Supplementary Material

*for*

The knowns and unknowns in our understanding of how plastics impact climate change: A systematic review

Xia Zhu1\*, Justin Konik2, Holly Kaufman3

1Department of Ocean Sciences, Memorial University of Newfoundland, St. John’s, Newfoundland and Labrador, Canada

2Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, Canada

3World Resources Institute, San Francisco, California, United States of America

**\* Correspondence:**Corresponding Author  
alice.zhu@mun.ca

Number of figures: 2

Number of tables: 1

# Supplementary Text 1 – Search query

The following three search queries were combined and used to identify relevant studies between January 1 1900 and August 29 2023 in Web of Science All Databases:

1. Studies relevant to greenhouse gas emissions from the plastics lifecycle:

(plastic\* OR microplastic\* OR nanoplastic\* OR plastic pollution) AND (greenhouse gas\* OR GHG\* OR carbon dioxide OR methane OR lifecycle\* OR black carbon OR climate change OR recycle OR recycling OR landfill OR composting OR dumping OR incineration OR incinerate OR burning)

1. Studies relevant to the impact of plastics on carbon cycling:

(plastic\* OR microplastic\* OR nanoplastic\* OR plastic pollution) AND (ocean carbon sink OR marine carbon OR DOC OR dissolved organic carbon OR marine photosynthesis OR bacterial remineralization OR microbial loop OR biological carbon pump OR biological pump OR marine snow OR (phytoplankton AND (effect\* OR toxicity)) OR (zooplankton AND (effect\* OR toxicity)) OR ballasting OR grazing OR soil respiration OR soil carbon OR blue carbon ecosystem OR carbon fixation OR (microbial AND (effect\* OR toxicity)) OR carbon cycl\*)

1. Studies relevant to the impact of plastics on Earth’s radiation budget:

(plastic\* OR microplastic\* OR nanoplastic\* OR plastic pollution) AND (radiation\* OR radiative forcing OR Earth’s radiation budget OR aerosol\* OR cloud\* OR albedo OR radiative)

# Supplementary Text 2 – Note about bioplastics

The focus of this review was on conventional plastic polymers and their impact on climate, i.e., studies solely focusing on bioplastics were excluded. “Bioplastics” is an umbrella term referring to a variety of plastic materials with different properties and applications (European Bioplastics, n.d.; Lambert and Wagner, 2017). The expectation is that they possess the same desirable qualities as their petroleum-based counterparts, but with the added benefit of being safer and more sustainable; however, expectation does not always meet reality (5 Gyres Institute, 2018; Napper and Thompson, 2019; Zimmermann et al., 2020). Some of the studies conducted investigations of conventional polymers as well as bioplastic polymers (as separate treatments, not mixed together in the same treatment); however, we only included the treatments with conventional polymers in our analyses. We chose to focus our study on conventional polymers because, while bioplastics are an emerging stream of plastic polymers with accelerating production volumes, at the moment they do not make up much of the global production volume (< 1% in 2022) (European Environment Agency, 2024). Due to their low production volume, we anticipate that their effects on climate are not significant at this point in time. However, their growing consumption calls for future research to determine how they may contribute to climate change.

# Supplementary Text 3 – Extracting relevant information

3.1 Studies of GHG emissions from the plastics lifecycle

From the studies that investigated GHG and black carbon emissions from the plastics lifecycle, we extracted information on the year of publication, geographical focus of the study, relevant stage(s) of the plastics lifecycle, and absolute emissions and/or emissions intensity (amount of emissions per amount of plastic) values where applicable. The absolute GHG emissions and emissions intensities were grouped into the following lifecycle stages: primary production, product manufacture, transportation and consumption, and after use. The primary production stage encompasses all activities from the extraction of fossil fuels through to the production of virgin pellets. The product manufacture stage describes the formation of plastic products. The transportation stage describes the movement of plastic products from production plant to consumer, including import and export activities. The consumption stage refers to plastic products in their useful stage of life. The two subcategories within the after-use stage are waste management and unmanaged (or mismanaged) waste. Waste management strategies are categorized as recycling (unspecified), mechanical recycling, chemical recycling, incineration, open burning, opening dumping, and landfilling.

3.2 Impacts of plastics on carbon sequestration

Studies on the impact of plastics on Earth’s carbon sinks were grouped into terrestrial, coastal blue carbon, and marine ecosystems. For terrestrial and coastal blue carbon ecosystem studies, we extracted information on the article type, study approach, year of publication, characteristics of the plastics measured in the field/used in experiments, characteristics of the soil, experimental details (length, control, treatments; if applicable), if the study assessed the co-impact of plastic with another stressor, climate-relevant endpoints measured (if applicable), and direction of effect on climate change (if applicable). For marine ecosystem studies, we extracted information on article type, study approach, year of publication, characteristics of the plastics measured in the field/used in experiments, experimental details (length, control, treatments; if applicable) if the study assessed the co-impact of plastics with another stressor, climate-relevant endpoints measured (if applicable), and direction of effect on climate change (if applicable).

3.3 Impact of plastics on Earth’s radiation budget

Studies on the radiative impacts of plastics were categorized as direct RF (via aerosols), indirect RF (via interaction with clouds), and albedo or melting (change in radiative properties of surfaces, ice, or snow) studies. For each study, we extracted information on the article type, study approach, year of publication, characteristics of the plastics measured in the field/used in experiments, experimental details (if applicable), climate-relevant endpoints measured (if applicable), and direction of effect on climate change (if applicable).

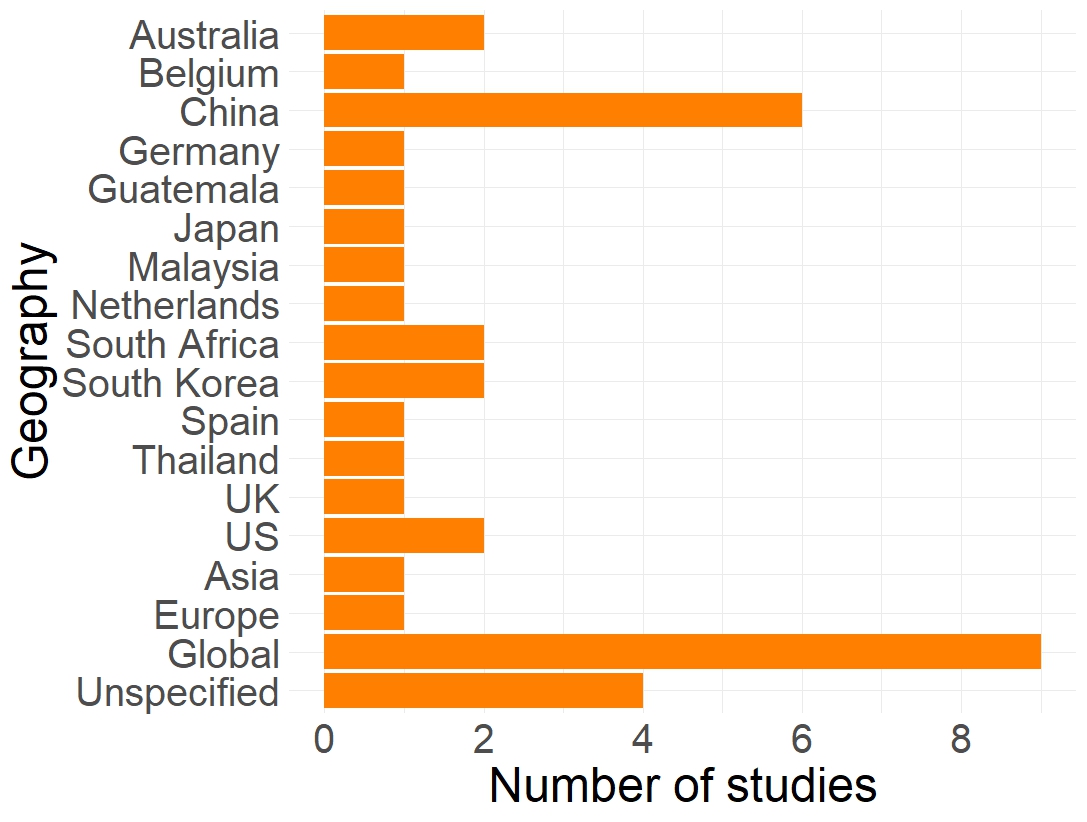
# Supplementary Text 4 – Summary of publication trends

The volume of literature exploring the impacts of plastics on climate change has grown considerably over recent decades (**Figure S1**). In the year 2000, there was one study published pertaining to GHG emissions from the plastics lifecycle, and no studies on the impact of plastics on carbon cycling or radiation; in contrast, in 2023, 9 lifecycle studies, 32 carbon cycling studies, and 3 radiation studies were published. (**Figure S1**).

A graph of a number of years

AI-generated content may be incorrect.

**Figure S1.** Quantity of publications over time which pertain to the impact of plastics on climate, both tested and speculated. Publications are separated by category of impact – lifecycle GHG emissions, carbon cycle, and radiation.



**Figure S2**. Number of studies pertaining to GHG emissions from the plastics lifecycle by geography - the global scale, continental scale, or a specific country.

**Table S1.** List of peer-reviewed articles included in systematic review.

|  |  |
| --- | --- |
| **Citation** | **Impact Category** |
| (Rahim and Abdul Raman, 2017) | lifecycle GHG emissions |
| (Wu et al., 2022) | lifecycle GHG emissions |
| (Ding et al., 2023) | lifecycle GHG emissions |
| (Manzhi Liu et al., 2023) | lifecycle GHG emissions |
| (Royer et al., 2018) | lifecycle GHG emissions |
| (Sevigné-Itoiz et al., 2015) | lifecycle GHG emissions |
| (Smith et al., 2022) | lifecycle GHG emissions |
| (Liu et al., 2022) | lifecycle GHG emissions |
| (Ross and Evans, 2003) | lifecycle GHG emissions |
| (Zheng and Suh, 2019) | lifecycle GHG emissions |
| (Bora et al., 2020) | lifecycle GHG emissions |
| (Demetrious and Crossin, 2019) | lifecycle GHG emissions |
| (Astrup et al., 2009) | lifecycle GHG emissions |
| (Gradus et al., 2017) | lifecycle GHG emissions |
| (Patel et al., 2000) | lifecycle GHG emissions |
| (Shan et al., 2023) | lifecycle GHG emissions |
| (Goga et al., 2022) | lifecycle GHG emissions |
| (Jang et al., 2020) | lifecycle GHG emissions |
| (van der Hulst et al., 2022) | lifecycle GHG emissions |
| (Rose et al., 2020) | lifecycle GHG emissions |
| (Goga et al., 2023) | lifecycle GHG emissions |
| (Poovarodom et al., 2015) | lifecycle GHG emissions |
| (Cruz et al., 2022) | lifecycle GHG emissions |
| (Vesamäki et al., 2022) | lifecycle GHG emissions |
| (Breyer et al., 2017) | lifecycle GHG emissions |
| (Chung et al., 2003) | lifecycle GHG emissions |
| (Kwon et al., 2023) | lifecycle GHG emissions |
| (Chu et al., 2022a) | lifecycle GHG emissions |
| (Chu et al., 2022b) | lifecycle GHG emissions |
| (Cabernard et al., 2021) | lifecycle GHG emissions |
| (Shaw et al., 2023) | lifecycle GHG emissions |
| (Waxman et al., 2020) | lifecycle GHG emissions |
| (Delre et al., 2023) | lifecycle GHG emissions |
| (Drewniok et al., 2023) | lifecycle GHG emissions |
| (Zappitelli et al., 2021) | lifecycle GHG emissions |
| (An et al., 2022) | lifecycle GHG emissions |
| (Adyel and Macreadie, 2022) | carbon cycling |
| (Chen et al., 2022) | carbon cycling |
| (K. Chen et al., 2023) | carbon cycling |
| (W. Zhao et al., 2023) | carbon cycling |
| (Menicagli et al., 2023) | carbon cycling |
| (Zhou et al., 2023) | carbon cycling |
| (Galgani et al., 2022) | carbon cycling |
| (Hou et al., 2023) | carbon cycling |
| (Kvale et al., 2023) | carbon cycling |
| (S. Zhao et al., 2023) | carbon cycling |
| (Li et al., 2023) | carbon cycling |
| (Romera-Castillo et al., 2018) | carbon cycling |
| (He et al., 2022) | carbon cycling |
| (Geng et al., 2021) | carbon cycling |
| (Wieczorek et al., 2019) | carbon cycling |
| (Bermúdez et al., 2021) | carbon cycling |
| (Beiras et al., 2019) | carbon cycling |
| (Lins et al., 2022) | carbon cycling |
| (Beiras et al., 2018) | carbon cycling |
| (Fulfer and Menden-Deuer, 2021) | carbon cycling |
| (Kvale et al., 2021) | carbon cycling |
| (J. Zhang et al., 2022) | carbon cycling |
| (Mingjian Liu et al., 2023) | carbon cycling |
| (Shen et al., 2020b) | carbon cycling |
| (Galgani and Loiselle, 2021) | carbon cycling |
| (Dees et al., 2021) | carbon cycling |
| (Zhu, 2021) | carbon cycling |
| (Botterell et al., 2019) | carbon cycling |
| (Shen et al., 2020a) | carbon cycling |
| (Goddijn-Murphy et al., 2023) | carbon cycling |
| (Sharma et al., 2023) | carbon cycling |
| (Kvale, 2022) | carbon cycling |
| (Shen et al., 2023) | carbon cycling |
| (Cole et al., 2016) | carbon cycling |
| (Galloway et al., 2018) | carbon cycling |
| (Galgani et al., 2023) | carbon cycling |
| (Shi et al., 2023) | carbon cycling |
| (Sun et al., 2023) | carbon cycling |
| (Kim et al., 2021) | carbon cycling |
| (Wang et al., 2022) | carbon cycling |
| (Meng et al., 2022) | carbon cycling |
| (J. Y. Chen et al., 2023) | carbon cycling |
| (Šourková et al., 2021) | carbon cycling |
| (Huang et al., 2021) | carbon cycling |
| (Mai et al., 2023) | carbon cycling |
| (Meng et al., 2023) | carbon cycling |
| (Zhang et al., 2023) | carbon cycling |
| (S. Liu et al., 2023) | carbon cycling |
| (Gao et al., 2022) | carbon cycling |
| (Han et al., 2023) | carbon cycling |
| (Khalid et al., 2023) | carbon cycling |
| (Yu et al., 2021) | carbon cycling |
| (Li et al., 2024) | carbon cycling |
| (Palansooriya et al., 2022) | carbon cycling |
| (Qian et al., 2018) | carbon cycling |
| (Yi et al., 2021) | carbon cycling |
| (Ren et al., 2020) | carbon cycling |
| (Xu et al., 2021) | carbon cycling |
| (Wiedner and Polifka, 2020) | carbon cycling |
| (B. Wang et al., 2023) | carbon cycling |
| (Wang et al., 2020) | carbon cycling |
| (Elbasiouny et al., 2023) | carbon cycling |
| (Ma et al., 2023) | carbon cycling |
| (Zhao et al., 2022) | carbon cycling |
| (Ju et al., 2019) | carbon cycling |
| (Li et al., 2021) | carbon cycling |
| (Chahal et al., 2023) | carbon cycling |
| (Pang et al., 2023) | carbon cycling |
| (Mondal et al., 2022) | carbon cycling |
| (X. Liu et al., 2023) | carbon cycling |
| (Qiang et al., 2023) | carbon cycling |
| (Mbachu et al., 2021) | carbon cycling |
| (KAUR et al., 2022) | carbon cycling |
| (Luo et al., 2023) | carbon cycling |
| (Yao et al., 2022) | carbon cycling |
| (Chia et al., 2023) | carbon cycling |
| (Rillig et al., 2021b) | carbon cycling |
| (Maity and Pramanick, 2020) | carbon cycling |
| (Medyńska-Juraszek and Jadhav, 2022) | carbon cycling |
| (Zhao et al., 2021) | carbon cycling |
| (Menicagli et al., 2019) | carbon cycling |
| (Rillig et al., 2021a) | carbon cycling |
| (Wei et al., 2022) | carbon cycling |
| (Revell et al., 2021) | Earth's radiation budget |
| (Islam et al., 2022) | Earth's radiation budget |
| (Fan et al., 2014) | Earth's radiation budget |
| (Pandey et al., 2022) | Earth's radiation budget |
| (Borysov et al., 2020) | Earth's radiation budget |
| (Rosso et al., 2023) | Earth's radiation budget |
| (Yang and Ma, 2023) | Earth's radiation budget |
| (Y. Wang et al., 2023) | Earth's radiation budget |
| (Abdel-Ghany and Al-Helal, 2012) | Earth's radiation budget |
| (Wu et al., 2021) | Earth's radiation budget |
| (Aeschlimann et al., 2022) | Earth's radiation budget |
| (Ganguly and Ariya, 2019) | Earth's radiation budget |
| (Evangeliou et al., 2020) | Earth's radiation budget |
| (Y. Zhang et al., 2022) | Earth's radiation budget |
| (Y. L. Zhang et al., 2022) | Earth's radiation budget |
| (Geilfus et al., 2019) | Earth's radiation budget |
| (Allen et al., 2022) | Earth's radiation budget |
| (Trainic et al., 2020) | Earth's radiation budget |
| (Lebedev et al., 2018) | Earth's radiation budget |
| (Crosta et al., 2022) | Earth's radiation budget |
| (Aves et al., 2022) | Earth's radiation budget |
| (Materić et al., 2022) | Earth's radiation budget |
| (Cabrera et al., 2022) | Earth's radiation budget |
| (Zhang et al., 2021) | Earth's radiation budget |

**References**

Abdel-Ghany, A.M., Al-Helal, I.M., 2012. Modeling approach for determining equivalent optical constants of plastic shading nets under solar radiation conditions. Advances in Materials Science and Engineering 2012. https://doi.org/10.1155/2012/158067

Adyel, T.M., Macreadie, P.I., 2022. Plastics in blue carbon ecosystems: a call for global cooperation on climate change goals. Lancet Planet Health. https://doi.org/10.1016/S2542-5196(21)00327-2

Aeschlimann, M., Li, G., Kanji, Z.A., Mitrano, D.M., 2022. Potential impacts of atmospheric microplastics and nanoplastics on cloud formation processes. Nat Geosci 15, 967–975. https://doi.org/10.1038/s41561-022-01051-9

Allen, D., Allen, S., Abbasi, S., Baker, A., Bergmann, M., Brahney, J., Butler, T., Duce, R.A., Eckhardt, S., Evangeliou, N., Jickells, T., Kanakidou, M., Kershaw, P., Laj, P., Levermore, J., Li, D., Liss, P., Liu, K., Mahowald, N., Masque, P., Materić, D., Mayes, A.G., McGinnity, P., Osvath, I., Prather, K.A., Prospero, J.M., Revell, L.E., Sander, S.G., Shim, W.J., Slade, J., Stein, A., Tarasova, O., Wright, S., 2022. Microplastics and nanoplastics in the marine-atmosphere environment. Nat Rev Earth Environ. https://doi.org/10.1038/s43017-022-00292-x

An, J., Wu, F., Wang, D., You, J., 2022. Estimated material metabolism and life cycle greenhouse gas emission of major plastics in China: A commercial sector-scale perspective. Resour Conserv Recycl 180. https://doi.org/10.1016/j.resconrec.2022.106161

Astrup, T., Fruergaard, T., Christensen, T.H., 2009. Recycling of plastic: Accounting of greenhouse gases and global warming contributions. Waste Management and Research. https://doi.org/10.1177/0734242X09345868

Aves, A.R., Revell, L.E., Gaw, S., Ruffell, H., Schuddeboom, A., Wotherspoon, N.E., Larue, M., Mcdonald, A.J., 2022. First evidence of microplastics in Antarctic snow. Cryosphere 16, 2127–2145. https://doi.org/10.5194/tc-16-2127-2022

Beiras, R., Bellas, J., Cachot, J., Cormier, B., Cousin, X., Engwall, M., Gambardella, C., Garaventa, F., Keiter, S., Le Bihanic, F., López-Ibáñez, S., Piazza, V., Rial, D., Tato, T., Vidal-Liñán, L., 2018. Ingestion and contact with polyethylene microplastics does not cause acute toxicity on marine zooplankton. J Hazard Mater 360, 452–460. https://doi.org/10.1016/j.jhazmat.2018.07.101

Beiras, R., Muniategui-Lorenzo, S., Rodil, R., Tato, T., Montes, R., López-Ibáñez, S., Concha-Graña, E., Campoy-López, P., Salgueiro-González, N., Quintana, J.B., 2019. Polyethylene microplastics do not increase bioaccumulation or toxicity of nonylphenol and 4-MBC to marine zooplankton. Science of the Total Environment 692, 1–9. https://doi.org/10.1016/j.scitotenv.2019.07.106

Bermúdez, J.R., Metian, M., Oberhänsli, F., Taylor, A., Swarzenski, P.W., 2021. Preferential grazing and repackaging of small polyethylene microplastic particles (≤ 5 μm) by the ciliate Sterkiella sp. Mar Environ Res 166. https://doi.org/10.1016/j.marenvres.2021.105260

Bora, R.R., Wang, R., You, F., 2020. Waste polypropylene plastic recycling toward climate change mitigation and circular economy: Energy, environmental, and technoeconomic perspectives. ACS Sustain Chem Eng 8, 16350–16363. https://doi.org/10.1021/acssuschemeng.0c06311

Borysov, A., Tarasenko, A., Krisanova, N., Pozdnyakova, N., Pastukhov, A., Dudarenko, M., Paliienko, K., Borisova, T., 2020. Plastic smoke aerosol: Nano-sized particle distribution, absorption/fluorescent properties, dysregulation of oxidative processes and synaptic transmission in rat brain nerve terminals. Environmental Pollution 263. https://doi.org/10.1016/j.envpol.2020.114502

Botterell, Z.L.R., Beaumont, N., Dorrington, T., Steinke, M., Thompson, R.C., Lindeque, P.K., 2019. Bioavailability and effects of microplastics on marine zooplankton: A review. Environmental Pollution. https://doi.org/10.1016/j.envpol.2018.10.065

Breyer, S., Mekhitarian, L., Rimez, B., Haut, B., 2017. Production of an alternative fuel by the co-pyrolysis of landfill recovered plastic wastes and used lubrication oils. Waste Management 60, 363–374. https://doi.org/10.1016/j.wasman.2016.12.011

Cabernard, L., Pfister, S., Oberschelp, C., Hellweg, S., 2021. Growing environmental footprint of plastics driven by coal combustion. Nature Sustainability 2021 1–10. https://doi.org/10.1038/s41893-021-00807-2

Cabrera, M., Moulatlet, G.M., Valencia, B.G., Maisincho, L., Rodríguez-Barroso, R., Albendín, G., Sakali, A., Lucas-Solis, O., Conicelli, B., Capparelli, M. V., 2022. Microplastics in a tropical Andean Glacier: A transportation process across the Amazon basin? Science of the Total Environment 805. https://doi.org/10.1016/j.scitotenv.2021.150334

Chahal, S., Wang, P., Bueno, V., Anand, H., Bayen, S., Ghoshal, S., Gravel, V., Tufenkji, N., 2023. Effect of emerging contaminants on soil microbial community composition, soil enzyme activity, and strawberry plant growth in polyethylene microplastic-containing soils. Environmental Science: Advances 2, 629–644. https://doi.org/10.1039/d2va00233g

Chen, J.Y., Liu, S., Deng, W.K., Niu, S.H., Liao, X. Di, Xiang, L., Xing, S.C., 2023. The effect of manure-borne doxycycline combined with different types of oversized microplastic contamination layers on carbon and nitrogen metabolism in sandy loam. J Hazard Mater 456. https://doi.org/10.1016/j.jhazmat.2023.131612

Chen, K., Zhou, S., Long, Y., Xu, H., Zhou, J., Jiang, Z., Xi, M., Zheng, H., 2023. Long-term aged fibrous polypropylene microplastics promotes nitrous oxide, carbon dioxide, and methane emissions from a coastal wetland soil. Science of the Total Environment 896. https://doi.org/10.1016/j.scitotenv.2023.166332

Chen, M.M., Nie, F.H., Qamar, A., Zhu, D. hua, Hu, Y., Zhang, M., Song, Q.L., Lin, H.Y., Chen, Z.B., Liu, S.Q., Chen, J.J., 2022. Effects of Microplastics on Microbial Community in Zhanjiang Mangrove Sediments. Bull Environ Contam Toxicol 108, 867–877. https://doi.org/10.1007/s00128-021-03429-8

Chia, R.W., Lee, J.Y., Lee, M., Lee, G.S., Jeong, C.D., 2023. Role of soil microplastic pollution in climate change. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2023.164112

Chu, J., Zhou, Y., Cai, Y., Wang, X., Li, C., Liu, Q., 2022a. Life-cycle greenhouse gas emissions and the associated carbon-peak strategies for PS, PVC, and ABS plastics in China. Resour Conserv Recycl 182. https://doi.org/10.1016/j.resconrec.2022.106295

Chu, J., Zhou, Y., Cai, Y., Wang, X., Li, C., Liu, Q., 2022b. A life-cycle perspective for analyzing carbon neutrality potential of polyethylene terephthalate (PET) plastics in China. J Clean Prod 330. https://doi.org/10.1016/j.jclepro.2021.129872

Chung, J.-C., Park, C.-H., Lee, J.-W., Kim, Y.-J., 2003. Development of Institutional System for Efficient Recycling Waste Plastic. Journal of the Korea Organic Resources Recycling Association.

Cole, M., Lindeque, P.K., Fileman, E., Clark, J., Lewis, C., Halsband, C., Galloway, T.S., 2016. Microplastics Alter the Properties and Sinking Rates of Zooplankton Faecal Pellets. Environ Sci Technol 50, 3239–3246. https://doi.org/10.1021/acs.est.5b05905

Crosta, A., De Felice, B., Antonioli, D., Chiarcos, R., Perin, E., Ortenzi, M.A., Gazzotti, S., Azzoni, R.S., Fugazza, D., Gianotti, V., Laus, M., Diolaiuti, G., Pittino, F., Franzetti, A., Ambrosini, R., Parolini, M., 2022. Microplastic contamination of supraglacial debris differs among glaciers with different anthropic pressures. Science of the Total Environment 851. https://doi.org/10.1016/j.scitotenv.2022.158301

Cruz, M.B., Saikawa, E., Hengstermann, M., Ramirez, A., McCracken, J.P., Thompson, L.M., 2022. Plastic waste generation and emissions from the domestic open burning of plastic waste in Guatemala. Environmental Science: Atmospheres 3, 156–167. https://doi.org/10.1039/d2ea00082b

Dees, J.P., Ateia, M., Sanchez, D.L., 2021. Microplastics and Their Degradation Products in Surface Waters: A Missing Piece of the Global Carbon Cycle Puzzle. Environmental Science & Technology Water. https://doi.org/10.1021/acsestwater.0c00205

Delre, A., Goudriaan, M., Morales, V.H., Vaksmaa, A., Ndhlovu, R.T., Baas, M., Keijzer, E., de Groot, T., Zeghal, E., Egger, M., Röckmann, T., Niemann, H., 2023. Plastic photodegradation under simulated marine conditions. Mar Pollut Bull 187. https://doi.org/10.1016/j.marpolbul.2022.114544

Demetrious, A., Crossin, E., 2019. Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis. J Mater Cycles Waste Manag 21, 850–860. https://doi.org/10.1007/s10163-019-00842-4

Ding, H., Liao, S., Tu, D., Hua, P., Zhang, J., 2023. Trade drives leakage of life-cycle carbon dioxide emissions from plastics in China over 2010–2021. J Clean Prod 417. https://doi.org/10.1016/j.jclepro.2023.137994

Drewniok, M.P., Gao, Y., Cullen, J.M., Cabrera Serrenho, A., 2023. What to Do about Plastics? Lessons from a Study of United Kingdom Plastics Flows. Environ Sci Technol 57, 4513–4521. https://doi.org/10.1021/acs.est.3c00263

Elbasiouny, H., Mostafa, A.A., Zedan, A., Elbltagy, H.M., Dawoud, S.F.M., Elbanna, B.A., El-Shazly, S.A., El-Sadawy, A.A., Sharaf-Eldin, A.M., Darweesh, M., Ebrahim, A.Z.E.E., Amer, S.M., Albeialy, N.O., Alkharsawey, D.S., Aeash, N.R., Abuomar, A.O., Hamd, R.E., Elbehiry, F., 2023. Potential Effect of Biochar on Soil Properties, Microbial Activity and Vicia faba Properties Affected by Microplastics Contamination. Agronomy 13. https://doi.org/10.3390/agronomy13010149

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., Stohl, A., 2020. Atmospheric transport is a major pathway of microplastics to remote regions. Nat Commun 11. https://doi.org/10.1038/s41467-020-17201-9

Fan, X., Chen, H., Xia, X., Yu, Y., 2014. Increase in surface albedo caused by agricultural plastic film. Atmospheric Science Letters 16, 291–296. https://doi.org/10.1002/ASL2.556

Fulfer, V.M., Menden-Deuer, S., 2021. Heterotrophic Dinoflagellate Growth and Grazing Rates Reduced by Microplastic Ingestion. Front Mar Sci 8. https://doi.org/10.3389/fmars.2021.716349

Galgani, L., Goßmann, I., Scholz-Böttcher, B., Jiang, X., Liu, Z., Scheidemann, L., Schlundt, C., Engel, A., 2022. Hitchhiking into the Deep: How Microplastic Particles are Exported through the Biological Carbon Pump in the North Atlantic Ocean. Environ Sci Technol 56, 15638–15649. https://doi.org/10.1021/acs.est.2c04712

Galgani, L., Loiselle, S.A., 2021. Plastic pollution impacts on marine carbon biogeochemistry. Environmental Pollution 268, 115598. https://doi.org/10.1016/j.envpol.2020.115598

Galgani, L., Tzempelikou, E., Kalantzi, I., Tsiola, A., Tsapakis, M., Pitta, P., Esposito, C., Tsotskou, A., Magiopoulos, I., Benavides, R., Steinhoff, T., Loiselle, S.A., 2023. Marine plastics alter the organic matter composition of the air-sea boundary layer, with influences on CO2 exchange: a large-scale analysis method to explore future ocean scenarios. Science of the Total Environment 857. https://doi.org/10.1016/j.scitotenv.2022.159624

Galloway, T.S., Cole, M., Lewis, C., 2018. ORE Open Research Exeter A NOTE ON VERSIONS Interactions of microplastic debris throughout the marine ecosystem 1 2.

Ganguly, M., Ariya, P.A., 2019. Ice Nucleation of Model Nanoplastics and Microplastics: A Novel Synthetic Protocol and the Influence of Particle Capping at Diverse Atmospheric Environments. ACS Earth Space Chem 3, 1729–1739. https://doi.org/10.1021/acsearthspacechem.9b00132

Gao, B., Li, Y., Zheng, N., Liu, C., Ren, H., Yao, H., 2022. Interactive effects of microplastics, biochar, and earthworms on CO2 and N2O emissions and microbial functional genes in vegetable-growing soil. Environ Res 213. https://doi.org/10.1016/j.envres.2022.113728

Geilfus, N.X., Munson, K.M., Sousa, J., Germanov, Y., Bhugaloo, S., Babb, D., Wang, F., 2019. Distribution and impacts of microplastic incorporation within sea ice. Mar Pollut Bull 145, 463–473. https://doi.org/10.1016/j.marpolbul.2019.06.029

Geng, X., Wang, J., Zhang, Y., Jiang, Y., 2021. How do microplastics affect the marine microbial loop? Predation of microplastics by microzooplankton. Science of the Total Environment 758. https://doi.org/10.1016/j.scitotenv.2020.144030

Goddijn-Murphy, L., Woolf, D.K., Pereira, R., Marandino, C.A., Callaghan, A.H., Piskozub, J., 2023. The links between marine plastic litter and the air-sea flux of greenhouse gases. Front Mar Sci. https://doi.org/10.3389/fmars.2023.1180761

Goga, T., Harding, K., Russo, V., von Blottnitz, H., 2023. A lifecycle-based evaluation of greenhouse gas emissions from the plastics industry in South Africa. S Afr J Sci 119, 2–6. https://doi.org/10.17159/sajs.2023/13842

Goga, T., Harding, K., Russo, V., von Blottnitz, H., 2022. What material flow analysis and life cycle assessment reveal about plastic polymer production and recycling in South Africa. S Afr J Sci 118. https://doi.org/10.17159/sajs.2022/12522

Gradus, R.H.J.M., Nillesen, P.H.L., Dijkgraaf, E., van Koppen, R.J., 2017. A Cost-effectiveness Analysis for Incineration or Recycling of Dutch Household Plastic Waste. Ecological Economics 135, 22–28. https://doi.org/10.1016/j.ecolecon.2016.12.021

Han, Y., Fu, M., Wu, J., Zhou, S., Qiao, Z., Peng, C., Zhang, W., Liu, F., Ye, C., Yang, J., 2023. Polylactic acid microplastics induce higher biotoxicity of decabromodiphenyl ethane on earthworms (Eisenia fetida) compared to polyethylene and polypropylene microplastics. Science of the Total Environment 862. https://doi.org/10.1016/j.scitotenv.2022.160909

He, M., Yan, M., Chen, X., Wang, X., Gong, H., Wang, W., Wang, J., 2022. Bioavailability and toxicity of microplastics to zooplankton. Gondwana Research 108, 120–126. https://doi.org/10.1016/j.gr.2021.07.021

Hou, X., Mu, L., Hu, X., Guo, S., 2023. Warming and microplastic pollution shape the carbon and nitrogen cycles of algae. J Hazard Mater 447. https://doi.org/10.1016/j.jhazmat.2023.130775

Huang, D., Xu, Y., Lei, F., Yu, X., Ouyang, Z., Chen, Y., Jia, H., Guo, X., 2021. Degradation of polyethylene plastic in soil and effects on microbial community composition. J Hazard Mater 416. https://doi.org/10.1016/j.jhazmat.2021.126173

Islam, M.R., Welker, J., Salam, A., Stone, E.A., 2022. Plastic Burning Impacts on Atmospheric Fine Particulate Matter at Urban and Rural Sites in the USA and Bangladesh. ACS Environmental Au 2, 409–417. https://doi.org/10.1021/acsenvironau.1c00054

Jang, Y.C., Lee, G., Kwon, Y., Lim, J. hong, Jeong, J. hyun, 2020. Recycling and management practices of plastic packaging waste towards a circular economy in South Korea. Resour Conserv Recycl 158. https://doi.org/10.1016/j.resconrec.2020.104798

Ju, H., Zhu, D., Qiao, M., 2019. Effects of polyethylene microplastics on the gut microbial community, reproduction and avoidance behaviors of the soil springtail, Folsomia candida. Environmental Pollution 247, 890–897. https://doi.org/10.1016/j.envpol.2019.01.097

KAUR, P., SINGH, K., SINGH, B., 2022. Microplastics in soil: Impacts and microbial diversity and degradation. Pedosphere 32, 49–60. https://doi.org/10.1016/S1002-0160(21)60060-7

Khalid, A.R., Shah, T., Asad, M., Ali, A., Samee, E., Adnan, F., Bhatti, M.F., Marhan, S., Kammann, C.I., Haider, G., 2023. Biochar alleviated the toxic effects of PVC microplastic in a soil-plant system by upregulating soil enzyme activities and microbial abundance. Environmental Pollution 332. https://doi.org/10.1016/j.envpol.2023.121810

Kim, S.W., Liang, Y., Lozano, Y.M., Rillig, M.C., 2021. Microplastics Reduce the Negative Effects of Litter-Derived Plant Secondary Metabolites on Nematodes in Soil. Front Environ Sci 9. https://doi.org/10.3389/fenvs.2021.790560

Kvale, K., 2022. Implications of plastic pollution on global marine carbon cycling and climate. Emerg Top Life Sci. https://doi.org/10.1042/ETLS20220013

Kvale, K., Hunt, C., James, A., Koeve, W., 2023. Regionally disparate ecological responses to microplastic slowing of faecal pellets yields coherent carbon cycle response. Front Mar Sci 10. https://doi.org/10.3389/fmars.2023.1111838

Kvale, K., Prowe, A.E.F., Chien, C.T., Landolfi, A., Oschlies, A., 2021. Zooplankton grazing of microplastic can accelerate global loss of ocean oxygen. Nat Commun 12. https://doi.org/10.1038/s41467-021-22554-w

Kwon, S., Kang, J., Lee, B., Hong, S., Jeon, Y., Bak, M., Im, S.K., 2023. Nonviable carbon neutrality with plastic waste-to-energy. Energy Environ Sci 16, 3074–3087. https://doi.org/10.1039/d3ee00969f

Lebedev, A.T., Polyakova, O. V., Mazur, D.M., Artaev, V.B., Canet, I., Lallement, A., Vaïtilingom, M., Deguillaume, L., Delort, A.M., 2018. Detection of semi-volatile compounds in cloud waters by GC×GC-TOF-MS. Evidence of phenols and phthalates as priority pollutants. Environmental Pollution 241, 616–625. https://doi.org/10.1016/j.envpol.2018.05.089

Li, D., Tang, X., Xu, X., Zhao, Yirong, Li, L., Zhang, B., Zhao, Yan, 2023. UV-B radiation alleviated detrimental effects of polymethyl methacrylate microplastics on marine diatom Thalassiosira pseudonana. Science of the Total Environment 892. https://doi.org/10.1016/j.scitotenv.2023.164388

Li, H.Z., Zhu, D., Lindhardt, J.H., Lin, S.M., Ke, X., Cui, L., 2021. Long-Term Fertilization History Alters Effects of Microplastics on Soil Properties, Microbial Communities, and Functions in Diverse Farmland Ecosystem. Environ Sci Technol 55, 4658–4668. https://doi.org/10.1021/acs.est.0c04849

Li, M., Ma, Q., Su, T., Wang, Z., Tong, H., 2024. Effect of Polycaprolactone Microplastics on Soil Microbial Communities and Plant Growth. J Polym Environ 32, 1039–1045. https://doi.org/10.1007/s10924-023-03028-0

Lins, T.F., O’Brien, A.M., Kose, T., Rochman, C.M., Sinton, D., 2022. Toxicity of nanoplastics to zooplankton is influenced by temperature, salinity, and natural particulate matter. Environ Sci Nano 9, 2678–2690. https://doi.org/10.1039/d2en00123c

Liu, Manzhi, Wen, J., Zhang, L., Wu, J., Yang, X., Qin, Y., Liu, Y., 2023. A decision-support system for recycling of residents’ waste plastics in China based on material flow analysis and life cycle assessment. Environmental Science and Pollution Research 30, 29610–29634. https://doi.org/10.1007/s11356-022-24076-4

Liu, Mingjian, Yu, X., Yang, M., Shu, W., Cao, F., Liu, Q., Wang, J., Jiang, Y., 2023. The co-presence of polystyrene nanoplastics and ofloxacin demonstrates combined effects on the structure, assembly, and metabolic activities of marine microbial community. J Hazard Mater 459. https://doi.org/10.1016/j.jhazmat.2023.132315

Liu, S., Niu, S.H., Xiang, L., Liao, X. Di, Xing, S.C., 2023. Effects of the oversized microplastic pollution layer on soil aggregates and organic carbon at different soil depths. J Hazard Mater 450. https://doi.org/10.1016/j.jhazmat.2023.131014

Liu, X., Li, Y., Yu, Y., Yao, H., 2023. Effect of nonbiodegradable microplastics on soil respiration and enzyme activity: A meta-analysis. Applied Soil Ecology 184. https://doi.org/10.1016/j.apsoil.2022.104770

Liu, X., Lu, X., Feng, Y., Zhang, L., Yuan, Z., 2022. Recycled WEEE plastics in China: Generation trend and environmental impacts. Resour Conserv Recycl 177. https://doi.org/10.1016/j.resconrec.2021.105978

Luo, Z., Li, A., Wang, H., Xing, B., 2023. The frontier of microplastics and nanoplastics: Soil health and carbon neutrality. Pedosphere 33, 11–13. https://doi.org/https://doi.org/10.1016/j.pedsph.2023.01.008

Ma, J., Xu, M., Wu, J., Yang, G., Zhang, X., Song, C., Long, L., Chen, C., Xu, C., Wang, Y., 2023. Effects of variable-sized polyethylene microplastics on soil chemical properties and functions and microbial communities in purple soil. Science of the Total Environment 868. https://doi.org/10.1016/j.scitotenv.2023.161642

Mai, H., Thien, N.D., Dung, N.T., Valentin, C., 2023. Impacts of microplastics and heavy metals on the earthworm Eisenia fetida and on soil organic carbon, nitrogen, and phosphorus. Environmental Science and Pollution Research 30, 64576–64588. https://doi.org/10.1007/s11356-023-27002-4

Maity, S., Pramanick, K., 2020. Perspectives and challenges of micro/nanoplastics-induced toxicity with special reference to phytotoxicity. Glob Chang Biol. https://doi.org/10.1111/gcb.15074

Materić, D., Kjær, H.A., Vallelonga, P., Tison, J.L., Röckmann, T., Holzinger, R., 2022. Nanoplastics measurements in Northern and Southern polar ice. Environ Res 208. https://doi.org/10.1016/j.envres.2022.112741

Mbachu, O., Jenkins, G., Kaparaju, P., Pratt, C., 2021. The rise of artificial soil carbon inputs: Reviewing microplastic pollution effects in the soil environment. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2021.146569

Medyńska-Juraszek, A., Jadhav, B., 2022. Influence of Different Microplastic Forms on pH and Mobility of Cu2+ and Pb2+ in Soil. Molecules 27. https://doi.org/10.3390/molecules27051744

Meng, F., Yang, X., Riksen, M., Geissen, V., 2022. Effect of different polymers of microplastics on soil organic carbon and nitrogen – A mesocosm experiment. Environ Res 204. https://doi.org/10.1016/j.envres.2021.111938

Meng, Q., Diao, T., Yan, L., Sun, Y., 2023. Effects of single and combined contamination of microplastics and cadmium on soil organic carbon and microbial community structural: A comparison with different types of soil. Applied Soil Ecology 183. https://doi.org/10.1016/j.apsoil.2022.104763

Menicagli, V., Balestri, E., Giommoni, F., Vannini, C., Lardicci, C., 2023. Plastic litter changes the rhizosphere bacterial community of coastal dune plants. Science of the Total Environment 880. https://doi.org/10.1016/j.scitotenv.2023.163293

Menicagli, V., Balestri, E., Lardicci, C., 2019. Exposure of coastal dune vegetation to plastic bag leachates: A neglected impact of plastic litter. Science of the Total Environment 683, 737–748. https://doi.org/10.1016/j.scitotenv.2019.05.245

Mondal, T., Mondal, S., Ghosh, S.K., Pal, P., Soren, T., Pandey, S., Maiti, T.K., 2022. Phthalates - A family of plasticizers, their health risks, phytotoxic effects, and microbial bioaugmentation approaches. Environ Res. https://doi.org/10.1016/j.envres.2022.114059

Palansooriya, K.N., Shi, L., Sarkar, B., Parikh, S.J., Sang, M.K., Lee, S.R., Ok, Y.S., 2022. Effect of LDPE microplastics on chemical properties and microbial communities in soil. Soil Use Manag 38, 1481–1492. https://doi.org/10.1111/sum.12808

Pandey, D., Banerjee, T., Badola, N., Chauhan, J.S., 2022. Evidences of microplastics in aerosols and street dust: a case study of Varanasi City, India. Environmental Science and Pollution Research 29, 82006–82013. https://doi.org/10.1007/s11356-022-21514-1

Pang, X., Chen, C., Sun, J., Zhan, H., Xiao, Y., Cai, J., Yu, X., Liu, Y., Long, L., Yang, G., 2023. Effects of complex pollution by microplastics and heavy metals on soil physicochemical properties and microbial communities under alternate wetting and drying conditions. J Hazard Mater 458. https://doi.org/10.1016/j.jhazmat.2023.131989

Patel, M., Von Thienen, N., Jochem, E., Worrell, E., 2000. Recycling of plastics in Germany. Resour Conserv Recycl 29, 65–90.

Poovarodom, N., Ponnak, C., Manatphrom, N., 2015. Impact of production and conversion processes on the carbon footprint of flexible plastic films. Packaging Technology and Science 28, 519–528. https://doi.org/10.1002/pts.2118

Qian, H., Zhang, M., Liu, G., Lu, T., Qu, Q., Du, B., Pan, X., 2018. Effects of Soil Residual Plastic Film on Soil Microbial Community Structure and Fertility. Water Air Soil Pollut 229. https://doi.org/10.1007/s11270-018-3916-9

Qiang, L., Hu, H., Li, G., Xu, J., Cheng, J., Wang, J., Zhang, R., 2023. Plastic mulching, and occurrence, incorporation, degradation, and impacts of polyethylene microplastics in agroecosystems. Ecotoxicol Environ Saf. https://doi.org/10.1016/j.ecoenv.2023.115274

Rahim, R., Abdul Raman, A.A., 2017. Carbon dioxide emission reduction through cleaner production strategies in a recycled plastic resins producing plant. J Clean Prod 141, 1067–1073. https://doi.org/10.1016/j.jclepro.2016.09.023

Ren, X., Tang, J., Liu, X., Liu, Q., 2020. Effects of microplastics on greenhouse gas emissions and the microbial community in fertilized soil. Environmental Pollution 256. https://doi.org/10.1016/j.envpol.2019.113347

Revell, L.E., Kuma, P., Ru, E.C., Somerville, W.R.C., Gaw, S., 2021. Direct radiative effects of airborne microplastics. Nature 598. https://doi.org/10.1038/s41586-021-03864-x

Rillig, M.C., Hoffmann, M., Lehmann, A., Liang, Y., Lück, M., Augustin, J., 2021a. Microplastic fibers affect dynamics and intensity of CO2 and N2O fluxes from soil differently. Microplastics and Nanoplastics 1. https://doi.org/10.1186/s43591-021-00004-0

Rillig, M.C., Leifheit, E., Lehmann, J., 2021b. Microplastic effects on carbon cycling processes in soils. PLoS Biol. https://doi.org/10.1371/JOURNAL.PBIO.3001130

Romera-Castillo, C., Pinto, M., Langer, T.M., Álvarez-Salgado, X.A., Herndl, G.J., 2018. Dissolved organic carbon leaching from plastics stimulates microbial activity in the ocean. Nat Commun 9, 1–7. https://doi.org/10.1038/s41467-018-03798-5

Rose, R.S., Richardson, K.H., Latvanen, E.J., Hanson, C.A., Resmini, M., Sanders, I.A., 2020. Microbial degradation of plastic in aqueous solutions demonstrated by Co2 evolution and quantification. Int J Mol Sci 21. https://doi.org/10.3390/ijms21041176

Ross, S., Evans, D., 2003. The environmental effect of reusing and recycling a plastic-based packaging system. J Clean Prod 11, 561–571. https://doi.org/10.1016/S0959-6526(02)00089-6

Rosso, B., Corami, F., Barbante, C., Gambaro, A., 2023. Quantification and identification of airborne small microplastics (<100 μm) and other microlitter components in atmospheric aerosol via a novel elutriation and oleo-extraction method. Environmental Pollution 318. https://doi.org/10.1016/j.envpol.2022.120889

Royer, S.-J., Ferrón, S., Wilson, S.T., Karl, D.M., 2018. Production of methane and ethylene from plastic in the environment. PLoS One 13, e0200574. https://doi.org/10.1371/journal.pone.0200574

Sevigné-Itoiz, E., Gasol, C.M., Rieradevall, J., Gabarrell, X., 2015. Contribution of plastic waste recovery to greenhouse gas (GHG) savings in Spain. Waste Management 46, 557–567. https://doi.org/10.1016/j.wasman.2015.08.007

Shan, C., Pandyaswargo, A.H., Onoda, H., 2023. Environmental Impact of Plastic Recycling in Terms of Energy Consumption: A Comparison of Japan’s Mechanical and Chemical Recycling Technologies. Energies (Basel) 16. https://doi.org/10.3390/en16052199

Sharma, S., Sharma, V., Chatterjee, S., 2023. Contribution of plastic and microplastic to global climate change and their conjoining impacts on the environment - A review. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2023.162627

Shaw, C., Sarkar, S., Kumar, S., Rastogi, N., 2023. High release of isotopically depleted CO2 and CH4 from the photo-degradation of plastic: A pilot laboratory study. Physics and Chemistry of the Earth 132. https://doi.org/10.1016/j.pce.2023.103474

Shen, M., Huang, W., Chen, M., Song, B., Zeng, G., Zhang, Y., 2020a. (Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.120138

Shen, M., Liu, S., Hu, T., Zheng, K., Wang, Y., Long, H., 2023. Recent advances in the research on effects of micro/nanoplastics on carbon conversion and carbon cycle: A review. J Environ Manage. https://doi.org/10.1016/j.jenvman.2023.117529

Shen, M., Ye, S., Zeng, G., Zhang, Y., Xing, L., Tang, W., Wen, X., Liu, S., 2020b. Can microplastics pose a threat to ocean carbon sequestration? Mar Pollut Bull 150. https://doi.org/10.1016/j.marpolbul.2019.110712

Shi, J., Wang, Z., Peng, Y., Fan, Z., Zhang, Z., Wang, X., Zhu, K., Shang, J., Wang, J., 2023. Effects of Microplastics on Soil Carbon Mineralization: The Crucial Role of Oxygen Dynamics and Electron Transfer. Environ Sci Technol 57, 13588–13600. https://doi.org/10.1021/acs.est.3c02133

Smith, R.L., Takkellapati, S., Riegerix, R.C., 2022. Recycling of Plastics in the United States: Plastic Material Flows and Polyethylene Terephthalate (PET) Recycling Processes. ACS Sustain Chem Eng 10, 2084–2096. https://doi.org/10.1021/acssuschemeng.1c06845

Šourková, M., Adamcová, D., Vaverková, M.D., 2021. The influence of microplastics from ground tyres on the acute, subchronical toxicity and microbial respiration of soil. Environments - MDPI 8. https://doi.org/10.3390/environments8110128

Sun, X., Tao, R., Xu, D., Qu, M., Zheng, M., Zhang, M., Mei, Y., 2023. Role of polyamide microplastic in altering microbial consortium and carbon and nitrogen cycles in a simulated agricultural soil microcosm. Chemosphere 312. https://doi.org/10.1016/j.chemosphere.2022.137155

Trainic, M., Flores, J.M., Pinkas, I., Pedrotti, M.L., Lombard, F., Bourdin, G., Gorsky, G., Boss, E., Rudich, Y., Vardi, A., Koren, I., 2020. Airborne microplastic particles detected in the remote marine atmosphere. Commun Earth Environ 1. https://doi.org/10.1038/s43247-020-00061-y

van der Hulst, M.K., Ottenbros, A.B., van der Drift, B., Ferjan, Š., van Harmelen, T., Schwarz, A.E., Worrell, E., van Zelm, R., Huijbregts, M.A.J., Hauck, M., 2022. Greenhouse gas benefits from direct chemical recycling of mixed plastic waste. Resour Conserv Recycl 186. https://doi.org/10.1016/j.resconrec.2022.106582

Vesamäki, J.S., Nissinen, R., Kainz, M.J., Pilecky, M., Tiirola, M., Taipale, S.J., 2022. Decomposition rate and biochemical fate of carbon from natural polymers and microplastics in boreal lakes. Front Microbiol 13. https://doi.org/10.3389/fmicb.2022.1041242

Wang, B., Wang, P., Zhao, S., Shi, H., Zhu, Y., Teng, Y., Jiang, G., Liu, S., 2023. Combined effects of microplastics and cadmium on the soil-plant system: Phytotoxicity, Cd accumulation and microbial activity. Environmental Pollution 333. https://doi.org/10.1016/j.envpol.2023.121960

Wang, J., Liu, X., Dai, Y., Ren, J., Li, Y., Wang, X., Zhang, P., Peng, C., 2020. Effects of co-loading of polyethylene microplastics and ciprofloxacin on the antibiotic degradation efficiency and microbial community structure in soil. Science of the Total Environment 741. https://doi.org/10.1016/j.scitotenv.2020.140463

Wang, Q., Feng, X., Liu, Y., Cui, W., Sun, Y., Zhang, S., Wang, F., 2022. Effects of microplastics and carbon nanotubes on soil geochemical properties and bacterial communities. J Hazard Mater 433. https://doi.org/10.1016/j.jhazmat.2022.128826

Wang, Y., Okochi, H., Tani, Y., Hayami, H., Minami, Y., Katsumi, N., Takeuchi, M., Sorimachi, A., Fujii, Y., Kajino, M., Adachi, K., Ishihara, Y., Iwamoto, Y., Niida, Y., 2023. Airborne hydrophilic microplastics in cloud water at high altitudes and their role in cloud formation. Environ Chem Lett 21, 3055–3062. https://doi.org/10.1007/s10311-023-01626-x

Waxman, A.R., Khomaini, A., Leibowicz, B.D., Olmstead, S.M., 2020. Emissions in the stream: Estimating the greenhouse gas impacts of an oil and gas boom. Environmental Research Letters 15. https://doi.org/10.1088/1748-9326/ab5e6f

Wei, H., Wu, L., Liu, Z., Saleem, M., Chen, X., Xie, J., Zhang, J., 2022. Meta-analysis reveals differential impacts of microplastics on soil biota. Ecotoxicol Environ Saf 230, 113150. https://doi.org/10.1016/j.ecoenv.2021.113150

Wieczorek, A.M., Croot, P.L., Lombard, F., Sheahan, J.N., Doyle, T.K., 2019. Microplastic Ingestion by Gelatinous Zooplankton May Lower Efficiency of the Biological Pump. Environ Sci Technol 53, 5387–5395. https://doi.org/10.1021/acs.est.8b07174

Wiedner, K., Polifka, S., 2020. Effects of microplastic and microglass particles on soil microbial community structure in an arable soil (Chernozem). SOIL 6, 315–324. https://doi.org/10.5194/soil-6-315-2020

Wu, D., Li, Q., Shang, X., Liang, Y., Ding, X., Sun, H., Li, S., Wang, S., Chen, Y., Chen, J., 2021. Commodity plastic burning as a source of inhaled toxic aerosols. J Hazard Mater 416. https://doi.org/10.1016/j.jhazmat.2021.125820

Wu, H., Mehrabi, H., Karagiannidis, P., Naveed, N., 2022. Additive manufacturing of recycled plastics: Strategies towards a more sustainable future. J Clean Prod 335. https://doi.org/10.1016/j.jclepro.2021.130236

Xu, M., Du, W., Ai, F., Xu, F., Zhu, J., Yin, Y., Ji, R., Guo, H., 2021. Polystyrene microplastics alleviate the effects of sulfamethazine on soil microbial communities at different CO2 concentrations. J Hazard Mater 413. https://doi.org/10.1016/j.jhazmat.2021.125286

Yang, L., Ma, C., 2023. Toward a better understanding of microalgal photosynthesis in medium polluted with microplastics: a study of the radiative properties of microplastic particles. Front Bioeng Biotechnol 11. https://doi.org/10.3389/fbioe.2023.1193033

Yao, Y., Lili, W., Shufen, P., Gang, L., Hongmei, L., Weiming, X., Lingxuan, G., Jianning, Z., Guilong, Z., Dianlin, Y., 2022. Can microplastics mediate soil properties, plant growth and carbon/nitrogen turnover in the terrestrial ecosystem? Ecosystem Health and Sustainability. https://doi.org/10.1080/20964129.2022.2133638

Yi, M., Zhou, S., Zhang, L., Ding, S., 2021. The effects of three different microplastics on enzyme activities and microbial communities in soil. Water Environment Research 93, 24–32. https://doi.org/10.1002/wer.1327

Yu, H., Zhang, Z., Zhang, Y., Song, Q., Fan, P., Xi, B., Tan, W., 2021. Effects of microplastics on soil organic carbon and greenhouse gas emissions in the context of straw incorporation: A comparison with different types of soil. Environmental Pollution 288. https://doi.org/10.1016/j.envpol.2021.117733

Zappitelli, J., Smith, E., Padgett, K., Bilec, M.M., Babbitt, C.W., Khanna, V., 2021. Quantifying Energy and Greenhouse Gas Emissions Embodied in Global Primary Plastic Trade Network. ACS Sustain Chem Eng 9, 14927–14936. https://doi.org/10.1021/acssuschemeng.1c05236

Zhang, J., Xiao, Z., Li, D., Wang, X., Lu, C., Du, Z., Li, B., Wang, Jinhua, Wang, Jun, Zhu, L., 2023. Effect of flumetsulam alone and coexistence with polyethylene microplastics on soil microbial carbon and nitrogen cycles: Elucidation of bacterial community structure, functional gene expression, and enzyme activity. J Hazard Mater 460. https://doi.org/10.1016/j.jhazmat.2023.132367

Zhang, J., Yu, F., Hu, X., Gao, Y., Qu, Q., 2022. Multifeature superposition analysis of the effects of microplastics on microbial communities in realistic environments. Environ Int 162. https://doi.org/10.1016/j.envint.2022.107172

Zhang, Y., Gao, T., Kang, S., Allen, S., Luo, X., Allen, D., 2021. Microplastics in glaciers of the Tibetan Plateau: Evidence for the long-range transport of microplastics. Science of the Total Environment 758. https://doi.org/10.1016/j.scitotenv.2020.143634

Zhang, Y., Gao, T., Kang, S., Shi, H., Mai, L., Allen, D., Allen, S., 2022. Current status and future perspectives of microplastic pollution in typical cryospheric regions. Earth Sci Rev. https://doi.org/10.1016/j.earscirev.2022.103924

Zhang, Y.L., Kang, S.C., Gao, T.G., 2022. Microplastics have light-absorbing ability to enhance cryospheric melting. Advances in Climate Change Research 13, 455–458. https://doi.org/10.1016/j.accre.2022.06.005

Zhao, M., Liu, R., Wang, X., Zhang, J., Wang, J., Cao, B., Zhao, Y., Xu, L., Chen, Y., Zou, G., 2022. How do controlled-release fertilizer coated microplastics dynamically affect Cd availability by regulating Fe species and DOC content in soil? Science of the Total Environment 850. https://doi.org/10.1016/j.scitotenv.2022.157886

Zhao, S., Mincer, T.J., Lebreton, L., Egger, M., 2023. Pelagic microplastics in the North Pacific Subtropical Gyre: A prevalent anthropogenic component of the particulate organic carbon pool. PNAS Nexus 2. https://doi.org/10.1093/pnasnexus/pgad070

Zhao, T., Lozano, Y.M., Rillig, M.C., 2021. Microplastics Increase Soil pH and Decrease Microbial Activities as a Function of Microplastic Shape, Polymer Type, and Exposure Time. Front Environ Sci 9. https://doi.org/10.3389/fenvs.2021.675803

Zhao, W., Zhu, K.-H., Ge, Z.-M., Lv, Q., Liu, S.-X., Zhang, W., Xin, P., 2023. Effects of plastic contamination on carbon fluxes in a subtropical coastal wetland of East China. J Environ Manage 345, 118654.

Zheng, J., Suh, S., 2019. Strategies to reduce the global carbon footprint of plastics. Nat Clim Chang 9, 374–378. https://doi.org/10.1038/s41558-019-0459-z

Zhou, X., Xiao, C., Li, X., Chen, T., Yang, X., 2023. Microplastics in coastal blue carbon ecosystems: A global Meta-analysis of its distribution, driving mechanisms, and potential risks. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2023.163048

Zhu, 2021. The Plastic Cycle – An Unknown Branch of the Carbon Cycle. Front Mar Sci 7, 609243. https://doi.org/10.3389/fmars.2020.609243