.4	1.4	Export
Potatoes	0.1	0.8	0.5	Export
Soft Drinks	10.0	10.0	10.0	Export
Vegetables	1.2	1.4	1.3	Export
Bakery	10.0	10.2	10.1	Incineration
Bottled Water	7.7	7.7	7.7	Incineration
Confectionery	7.5	7.5	7.5	Incineration
Dairy	30.0	30.0	30.0	Incineration
Eggs	0.0	4.4	2.2	Incineration
Fish	2.3	2.3	2.3	Incineration
Fruits	17.5	17.5	17.5	Incineration
Groceries	31.9	32.6	32.3	Incineration
Liquids	19.7	24.1	21.9	Incineration
Meat	7.8	7.9	7.8	Incineration
Potatoes	0.7	7.3	4.0	Incineration
Soft Drinks	39.8	39.8	39.8	Incineration
Vegetables	10.0	11.6	10.8	Incineration
Bakery	3.1	3.2	3.1	Recycled
Bottled Water	1.8	1.8	1.8	Recycled
Confectionery	2.7	2.7	2.7	Recycled

Dairy	8.6	8.6	8.6	Recycled
Eggs	0.0	1.2	0.6	Recycled
Fish	0.7	0.7	0.7	Recycled
Fruits	5.7	5.7	5.7	Recycled
Groceries	9.9	10.1	10.0	Recycled
Liquids	6.4	7.8	7.1	Recycled
Meat	1.9	1.9	1.9	Recycled
Potatoes	0.2	2.3	1.3	Recycled
Soft Drinks	10.0	10.0	10.0	Recycled
Vegetables	3.7	4.3	4.0	Recycled
Bakery	0.3	0.3	0.3	Litter
Bottled Water	0.2	0.2	0.2	Litter
Confectionery	0.2	0.2	0.2	Litter
Dairy	0.9	0.9	0.9	Litter
Eggs	0.0	0.1	0.1	Litter
Fish	0.1	0.1	0.1	Litter
Fruits	0.5	0.5	0.5	Litter
Groceries	1.0	1.0	1.0	Litter
Liquids	0.6	0.7	0.7	Litter
Meat	0.2	0.2	0.2	Litter
Potatoes	0.0	0.2	0.1	Litter
Soft Drinks	1.2	1.2	1.2	Litter
Vegetables	0.3	0.4	0.3	Litter
Export	1.0	1.1	1.0	Eastern Asia
Export	0.0	0.0	0.0	Europe
Export	19.7	21.3	20.5	South and Southeast Asia
Export	13.2	14.2	13.7	West and Central Asia
Export	1.8	1.9	1.8	Rest of World (RoW)
Eastern Asia	0.0	0.1	0.1	Leaked
South and Southeast Asia	1.5	6.9	3.4	Leaked
West and Central Asia	0.3	3.8	1.4	Leaked
Rest of World (RoW)	0.1	0.2	0.1	Leaked

Europe	0.0	0.0	0.0	Recycle/EU-Disposed
Litter	4.8	3.7	4.4	Incineration
Litter	0.8	2.5	1.5	Leaked

Table B8. Trade partners of total Dutch plastic waste exports (in kt). Indirect exports are shipped through intermediary partners while direct exports are shipped directly from the Netherlands to the final import destination.

Final Importer	Min Direct exports	Min Indirect exports	Min Total exports	Max Direct exports	Max Indirect exports	Max Total exports	Mean Direct exports	Mean Indirect exports	Mean Total exports
Turkey	6.75	6.08	12.84	7.27	6.60	13.87	7.01	6.34	13.35
Indonesia	4.63	1.69	6.32	4.98	1.82	6.80	4.81	1.75	6.56
India	1.32	1.63	2.95	1.44	1.76	3.21	1.38	1.70	3.08
Viet Nam	1.28	1.27	2.55	1.38	1.37	2.75	1.33	1.32	2.65
Malaysia	0.70	5.49	6.19	0.76	5.95	6.72	0.73	5.72	6.45
Republic of Korea	0.23	0.39	0.62	0.25	0.43	0.69	0.24	0.41	0.65
Other Asia, not elsewhere specified	0.21	0.42	0.63	0.23	0.46	0.69	0.22	0.44	0.66
Canada	0.16	0.06	0.21	0.17	0.07	0.23	0.16	0.06	0.22
Pakistan	0.15	0.45	0.61	0.17	0.50	0.66	0.16	0.47	0.63
Serbia	0.13	0.09	0.23	0.14	0.10	0.24	0.14	0.10	0.24
Singapore	0.13	0.04	0.17	0.14	0.04	0.19	0.14	0.04	0.18
China	0.06	0.28	0.34	0.07	0.30	0.37	0.07	0.29	0.35
Saudi Arabia	0.05	0.05	0.10	0.06	0.06	0.12	0.05	0.06	0.11
Australia	0.02	0.04	0.06	0.02	0.05	0.07	0.02	0.05	0.07

South Africa	0.02	0.03	0.05	0.02	0.03	0.06	0.02	0.03	0.05
USA, Puerto Rico and US Virgin Islands	0.01	0.30	0.32	0.02	0.34	0.36	0.02	0.32	0.34
Russian Federation	0.01	0.06	0.07	0.01	0.07	0.08	0.01	0.06	0.08
Mexico	0.01	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.03
Brazil	0.01	0.03	0.03	0.01	0.03	0.04	0.01	0.03	0.03
Thailand	0.00	0.31	0.31	0.00	0.34	0.34	0.00	0.32	0.33
Nigeria	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Philippines	0.00	0.03	0.03	0.00	0.03	0.03	0.00	0.03	0.03
New Zealand	0.00	0.03	0.03	0.00	0.04	0.04	0.00	0.03	0.04
Ethiopia	0.00		0.00	0.00		0.00	0.00		0.00
Argentina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japan	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
Chile	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01
Morocco	0.00	0.04	0.04	0.00	0.05	0.05	0.00	0.04	0.04
United Republic of Tanzania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Israel	0.00	0.02	0.02	0.00	0.02	0.02	0.00	0.02	0.02
Bosnia Herzegovina	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01
Sudan	0.00		0.00	0.00		0.00	0.00		0.00

Suriname	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ghana	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01
Bahrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gambia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equatorial Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Azerbaijan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.00	0.34	0.34	0.00	0.36	0.36	0.00	0.35	0.35
Algeria		0.00	0.00		0.00	0.00		0.00	0.00
Angola		0.00	0.00		0.00	0.00		0.00	0.00
Armenia		0.00	0.00		0.00	0.00		0.00	0.00
Austria		0.36	0.36		0.39	0.39		0.38	0.38
Bangladesh		0.03	0.03		0.03	0.03		0.03	0.03
Belarus		0.04	0.04		0.04	0.04		0.04	0.04
Belgium		0.54	0.54		0.58	0.58		0.56	0.56
Brunei Darussalam		0.00	0.00		0.00	0.00		0.00	0.00
Bulgaria		0.17	0.17		0.18	0.18		0.17	0.17
Cabo Verde		0.00	0.00		0.00	0.00		0.00	0.00
Cambodia		0.00	0.00		0.00	0.00		0.00	0.00
Cameroon		0.00	0.00		0.00	0.00		0.00	0.00

China, Macao Special Administrative Region	0.00	0.00	0.00	0.00	0.00	0.00
Colombia	0.00	0.00	0.00	0.00	0.00	0.00
Comoros	0.00	0.00	0.00	0.00	0.00	0.00
Congo	0.00	0.00	0.00	0.00	0.00	0.00
Costa Rica	0.00	0.00	0.00	0.00	0.00	0.00
Côte d'Ivoire	0.00	0.00	0.00	0.00	0.00	0.00
Croatia	0.04	0.04	0.05	0.05	0.04	0.04
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00
Czechia	0.44	0.44	0.49	0.49	0.47	0.47
Denmark	0.18	0.18	0.19	0.19	0.19	0.19
Djibouti	0.00	0.00	0.00	0.00	0.00	0.00
Ecuador	0.00	0.00	0.00	0.00	0.00	0.00
Egypt	0.02	0.02	0.03	0.03	0.02	0.02
El Salvador	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	0.03	0.03	0.03	0.03	0.03	0.03
Finland	0.01	0.01	0.02	0.02	0.02	0.02
France, Monaco	0.62	0.62	0.68	0.68	0.65	0.65
Gabon	0.00	0.00	0.00	0.00	0.00	0.00
Georgia	0.00	0.00	0.00	0.00	0.00	0.00

Germany	1.05	1.05	1.15	1.15	1.10	1.10
Greece	0.05	0.05	0.06	0.06	0.06	0.06
Guatemala	0.00	0.00	0.00	0.00	0.00	0.00
Guinea	0.00	0.00	0.00	0.00	0.00	0.00
Honduras	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	0.05	0.05	0.06	0.06	0.05	0.05
Iceland	0.00	0.00	0.00	0.00	0.00	0.00
Iran	0.00	0.00	0.00	0.00	0.00	0.00
Ireland	0.24	0.24	0.26	0.26	0.25	0.25
Italy	0.58	0.58	0.64	0.64	0.61	0.61
Jordan	0.00	0.00	0.00	0.00	0.00	0.00
Kenya	0.01	0.01	0.01	0.01	0.01	0.01
Kuwait	0.00	0.00	0.00	0.00	0.00	0.00
Kyrgyzstan	0.00	0.00	0.00	0.00	0.00	0.00
Lao People's Dem. Rep.	0.03	0.03	0.03	0.03	0.03	0.03
Latvia	0.18	0.18	0.20	0.20	0.19	0.19
Lebanon	0.01	0.01	0.01	0.01	0.01	0.01
Libya	0.00	0.00	0.00	0.00	0.00	0.00
Lithuania	0.24	0.24	0.26	0.26	0.25	0.25
Luxembourg	0.14	0.14	0.16	0.16	0.15	0.15

Malawi	0.00	0.00	0.00	0.00	0.00	0.00
Malta	0.00	0.00	0.00	0.00	0.00	0.00
Mauritania	0.00	0.00	0.00	0.00	0.00	0.00
Mauritius	0.00	0.00	0.00	0.00	0.00	0.00
Myanmar	0.00	0.00	0.00	0.00	0.00	0.00
New Caledonia	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	0.00	0.00	0.00	0.00	0.00	0.00
Norway, Svalbard and Jan Mayen	0.01	0.01	0.01	0.01	0.01	0.01
Oman	0.01	0.01	0.01	0.01	0.01	0.01
Panama	0.00	0.00	0.00	0.00	0.00	0.00
Paraguay	0.00	0.00	0.00	0.00	0.00	0.00
Peru	0.00	0.00	0.00	0.00	0.00	0.00
Plurinational State of Bolivia	0.00	0.00	0.00	0.00	0.00	0.00
Poland	0.78	0.78	0.86	0.86	0.82	0.82
Portugal	0.40	0.40	0.44	0.44	0.42	0.42
Qatar	0.00	0.00	0.00	0.00	0.00	0.00
Republic of Moldova	0.00	0.00	0.00	0.00	0.00	0.00
Romania	0.15	0.15	0.17	0.17	0.16	0.16

Saint Lucia	0.00	0.00	0.00	0.00	0.00	0.00
Samoa	0.00	0.00	0.00	0.00	0.00	0.00
Senegal	0.03	0.03	0.03	0.03	0.03	0.03
Seychelles	0.00	0.00	0.00	0.00	0.00	0.00
Slovakia	0.17	0.17	0.19	0.19	0.18	0.18
Slovenia	0.20	0.20	0.22	0.22	0.21	0.21
Spain	0.73	0.73	0.81	0.81	0.77	0.77
Sri Lanka	0.00	0.00	0.00	0.00	0.00	0.00
State of Palestine	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	0.06	0.06	0.07	0.07	0.06	0.06
Switzerland, Liechtenstein	0.21	0.21	0.23	0.23	0.22	0.22
Syria	0.00	0.00	0.00	0.00	0.00	0.00
The Former Yugoslav Republic of Macedonia	0.00	0.00	0.00	0.00	0.00	0.00
Togo	0.00	0.00	0.00	0.00	0.00	0.00
Tunisia	0.01	0.01	0.01	0.01	0.01	0.01
United Arab Emirates	0.03	0.03	0.03	0.03	0.03	0.03
United Kingdom	0.56	0.56	0.61	0.61	0.58	0.58

Uzbekistan	0.05	0.05	0.05	0.05	0.05	0.05
Venezuela	0.00	0.00	0.00	0.00	0.00	0.00
Yemen	0.09	0.09	0.10	0.10	0.10	0.10
Zambia	0.00	0.00	0.00	0.00	0.00	0.00
Zimbabwe	0.00	0.00	0.00	0.00	0.00	0.00

Table B9. Leakage points of Dutch plastic food packaging to the marine environment in tons/yr. The minimum and maximum values are calculated using ranges of plastic packaging intensities for different food items, ranges of national mismanaged waste fractions, and ranges of mismanaged waste conversion to plastic debris.

Final Importer	UN Group	Mean Plastic leakage to ocean	Min. Plastic leakage to ocean	Max. Plastic leakage to ocean
Netherlands	Europe	1404.6	814.0	2321.4
Turkey	West and Central Asia	1393.3	317.5	3715.8
Malaysia	South and Southeast Asia	1112.9	510.4	2229.9
Indonesia	South and Southeast Asia	850.0	218.1	2193.0
India	South and Southeast Asia	647.9	367.4	1094.7
Viet Nam	South and Southeast Asia	556.4	313.6	945.8
Pakistan	South and Southeast Asia	142.1	78.3	246.8
China	Eastern Asia	63.1	34.7	109.7
Ukraine	Europe (not EU)	54.9	24.7	111.3
Thailand	South and Southeast Asia	53.7	27.1	100.4
Poland	Europe	27.7	13.7	52.7
Other Asia, not elsewhere specified	Other	21.4	12.3	35.7
Yemen	West and Central Asia	17.1	9.4	29.8
Romania	Europe	11.7	5.9	21.9
Bulgaria	Europe	10.2	3.8	22.9
Bangladesh	South and Southeast Asia	7.5	4.0	13.3
South Africa	Sub-Saharan Africa	7.4	3.9	13.4

Lithuania	Europe	7.2	3.1	15.1
Morocco	North Africa	6.8	3.7	12.1
Philippines	South and Southeast Asia	6.7	3.8	11.3
Senegal	Sub-Saharan Africa	5.9	3.1	10.6
Egypt	North Africa	4.5	2.3	8.2
Slovenia	Europe	3.5	0.3	10.6
Russian Federation	Europe (not EU)	3.5	1.8	6.4
Latvia	Europe	3.3	0.0	11.0
Ghana	Sub-Saharan Africa	2.4	1.3	4.3
Brazil	Latin America	2.1	0.4	5.8
Croatia	Europe	1.9	0.6	4.6
Bosnia Herzegovina	Europe (not EU)	1.8	0.8	3.5
Mexico	Latin America	1.6	0.5	3.9
Kenya	Sub-Saharan Africa	1.4	0.8	2.5
Tunisia	North Africa	1.3	0.6	2.7
Nigeria	Sub-Saharan Africa	1.2	0.6	2.4
Saudi Arabia	West and Central Asia	1.1	0.0	3.7
Lebanon	West and Central Asia	0.8	0.4	1.5
Côte d'Ivoire	Sub-Saharan Africa	0.7	0.4	1.3
Myanmar	South and Southeast Asia	0.6	0.3	1.1
Algeria	North Africa	0.6	0.3	1.1
Djibouti	Sub-Saharan Africa	0.5	0.2	0.9
Estonia	Europe	0.4	0.1	0.9
Sri Lanka	South and Southeast Asia	0.4	0.2	0.7
Chile	Latin America	0.4	0.1	0.8
Republic of Moldova	Europe (not EU)	0.3	0.1	0.4

Ecuador	Latin America	0.3	0.1	0.6
Libya	North Africa	0.2	0.1	0.4
Cameroon	Sub-Saharan Africa	0.1	0.1	0.2
United Republic of Tanzania	Sub-Saharan Africa	0.1	0.1	0.2
State of Palestine	West and Central Asia	0.1	0.0	0.4
Mauritius	Sub-Saharan Africa	0.1	0.0	0.4
Honduras	Latin America	0.1	0.0	0.2
Cambodia	South and Southeast Asia	0.1	0.0	0.1
Argentina	Latin America	0.1	0.0	0.1
Sudan	North Africa	0.1	0.0	0.1
Oman	West and Central Asia	0.1	0.0	0.2
Jordan	West and Central Asia	0.0	0.0	0.1
Plurinational State of Bolivia	Latin America	0.0	0.0	0.1
Panama	Latin America	0.0	0.0	0.1
Suriname	Latin America	0.0	0.0	0.1
Nicaragua	Latin America	0.0	0.0	0.1
Togo	Sub-Saharan Africa	0.0	0.0	0.0
China, Macao Special Administrative Region	South and Southeast Asia	0.0	0.0	0.1
Guatemala	Latin America	0.0	0.0	0.0
Venezuela	Latin America	0.0	0.0	0.1
Israel	West and Central Asia	0.0	0.0	0.1
Cyprus	Europe	0.0	0.0	0.1
Bahrain	West and Central Asia	0.0	0.0	0.0
Singapore	Other	0.0	0.0	0.0
Peru	Latin America	0.0	0.0	0.0
Colombia	Latin America	0.0	0.0	0.0

Cabo Verde	Sub-Saharan Africa	0.0	0.0	0.0
Malta	Europe	0.0	0.0	0.0
El Salvador	Latin America	0.0	0.0	0.0
Syria	West and Central Asia	0.0	0.0	0.0
Georgia	Europe (not EU)	0.0	0.0	0.0
Saint Lucia	Latin America	0.0	0.0	0.0
United Arab Emirates	West and Central Asia	0.0	0.0	0.0
Gambia	Sub-Saharan Africa	0.0	0.0	0.0
Iran	South and Southeast Asia	0.0	0.0	0.0
Equatorial Guinea	Sub-Saharan Africa	0.0	0.0	0.0
Seychelles	Sub-Saharan Africa	0.0	0.0	0.0
Mauritania	Sub-Saharan Africa	0.0	0.0	0.0
Comoros	Sub-Saharan Africa	0.0	0.0	0.0
Brunei Darussalam	South and Southeast Asia	0.0	0.0	0.0
Samoa	Oceania	0.0	0.0	0.0
Gabon	Sub-Saharan Africa	0.0	0.0	0.0
Guinea	Sub-Saharan Africa	0.0	0.0	0.0
Congo	Sub-Saharan Africa	0.0	0.0	0.0
Kuwait	West and Central Asia	0.0	0.0	0.0
Costa Rica	Latin America	0.0	0.0	0.0
Qatar	West and Central Asia	0.0	0.0	0.0
Republic of Korea	Eastern Asia	0.0	0.0	0.0
Portugal	Europe	0.0	0.0	0.0
Spain	Europe	0.0	0.0	0.0
Italy	Europe	0.0	0.0	0.0
Greece	Europe	0.0	0.0	0.0

United Kingdom	Europe	0.0	0.0	0.0
Germany	Europe	0.0	0.0	0.0
France, Monaco	Europe	0.0	0.0	0.0
Ireland	Europe	0.0	0.0	0.0
New Zealand	Oceania	0.0	0.0	0.0
Belgium	Europe	0.0	0.0	0.0
USA, Puerto Rico and US Virgin Islands	North America	0.0	0.0	0.0
Canada	North America	0.0	0.0	0.0
Sweden	Europe	0.0	0.0	0.0
Finland	Europe	0.0	0.0	0.0
Denmark	Europe	0.0	0.0	0.0
Australia	Oceania	0.0	0.0	0.0
Japan	Eastern Asia	0.0	0.0	0.0
Iceland	Europe	0.0	0.0	0.0
Norway, Svalbard and Jan Mayen	Europe	0.0	0.0	0.0
New Caledonia	Oceania	0.0	0.0	0.0

Appendix C – Appendix to Chapter 4

Appendix C includes the following supporting information for chapter 4:

- Model comparison
- Sensitivity Analysis
- Figure C1
- Table C6

The remaining supplementary materials for chapter 4 can be found at https://github.com/nicolas-navarre/Global-Plastic-Pollution and includes the following:

- Supplemental Information Table C1. Country-level input statistics
- Supplemental Information Table C2. Country-level pollution summaries
- Supplemental Information Table C3. Country-level trade network
- Supplemental Information Table C4. Port-level pollution summaries
- Supplemental Information Table C5. River-level pollution summaries

Model comparison

We model that in 2019, 235 Mt of plastic waste were generated across 210 countries, territories, and special administrative regions (SARs) of which 92 Mt (range: 69-115 Mt) was mismanaged and leaked to the environment. These result are in-line with the estimate of Lau et al. (2020), who predict approximately 230 Mt of global plastic generation of which 100 Mt is mismanaged in 2016, and Lebreton and Andrady (2019), who calculated 181 Mt plastic waste was generated in 2015 of which 80Mt (60-99 Mt) was leaked to the environment (Lau et al., 2020; Lebreton & Andrady, 2019b).

From this domestic mismanaged waste, we model that 34 Mt (21-48 Mt) entered the aquatic environment (i.e. lakes larger than 100 km^2, oceans, and rivers with a 50% chance, or less, of intermittence of at least 1 day per year; Fig. 1). Our estimate of plastic waste entering the aquatic environment, is within the uncertainty ranges of the estimate presented by Borrelle et al. (2020), who modeled values of approximately 30Mt for 2019 (Borrelle et al., 2020). Most global plastic leakage to aquatic environments occurs in Asia (25 Mt), followed by Australasia (9 Mt; 8-10 Mt), and Africa (8 Mt; 7-9 Mt), whereby, China (8 Mt), Indonesia (6 Mt), and Russia (3 Mt) represent nations with significant sources of aquatic plastic pollution. The most polluted watersheds were estimated to be the Yangtse in Asia (3 Mt), the Volga in Europe (1 Mt) and the Congo in Africa (1 Mt).

We model that 14 Mt (9-18 Mt) of plastic waste directly entered coastal environments (i.e. aquatic environments within 50 km of a coastline; Fig. 1). Although our estimate is higher than Jambeck et al.'s 2010 estimate of 4.8-12.7 Mts, our global average conversion of mismanaged waste plastic to coastal aquatic environments of 14%, calculated using spatially detailed mismanaged waste and aquatic features, is lower than Jambeck et al.'s original global assumption of 25% (Jambeck et al., 2015b). The expected increase in total waste reaching coastal environments is a result of increased plastic waste generation per capita and population growth between 2010 and 2019 (Kaza et al., 2018; WorldPop, 2018).

Finally, we model that 1.7 Mt (1.1-2.2 Mt) of plastic waste entered oceans via rivers in 2019. Although estimates of plastic waste transported to oceans have yielded a wide range of results both at the

global (0.47-2.75 Mt) and river scale, our results are generally in line with previous estimates of both scales that have included macroplastics (Lebreton et al., 2017; Meijer et al., 2021b; OECD, 2022; Schmidt et al., 2017). Our results indicate that the river to ocean plastic flux is dominated by pollution within Asian rivers, though direct riverine comparisons are difficult as the ranges of previous estimates span four orders of magnitude. For instance, plastic pollution estimates in the Yangtze River range between 471-1.54*10^6 tons and 10-1.76*10^5 tons in the Indus River (González-Fernández et al., 2023). Nonetheless, our estimates by river generally fall within these wide ranges (river estimates available in Supplementary Table 5). The vast majority of ocean plastic originates in the marine environments of the Malay Archipelago and Chinese coastline (910 kilotons; kt), but are also found to pollute the Bay of Bengal (77 kt), the Caribbean Sea (46 kt), Northern European Seas (27 kt) and the Gulf of Guinea (26 kt), threatening biodiverse Ecomarine regions across the planet (Jenkins & Van Houtan, 2016b; Olson et al., 2001).

Sensitivity analysis

The ranges presented in this paper are the result of utilizing various sources of national scale plastic waste mismanagement rates, trade patterns, and aquatic environment reaches. In certain countries, national plastic waste mismanagement rates vary significantly depending on the reporting sources (e.g. Russia 18.5%-97.5% mismanagement rate) generating a significant amount of uncertainty (Kaza et al., 2018; Lebreton & Andrady, 2019b). Furthermore, the comparative fate of imported plastic waste compared to domestically produced plastic waste remains unclear. High-income countries typically guarantee the fate of their plastic waste exports as recyclate; however, research indicates that plastic waste imports are not more likely to be recycled than domestic waste and are frequently mixed with it (Gobbi et al., 2019; Liang et al., 2021). Moreover, contaminated plastic waste that is not suitable for recycling is routinely mislabeled as recyclable to avoid trade restriction (Basel Convention COP, 2023; Khan, 2020). In certain cases, waste is imported to be recycled, despite importing parties having no infrastructure to do so, increasing the likelihood of the imports being mismanaged (Gündoğdu & Walker, 2021; UNEP, 2020).

In addition to unclear mismanagement rates of both domestic and imported waste, including trade adds an additional layer regarding international and intra-national re-exports. Although we model one generation of re-exports, untangling the plastic waste trade network remains extremely arduous. Countries are not obligated to report re-exports as such, and may export plastic waste illegally or report the waste under unrelated HS codes (Bishop et al., 2020c; Gündoğdu & Walker, 2021; Liang et al., 2021). For example, in 2019 authorities intercepted plastic waste illegally exported from Canada to India, via Belgium (Basel Convention COP, 2023; Khan, 2020). However, with congested ports, limited workforces, and massive volumes of goods to monitor, even suspicious trade cargo are typically not inspected (Khan, 2020). As a result, effectively tracking the original source, true quality, and true quantities of plastic waste exports remains an obstacle to develop global inventories of plastic waste sources (Simon et al., 2021).

Probabilistic models attempt to incorporate the influence of many parameters such as wind, terrain slope, and precipitation, river flow, and stream order however these can be difficult to properly calibrate, particularly at a global scale (Meijer et al., 2021b; Roebroek et al., 2022). Other modeling approaches include observational extrapolation or linear regression models connected to environmental drivers, though these may be skewed by incomplete or unrepresentative samples (Mai et al., 2020; Roebroek et al., 2022; Weiss et al., 2021). These different techniques have led estimates of plastic litter in the environment spanning more than four order of magnitudes across the literature (González-Fernández et al., 2023). In the case of our probabilistic model, the relationship between mismanaged waste and the aquatic environment was a highly uncertain parameter. We modeled the spatial reach of the aquatic environment by using state-of-the-art hydrological information on the location of permanent surface water bodies, however the extent of the aquatic environment varies drastically depending on probability of intermittence used as the minimum threshold of a permanent water body (Messager et al., 2021).

To explore the influence of these uncertain factors on our model, we performed a sensitivity analysis on five key input parameters (Figure C1). First, we develop minimum and maximum plastic mismanagement waste rates for each country using the data reported by Kaza et al. (2018) and Lebreton and Andrady (2019), and their mean as a midpoint estimate. We find this decreases total aquatic plastic waste to a

minimum of 23 Mt and a maximum of 50 Mt, highlighting the wide ranges of expected mismanaged wastes (Supplementary Table 1) for certain critical countries that generate large amounts of plastic waste annually such as China (range: 11Mt), Russia (range: 5Mt) and Indonesia (range: 1 Mt). Secondly, we modified which waste disposal pathways may be considered mismanaged for each income level. In this analysis we only consider dumped and unaccounted waste across all income levels as mismanaged waste (Extended Data Table 1). Doing so decreases mismanaged plastic waste to 28 Mt, with Indonesia (4 Mt) and China (2 Mt) accounting for the majority of this decrease. These two countries generate large amounts of plastic waste, of which more than 60% is disposed of in 'unspecified landfills' (Supplementary Table 6). Nevertheless, excluding these two countries, the majority of mismanaged waste in the midpoint estimate is reported as dumped or is unaccounted for, with only a fraction of mismanaged waste being considered as disposed of in various types of landfills (Supplementary Table 6. Thirdly, we adjusted the rate of waste mismanagement of imports by □ 50% (maximum of 100%) of the mismanagement rate of domestic waste. Doing so creates a range between 0.7-2.1Mt of trade plastic waste reaching the aquatic environment, most affecting Malaysia (range: 0.3 Mt), Vietnam (range: 0.3 Mt), and Thailand (range: 0.2 Mt) highlighting the importance of ensuring adequate plastic waste disposal capacity in all major importing nations. Fourthly, we explored the impact of removing our re-export modeling due to the inherent uncertainty from a lack of reported data. This slightly reduces our estimate to 1.2 Mt (from 1.5 Mt), as the majority of intermediaries were found to be high-income countries before reaching their final destination. Without the re-export algorithm these high-income countries, with low mismanagement rates become the destination of trade plastic waste, reducing the global mismanagement rate of traded plastics. With this form of the plastic waste trade, we expect Vietnam would leak 0.15 Mt less plastic waste, Thailand 0.08 Mt, and Malaysia 0.05 Mt. Finally, we altered the spatial reach of the aquatic environment, adjusting our criteria from rivers with a 50% chance or less of intermittence of at least 1 day per year to rivers with a 25% chance or less for a minimum estimate and a 75% chance or less for a maximum estimate. This parameter yields a total range of 25-43 Mt of total plastic waste entering the aquatic environment (Figure C1), particularly altering estimates in Asia, with China (range: 4 Mt),

Thailand (range: 2Mt), India (range: 2Mt), Indonesia (range: 2Mt) accounting for the largest disparities.

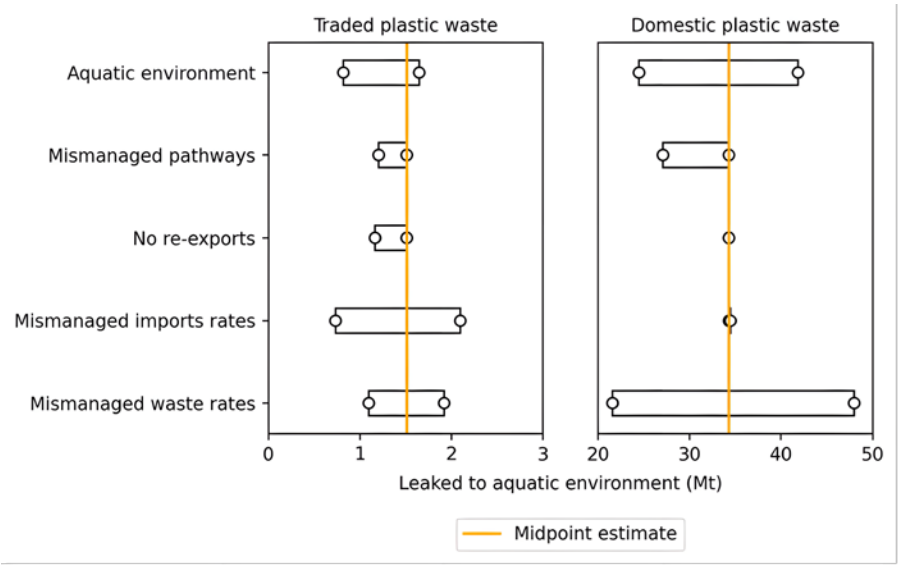

Figure C1. Results of sensitivity analysis. 'Mismanaged waste rates' indicates the ranges in domestic mismanaged waste rates provided by Kaza et al. (2018) and Lebreton and Andrady (2019). 'Mismanaged import rates' indicates a change of plus or minus 50% (maximum of 100%) in mismanaged rates of imports compared to domestic waste. 'No re-exports' removes the re-export algorithm applied to net-exporters (see methods). 'Mismanaged pathways' adjusts the mismanaged waste rates of Kaza et al. (2018) using only dumped or unaccounted waste (see Table C6). 'Aquatic environment' adjusts the criteria of perennial rivers from 25-75% chance of intermittence for at least 1 day in year (midpoint = 50%).

Table C6. Disposal pathways of plastic waste and their contribution to mismanagement. In red are pathways assumed to contribute to mismanagement in our midpoint estimate. These pathways are reduced to 0 in our sensitivity analysis to better understand their contribution to total plastic waste mismanagement.

	Mismanaged waste (%)			
	HIC	**UMC**	**LMC**	**LIC**
Open dump	100	100	100	100
Incineration	0	0	0	0
Unspecified landfill	0	0	0	0
Controlled landfill	0	0	0	0
Sanitary landfill gas	0	0	0	0
Recycling	0	0	0	0
Other	0	0	0	0
Unaccounted	100	100	100	100
Marine Dump	100	100	100	100

Appendix D – Appendix to Chapter 5

The remaining supplementary materials for chapter 5 can be found at https://github.com/nicolas-navarre/Temporal-plastic-pollution and includes the following:

- Table D1-3