Call for Evidence: Nitrogen

Opportunity Green response to the Environment and Climate Change Committee's call for evidence on nitrogen | 06/03/2025

Opportunity Green

Opportunity Green is an NGO working to unlock the opportunities from tackling climate change using law, economics, and policy. We do this by amplifying diverse voices, forging ambitious collaborations and using legal innovation to motivate decision makers and achieve climate justice with particular emphasis on the aviation and shipping industries.

Response summary

The shipping industry is currently responsible for significant nitrogen (N) pollution. Ammonia (NH_3) has been suggested as a sustainable shipping fuel which may aid decarbonisation of the sector in the future. However, unless properly managed, the use of NH_3 as a shipping fuel has the potential to further disrupt Earth's N cycle and lead to significant climate, environmental and public health impacts, both in the UK and globally. In this response, we outline the potential risks of NH_3 as a shipping fuel, highlight potential management measures, and draw parallels with N pollution resulting from agriculture to emphasise the urgent need for effective N management to be holistically integrated within wider policy.

Question 1: What are the main sources of nitrogen pollution in the UK? How and why have these changed over time?

1. The use of fertilisers by the agriculture industry is the major contributor to N pollution globally.[1] However, reflecting our areas of expertise, we focus our response on highlighting N pollution resulting from shipping-related activities, using reference to the agriculture sector to illustrate key points. Currently, N pollution from shipping predominantly results from the production of nitrous oxide (N_2O) and nitrogen oxides (NO and NO_2: collectively NO_x) during fossil fuel combustion in ship engines.

[1] Canfield, D.E., Glazer, A.N., Falkowski, P.G., 2010. The Evolution and Future of Earth's Nitrogen Cycle. Science 330, 192–196. https://doi.org/10.1126/science.1186120

2. N_2O is a potent greenhouse gas (GHG) with a Global Warming Potential (GWP) some 273 times larger than CO_2 on a 100-year timescale.[2] Additionally, N_2O also causes stratospheric ozone depletion.[3]

3. In the UK in 2023, domestic and international shipping resulted in total N_2O emissions captured by the UK's GHG inventory equivalent to 0.13 $MtCO_2$, comprising ~ 1.2% of total GHG emissions from UK shipping[4] (though note that UK total shipping GHG emissions are estimated to be ~ 25% higher when best practise calculation methods are used[e.g. 5]). N_2O emissions from shipping fell by roughly 34% between 1990 and 2023, mirroring a roughly equivalent reduction in total GHG emissions.[4] It is thought that emissions reductions result from reduced domestic shipping, with possible contributions from improved vessel efficiency and technology.[e.g. 5]

4. NO_x species, secondly, are harmful contributors to air pollution emitted by ship engines.[e.g. 6] In fact, domestic shipping contributed some 11% of total domestic UK NO_x emissions in 2023.[6] International shipping activities occurring in UK waters (but not counted in the UK's domestic emissions inventory) emit substantially more NO_x than domestic shipping. For instance, one study estimates that in 2016, international shipping in, and transit through, UK waters together emitted around nine times more NO_x than UK domestic shipping,[7] an amount equivalent to more than 70% of the UK's total reported domestic NO_x emissions for that year.[8] Domestic shipping NO_x emissions decreased by 62% between 1999 and 2023, reflecting (as for N_2O) reduced shipping activity, as well as the introduction of global and regional measures such as engine standards.[6]

5. Both N_2O and NO_x are forms of reactive N (Nr), and their release contributes to overall anthropogenic N cycle disturbance. Despite recent reductions, Nr emissions from shipping in UK waters remain appreciable**. Importantly, it is possible that in the future, NH_3 will be used as a shipping fuel,[e.g. 9] with the potential to significantly increase N pollution unless effective management measures are introduced.**

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[2] Forster et al., 2021. The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi: 10.1017/9781009157896.009.

[3] Ravishankara, A.R., Daniel, J.S., Portmann, R.W., 2009. Nitrous Oxide (N_2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century. Science 326, 123–125. https://doi.org/10.1126/science.1176985

[4] Department for Energy Security and Net Zero, 2025a. Final UK greenhouse gas emissions statistics: 1990 to 2023. Retrieved 3 March, 2025 from https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-statistics-1990-to-2023

[5] Climate Change Committee, 2025. The Seventh Carbon Budget. Advice for the UK Government. Retrieved on 3 March, 2025 from https://www.theccc.org.uk/publication/the-seventh-carbon-budget/#publication-downloads

[6] Department for Environment, Food & Rural Affairs, 2025a. Emissions of air pollutants in the UK – Nitrogen oxides (NOx). Retrieved 3 March, 2025 from https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-nitrogen-oxides-nox#major-emission-sources-for-nitrogen-oxides-in-the-uk

[7] ApSimon, H., Oxley, T., Woodward, H., 2021. The contribution of shipping emissions to pollutant concentrations and nitrogen deposition across the UK. Retrieved 3 March, 2025 from https://uk-air.defra.gov.uk/library/reports?report_id=1028

[8] Department for Environment, Food & Rural Affairs, 2025b. Statistical data set ENV01 - Emissions of air pollutants. Retrieved 5 March, 2025 from https://www.gov.uk/government/statistical-data-sets/env01-emissions-of-air-pollutants

[9] Royal Society, 2020. Ammonia: zero-carbon fertiliser, fuel and energy store. Retrieved 12 February, 2025 from https://royalsociety.org/news-resources/projects/low-carbon-energy-programme/green-ammonia/

Question 2: How could nitrogen pollution be mitigated from relevant sectors, how effective are these approaches, and are there any trade-offs?

6. Currently, efforts to mitigate N pollution from shipping focus dominantly on NO_x emissions.

7. International engine standards regarding NO_x emissions are specified in the NOx Technical Code 2008.[10] The most stringent standards apply to qualifying ships operating in Emission Control Areas (ECAs). The North Sea ECA overlaps with UK waters.[11] Substantial reductions in NO_x emissions from conventional ship engines can be achieved using exhaust gas after-treatment systems, such as Selective Catalytic Reduction (SCR). Other efforts also aim to tackle UK NO_x emissions from shipping. For instance, the government published guidance for developing voluntary Port Air Quality Strategies in 2019.[12]

8. The recent focus on reducing NO_x emissions is appropriate given that the vast majority of ship engines currently use fossil fuels. In the future, however, **the potential use of NH_3 as a marine fuel will require mitigation measures which address wider N pollution** from sources including NH_3, N_2O and NO_x. In this context, potential mitigation measures are discussed in response to question 4.

Question 3: What solutions and technologies are available to increase nitrogen reuse and recycling, including in agriculture, waste, wastewater, industry, and transport sectors?

Question 4: What future developments could further increase nitrogen pollution, and how could those risks be reduced?

9. The effects of, and attempts to mitigate, climate change may present challenges for future N pollution. For example, considering the agriculture sector, the climate crisis is impacting food production globally.[13] Given the expected impacts on the UK's climate,[14] it is likely that food production in the UK will need to be expanded. Depending on the manner of this expansion (and the sustainability thereof[15]), it is possible that increased N pollution will occur.

10. Focusing on shipping, increased N pollution may arise from efforts to mitigate climate change. Emissions from domestic and international shipping in the UK equate to roughly 3% of the UK's total GHG emissions.[4;5] Decarbonisation of the

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[10] International Maritime Organization, 2025a. Nitrogen Oxides (NOx) – Regulation 13. Retrieved 5 March, 2025 from https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

[11] International Maritime Organization, 2025b. Emission Control Areas (ECAs) designated under MARPOL Annex VI. Retrieved 5 March, 2025 from https://www.imo.org/en/OurWork/Environment/Pages/Emission-Control-Areas-(ECAs)-designated-under-regulation-13-of-MARPOL-Annex-VI-(NOx-emission-control).aspx

[12] Department for Transport and Maritime and Coastguard Agency, 2019. Port air quality strategies. Retrieved 5 March, 2025 from https://www.gov.uk/government/publications/clean-maritime-plan-maritime-2050-environment-route-map

[13] Caparas, M., Zobel, Z., Castanho, A.D.A., Schwalm, C.R., 2021. Increasing risks of crop failure and water scarcity in global breadbaskets by 2030. Environ. Res. Lett. 16, 104013. https://doi.org/10.1088/1748-9326/ac22c1

[14] Energy & Climate Intelligence Unit, 2024. Estimated decline in headline self-sufficiency for UK food production due to the projected reduction in arable crop output in 2024. Retrieved 5 March, 2025 from https://ca1-eci.edcdn.com/Wet-winter-self-sufficiency-analysis-080524.pdf?v=1715248184

[15] Armstrong McKay, D.I., Dearing, J.A., Dyke, J.G., Poppy, G.M., Firbank, L.G., 2019. To what extent has sustainable intensification in England been achieved? Science of The Total Environment 648, 1560–1569. https://doi.org/10.1016/j.scitotenv.2018.08.207

sector is thus essential for meeting the UK's net zero obligations: the recently-published Seventh Carbon Budget balanced pathway foresees near-complete decarbonisation of the entire sector by 2050.[5] Additionally, the International Maritime Organization (IMO) has adopted a target to reduce emissions from the sector to net-zero by, or around, 2050.[16]

11. The vast majority of shipping emissions result from the unabated use of fossil fuels to power ships. As such, transitioning the industry to alternative fuels is essential. NH_3 has been touted as a promising candidate fuel,[9] primarily because ammonia combustion does not produce CO_2. Shipping firms have placed orders for ammonia-ready vessels,[17] and studies have forecast that a significant proportion of the global fleet may be powered by ammonia propulsion by 2050.[18] In the UK, the Seventh Carbon Budget balanced pathway foresees NH_3 meeting 22% of shipping energy use by 2040.[5]

12. Demand for NH_3 as a marine fuel has the potential to cause significant, additional N cycle disruption.[19] Though the use of NH_3 as a marine fuel is theoretically a closed loop, in reality Nr (including N_2O, NH_3 and NO_x) will be released to the environment throughout the fuel lifecycle (see paragraph 13). Estimates suggest that the amount of Nr lost could range from 0.5% to 5% of the supply chain input.[20] For context, one study has estimated that to fuel the entire global shipping fleet would require ~ 4 times as much NH_3 as is currently produced globally each year.[19]

13. Increased N pollution could occur between fuel production and final use onboard ships. Leaks and spills of NH_3 could occur during fuel production, transport, storage and use (e.g. due to a collision). Emissions of Nr species (NO_x, N_2O and unburned NH_3) may also occur during combustion in ship engines.

14. The environmental and public health impacts associated with N pollution from the use of NH_3 as a shipping fuel are covered in our responses to questions 5 and 6. Here, we also briefly highlight the potential climate change implications of using NH_3 as a marine fuel. N_2O is a potent GHG and causes stratospheric ozone depletion, as outlined in our response to question 1. N_2O emissions resulting from NH_3 combustion in ship engines are currently highly uncertain.[e.g.]

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[16] International Maritime Organization, 2023. 2023 IMO Strategy on Reduction of GHG Emissions from Ships. Retrieved 3 March, 2025 from https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

[17] Fullonton, A., Lea-Langton, A.R., Madugu, F., Larkin, A., 2025. Green ammonia adoption in shipping: Opportunities and challenges across the fuel supply chain. Marine Policy 171, 106444. https://doi.org/10.1016/j.marpol.2024.106444

[18] IEA, 2023. Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. IEA, Paris https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

[19] Wolfram, P., Kyle, P., Zhang, X., Gkantonas, S., Smith, S., 2022. Using ammonia as a shipping fuel could disturb the nitrogen cycle. Nat Energy 7, 1112–1114. https://doi.org/10.1038/s41560-022-01124-4

[20] Bertagni, M.B., Socolow, R.H., Martirez, J.M.P., Carter, E.A., Greig, C., Ju, Y., Lieuwen, T., Mueller, M.E., Sundaresan, S., Wang, R., Zondlo, M.A., Porporato, A., 2023. Minimizing the impacts of the ammonia economy on the nitrogen cycle and climate. Proc. Natl. Acad. Sci. U.S.A. 120, e2311728120. https://doi.org/10.1073/pnas.2311728120

[21] **The extent to which NH_3 can deliver meaningful emissions reductions compared with conventional marine fuels is highly dependent on reducing these N_2O emissions during combustion**.[19;20;21;22;23]

15. With no operational ships currently powered using NH_3, the efficacy of N pollution mitigation strategies is difficult to assess and we cannot advocate for specific solutions here. However, key points to consider are:

- **Wider N management measures will need to be adopted** extending beyond the industry's NO_x emissions, to also address NH_3 and N_2O. Pollution must be addressed throughout the fuel lifecycle (i.e. from fuel production to end use onboard ships).

- **Robust, transparent and comprehensive monitoring, evaluation and reporting of Nr release** throughout the NH_3 fuel lifecycle will be crucial.

- **Measures to reduce fuel consumption** would be beneficial, such as demand reduction and improving energy and operational efficiency.

- **Optimising engine design and combustion conditions, and using exhaust gas recirculation and after-treatment systems**, can reduce emissions of Nr species from NH_3 engines.[24;25;26;27;28] Importantly, there may be trade-offs whereby efforts to reduce emissions of one Nr species can result in an increase in emissions of another, meaning a holistic approach to reducing Nr emissions reductions is required.[e.g. 27] For example, there are concerns that using conventional SCR techniques on NH_3-powered ships could result in increased N_2O emissions.[28]

- **Expanding the Tier III engine standard requirements** which currently apply in ECAs globally could contribute to effectively mitigating NO_x emissions from NH_3 engines.[28] The UK government recently consulted on expanding the North Sea ECA to cover all UK waters.[29]

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[21] Tomos, B.A.D., Stamford, L., Welfle, A., Larkin, A., 2024. Decarbonising international shipping – A life cycle perspective on alternative fuel options. Energy Conversion and Management 299, 117848. https://doi.org/10.1016/j.enconman.2023.117848
[22] Dong, D.T., Schönborn, A., Christodoulou, A., Ölcer, A.I., González-Celis, J., 2024. Life cycle assessment of ammonia/hydrogen-driven marine propulsion. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 238, 531–542. https://doi.org/10.1177/14750902231207159
[23] Schuller, O., Bopp, J., Rapp, J., 2024. 1st Life Cycle GHG Emission Study on the Use of Ammonia as Marine Fuel. v1.1. Retrieved 12 February, 2025 via https://sphera.com/resources/report/1st-life-cycle-ghg-emission-study-on-the-use-of-ammonia-as-marine-fuel/
[24] Li, T., Zhou, X., Wang, N., Wang, X., Chen, R., Li, S., Yi, P., 2022. A comparison between low- and high-pressure injection dual-fuel modes of diesel-pilot-ignition ammonia combustion engines. Journal of the Energy Institute 102, 362–373. https://doi.org/10.1016/j.joei.2022.04.009
[25] Jin, S., Wu, B., Zi, Z., Yang, P., Shi, T., Zhang, J., 2023. Effects of fuel injection strategy and ammonia energy ratio on combustion and emissions of ammonia-diesel dual-fuel engine. Fuel 341, 127668. https://doi.org/10.1016/j.fuel.2023.127668
[26] Chen, R., Li, T., Wang, X., Huang, S., Zhou, X., Li, S., Yi, P., 2024. Engine-out emissions from an ammonia/diesel dual-fuel engine – The characteristics of nitro-compounds and GHG emissions. Fuel 362, 130740. https://doi.org/10.1016/j.fuel.2023.130740
[27] Drazdauskas, M., Lebedevas, S., 2024. Optimization of Combustion Cycle Energy Efficiency and Exhaust Gas Emissions of Marine Dual-Fuel Engine by Intensifying Ammonia Injection. Journal of Marine Science and Engineering 12, 309. https://doi.org/10.3390/jmse12020309
[28] Wong, A.Y.H., Selin, N.E., Eastham, S.D., Mounaïm-Rousselle, C., Zhang, Y., Allroggen, F., 2024. Climate and air quality impact of using ammonia as an alternative shipping fuel. Environ. Res. Lett. 19, 084002. https://doi.org/10.1088/1748-9326/ad5d07
[29] Department for Transport, 2024. Extending the emission control area to all UK waters. Retrieved 5 March, 2025 from https://www.gov.uk/government/calls-for-evidence/extending-the-emission-control-area-to-all-uk-waters/extending-the-emission-control-area-to-all-uk-waters#what-happens-next

- **Wider policy** could also be leveraged to control Nr release. For example, default N_2O emission factors for ships using NH_3 engines which will be adopted (for instance) by the IMO or under the proposed extension of the UK Emissions Trading Scheme,[30] could use conservative assumptions regarding N_2O emissions, thus incentivising industry to demonstrate superior GHG performance.

Question 5: What are the ecological impacts of nitrogen pollution in the UK and what implications do these have for national environmental and net zero targets?

16. The release of Nr into the environment by human activities has fundamentally altered the global N cycle.[1] It is thought that the safe "planetary boundary" for N release has already been exceeded, suggesting that current levels of N pollution create a high risk of systemic earth system change.[31] Specifically, N pollution results in a series of ecological impacts. Here, we focus on impacts arising from the shipping industry, which are influenced by the location of N pollution from shipping (i.e. at sea, and in ports).

17. In particular, release of Nr into marine ecosystems can result in eutrophication, an excess of nutrients which may stimulate algal growth. In turn, this can deplete local oxygen levels (termed hypoxia), resulting in oxygen depletion which can be deadly to aquatic and marine life.[e.g. 32] Deposition of Nr into marine environments from the shipping industry has also been shown to contribute to ocean acidification.[e.g. 33]

18. The above environmental effects can also impact on efforts to reduce GHG emissions. The ocean is a major source of N_2O to the atmosphere, and marine hypoxia and acidification have both been shown to increase oceanic N_2O emissions.[34;35] Additionally, the impacts of Nr deposition may degrade environments which store and sequester important quantities of carbon. For example, in the UK, N pollution can degrade marine and coastal habitats including saltmarsh and seagrass beds, which store and sequester significant quantities of carbon.[e.g. 36]

19. In addition, should NH_3 be adopted as a marine fuel in the future, the likelihood of NH_3 spills into the marine environment would increase. NH_3 is highly toxic to

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[30] Department for Energy Security and Net Zero, 2025b. UK ETS scope expansion: maritime sector. Retrieved 4 March, 2025 from https://www.gov.uk/government/consultations/uk-ets-scope-expansion-maritime-sector
[31] Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., Petri, S., Porkka, M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobian, A., Virkki, V., Wang-Erlandsson, L., Weber, L., Rockström, J., 2023. Earth beyond six of nine planetary boundaries. Science Advances 9, eadh2458. https://doi.org/10.1126/sciadv.adh2458
[32] Gray, J., Wu, R., Or, Y., 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. Mar. Ecol. Prog. Ser. 238, 249–279. https://doi.org/10.3354/meps238249
[33] Hassellöv, I. Turner, D. Lauer, A. Corbett, J., 2013. Shipping contributes to ocean acidification. Geophysical Research Letters. https://agupubs.onlinelibrary.wiley.com/doi/10.1002/grl.50521
[34] K.E. Limburg, D. Breitburg, D.P. Swaney, G. Jacinto, 2020. Ocean deoxygenation: a primer. One Earth, pp. 24-29, 10.1016/j.oneear.2020.01.001
[35] Breider, F., Yoshikawa, C., Makabe, A., Toyoda, S., Wakita, M., Matsui, Y., Kawagucci, S., Fujiki, T., Harada, N., Yoshida, N., 2019. Response of N_2O production rate to ocean acidification in the western North Pacific. Nat. Clim. Chang. 9, 954–958. https://doi.org/10.1038/s41558-019-0605-7
[36] Climate Change Committee, 2022. Briefing: Blue Carbon. Retrieved 4 March, 2025 from https://www.theccc.org.uk/publication/briefing-blue-carbon/

marine organisms, meaning spills could have both short-term toxic, as well as longer-term chronic, effects on marine organisms and ecosystems.[37]

20. In the future, the use of NH_3 as a shipping fuel has the potential to significantly exacerbate existing ecological issues related to N pollution, as well as posing new risks. This emphasises the need for effective management measures to minimise the release of Nr species throughout the fuel lifecycle.[19]

21. Returning to agriculture, finally, it is worth noting that land-based ecosystems are similarly sensitive to N pollution from fertiliser application,[38] which has reduced UK biodiversity levels. It has also been shown that higher levels of biodiversity can improve agricultural potential.[39] This emphasises the need to more effectively manage the application of N-based fertilisers: reducing N usage would not only contribute to UK Carbon Budget goals by lowering emissions from the agricultural sector,[5] but would also contribute to meeting biodiversity goals which the UK has previously had difficulty progressing with.[40]

Question 6: What are the public health impacts of nitrogen pollution and how are these accounted for in current government plans and targets?

22. The public health impacts of N pollution and use can be both indirect and direct. As an example of an indirect effect, production of N fertilisers is key for ensuring food security but is an energy-intensive process.[41] Fertiliser price (and by extension, food price at consumer level[42]) can therefore be vulnerable to energy cost fluctuation. Moving away from N fertiliser-heavy agricultural practices would reduce that vulnerability, in turn reducing the risk of increasing food poverty in the UK.

23. Focusing on shipping activities, these result in direct public health impacts by the release of NO_x, which is a major contributor to poor air quality. Globally, air quality impacts from shipping-related activities are estimated to have been associated with ~ 94,000 premature deaths globally in 2015.[43] This study also estimated that 4,500 of those deaths occurred in the UK.[43] **Air quality is recognised as the "largest environmental risk to people's health in the**

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[37] Dawson, L., Ware, J., Vest, L., 2021, Ammonia at sea: Studying the potential impacts of ammonia as a shipping fuel on marine ecosystems. EDF. Retrieved 4 March, 2025 from https://www.edfeurope.org/alternative-fuels-shipping
[38] Bobbink, R., Loran, C., Tomassen, H., (eds) 2022. Review and revision of empirical critical loads of nitrogen for Europe, Umwelt Bundesamt Texte 110/2022, 30. Retrieved 5 March, 2025 from https://www.umweltbundesamt.de/publikationen/review-revision-of-empirical-critical-loads-of
[39] Stiles, W., 2017. The importance of biodiversity and wildlife on farmland. Retrieved 5 March, 2025 from https://businesswales.gov.wales/farmingconnect/news-and-events/technical-articles/importance-biodiversity-and-wildlife-farmland#:~:text=Increasing%20biodiversity%2C%20particularly%20wildlife%20populations,and%20delivery%20of%20ecosystem%20services
[40] Ares, E., 2024. Biodiversity loss: The UK's international obligations. Retrieved 5 March, 2025 from https://commonslibrary.parliament.uk/biodiversity-loss-uk-international-obligations/
[41] Daramola, D., Hatzell, M., 2023. Energy Demand of Nitrogen and Phosphorus Based Fertilizers and Approaches to Circularity. ACS Energy Lett. 8, 3, 1493–1501. https://doi.org/10.1021/acsenergylett.2c02627
[42] Alexander, P., Arneth, A., Henry, R., Maire, J., Rabin, S., Rounsevell, M.D.A., 2023. High energy and fertilizer prices are more damaging than food export curtailment from Ukraine and Russia for food prices, health and the environment. Nat Food 4, 84–95. https://doi.org/10.1038/s43016-022-00659-9
[43] Zhang, Y., Eastham, S.D., Lau, A.K., Fung, J.C., Selin, N.E., 2021. Global air quality and health impacts of domestic and international shipping. Environ. Res. Lett. 16, 084055. https://doi.org/10.1088/1748-9326/ac146b

UK",[e.g. 44] and NO_x pollution emitted by the shipping industry makes a substantial contribution to this (see response to question 1).

24. The contribution of shipping activities to poor air quality has previously been recognised in UK government plans and targets, including for instance in the 2023 Air quality strategy for England[45] and the 2023 Environmental Improvement Plan.[46]

25. Looking ahead, **the potential use of NH_3 as a shipping fuel presents serious challenges for air quality and public health**. Using NH_3 as a fuel eliminates some carbon-based particles which contribute to poor air quality. However, unless mitigation measures are introduced, these benefits are estimated to be far outweighed by the health impacts of unburned NH_3 and NO_x emissions.[28] Importantly, this study emphasises that despite these challenges, overall public health benefits can be achieved by the transition to NH_3 as a marine fuel, if robust measures are introduced to control NO_x and unburned NH_3 emissions.[28]

Question 7: What are the economic impacts of nitrogen pollution and current nitrogen-mitigation policies, for the public, farmers and other stakeholders?

Question 8: How effective is existing policy at regulating and reducing nitrogen pollution? How could they be improved? Are there gaps?

Question 9: How effective is monitoring and enforcement of nitrogen-related regulations?

Question 10: Does current policy incentivise the capture and reuse of 'waste' nitrogen and, if not, what policy changes could support greater reuse of nitrogen?

Question 11: What are the pros and cons of taking a more holistic approach to nitrogen management in policy, and what opportunities to do so exist?

26. Considering N pollution from both agriculture and the potential use of NH_3 as a marine fuel emphasises the crucial importance of adopting a holistic and coordinated approach to N management.

27. For instance, controlling ship engine emissions of N_2O, NO_x and unburned NH_3 will result in trade-offs between the different Nr species. Optimising conditions

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[44] Environment Agency, Department for Environment, Food & Rural Affairs, Natural Resources Wales, UK Health Security Agency, 2025. Understanding and addressing inequalities in air quality: summary. Retrieved 6 March, 2025 from https://www.gov.uk/government/publications/understanding-and-addressing-inequalities-in-air-quality/understanding-and-addressing-inequalities-in-air-quality-summary

[45] Department for Environment, Food & Rural Affairs, 2023a. The air quality strategy for England. Retrieved 4 March, 2025 from https://www.gov.uk/government/publications/the-air-quality-strategy-for-england

[46] Department for Environment, Food & Rural Affairs, 2023b. Environmental Improvement Plan 2023. Retrieved 4 March, 2025 from https://www.gov.uk/government/publications/environmental-improvement-plan

to minimise emissions of one form of Nr may result in significant emissions of another, with potentially significant climate, environmental and/or public health implications (see questions 4, 5 and 6). It is essential that emissions of different Nr species are considered and managed together.[e.g. 27;28]

28. Furthermore, the use of N fertilisers for agricultural purposes is a problem which requires intervention at government level and throughout the food system. A combination of agroecological measures and other actions have been considered and recommended to address this.[e.g. 47] A holistic approach in this sense encourages the joint responsibility that is required to address high GHG-emitting sectors in line with the UK's Carbon Budget.[5] Such a holistic approach presents opportunities to improve biodiversity and land productivity by reducing the need for N-based fertiliser, as referred to in question 5 above.

29. Overall, N management must be integrated into wider policy discussions. Efforts to address the climate crisis must also address ecological, socio-economic and public health issues, and incorporating N management into climate policy is essential to ensure a just and equitable transition.

Question 12: What examples of best practice relating to monitoring, regulation or management of nitrogen should be considered, including international examples?

[47] Gu, B., Zhang, X., Lam, S.K., Yu, Y., van Grinsven, H.J.M., Zhang, S., Wang, X., Bodirsky, B.L., Wang, S., Duan, J., Ren, C., Bouwman, L., de Vries, W., Xu, J., Sutton, M.A., Chen, D., 2023. Cost-effective mitigation of nitrogen pollution from global croplands. Nature 613, 77–84. https://doi.org/10.1038/s41586-022-05481-8