Atmospheric Aerosol Loading

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Abstract

The global concentration of aerosol particles has more than doubled since pre-industrial times. Their harmful impacts on human health and the climate have justified the inclusion of 'atmospheric aerosol loading' as one of the nine planetary boundaries. The chapter maps the international legal landscape applicable to aerosol loading and identifies two categories of responses: one concentrating explicitly on limiting aerosol emissions, including by regulating air pollution, and the other indirectly targeting emissions by governing their sources, such as fossil fuel combustion and land-use changes. It is noteworthy that, in response to improved public awareness of air pollution, the international community has recently started to mobilize more adequately to protect this planetary boundary. However, it is arguably one of the more elusive planetary boundaries for policy-makers and lawyers, due to the complexity and remaining uncertainties surrounding scientific knowledge on aerosol loading. The planetary boundary is also difficult to apprehend because it concentrates only partially on the air pollution problem and proposes a global frame to respond to a primarily regional problem. A further hurdle lies in a lack of political appetite for an international, legally-binding, framework to govern aerosol loading. As a result, a complex international legal landscape has emerged, characterized by its fragmentation and reliance on non-treaty alternatives, that has, so far, been unable to provide an optimal and comprehensive response to protect the planetary boundary.

Keywords: atmospheric aerosol loading, planetary boundaries, air pollution, aerosols, black carbon, climate change

<1> Introduction

Air pollution features increasingly regularly in the news, as Indian cities close schools due to poor air quality,[1] and Saharan dust settles over European cities.[2] The global concentration of aerosol particles is closely associated with industrial development and has more than doubled

* The authors would like to thank Professor Martin Williams (Environmental Research Group, King's College London) for sharing his extensive experience on air quality policy with us and for his guidance regarding the scientific aspects of this chapter. All errors remain ours.

[1] 'India Air Pollution at 'Unbearable Levels', Delhi Minister Says' *BBC News* (London, 4 November 2019).

[2] 'UK Warns of Severe Air Pollution Across Country This Week' *Financial Times* (London, 26 February 2019).

since pre-industrial times.[3] Atmospheric aerosol loading has been proposed as one of the nine planetary boundaries because of its impacts on human health and the climate.[4] Yet, it is one of the lesser known planetary boundary: scientific knowledge about aerosol loading and its impacts remains uncertain, and a safe boundary value, above which the effects of aerosol loading may cause unacceptable change, has not yet been identified.[5]

This chapter maps, and reflects on, the extent to which law and governance responds to the problem of atmospheric aerosol loading. It concentrates on international and regional instruments and initiatives, the geographical scope of which is best suited to protect a planetary boundary. Such an analysis is a complex task for two main reasons. First, the term 'atmospheric aerosol loading' has not integrated into the legal lexicon; this means that while a number of legal frameworks, in particular pertaining to air pollution, will be relevant to respond to atmospheric aerosol loading, they have not been designed to explicitly protect the planetary boundary as such. Second, unlike other global environmental challenges, such as climate change or biodiversity loss that are primarily governed by a global framework agreement,[6] a comprehensive universal instrument able to protect air quality is yet to emerge. Instead, a review of the law applicable to this planetary boundary requires an assessment of vastly different legal and political instruments that vary significantly in terms of normative status, material and geographical scope as well as institutional oversight.

Section 2 briefly introduces the reader to the atmospheric aerosol loading planetary boundary by presenting the sources and impacts of aerosols. Section 3 then identifies and maps two categories of instruments and initiatives governing aerosol loading: one concentrating explicitly on limiting aerosol emissions, including by regulating air pollution, and the other indirectly targeting emissions by governing their sources, such as fossil fuel combustion and land-use changes. Section 4 identifies the scientific, political and legal factors that explain why the aerosol loading planetary boundary is arguably one of the more elusive planetary boundaries for policy-makers and lawyers, and why international legal frameworks have so far struggled to provide adequate responses to the problem. Section 5 concludes with recommendations to consider to better protect this planetary boundary.

<2> Presentation of the atmospheric aerosol loading planetary boundary

Aerosols are defined as a 'collection of airborne solid or liquid particles, with a typical size of between 0.01 and 10 micrometer (a millionth of a meter) that reside in the atmosphere for at least several hours'.[7] Primary aerosols are the result of the direct injection of particles into the atmosphere, such as dust or sea spray, or originate directly from combustion sources, such as

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3 Kostas Tsigaridis *et al.*, 'Change in Global Aerosol Composition Since Preindustrial Times' (2006) 6 Atmospheric Chemistry and Physics 5143.
4 Johan Rockström *et al*, 'Planetary Boundaries: Exploring the Safe Operating Space for Humanity' (2009) 14(2):32 Ecol Soc <http://www.ecologyandsociety.org/vol14/iss2/art32/ > accessed 10 November 2019.
5 Ibid.
6 See, respectively Verschuuren, chapter xxxx; Somsen and Trouwborst, chapter xxxx in this volume.
7 Rajendra K Pachauri and Andy Reisinger (eds), *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2007) 76.

the soot from poorly maintained diesel engines. Secondary aerosols, on the other hand, are the result of emission into the atmosphere of precursor pollutants (such as sulphur dioxide and ammonia) which undergo chemical reactions transforming them into aerosols after their release into the atmosphere.

Aerosols have natural or anthropogenic origins. Natural aerosols account for around 90 per cent of all global aerosols,[8] and include volcano dust, desert dust and sea salt. Anthropogenic aerosols include particulate matter (PM), emitted directly as a 'primary' aerosol, and nitrogen oxides, sulphur oxides, volatile organic compounds, and ammonia which can react in the atmosphere forming 'secondary' aerosols. The majority of anthropogenic aerosols are released as a result of fossil fuel combustion – due to transportation, electricity production, heating and industry – and land-use changes – such as forest burning and desertification.

The atmospheric aerosol planetary boundary was proposed mainly because of the impacts of aerosols on health and the environment. Ambient air pollution is considered by the World Health Organisation (WHO) to be a major cause of disease and death globally.[9] Short-term exposure to air pollution exacerbates existing respiratory problems (such as asthma), while long-term exposure leads to increased rates of mortality from cardiovascular and respiratory diseases as well as lung cancer.[10] Children have been shown to be particularly affected by air pollution that contributes to respiratory tract infections and causes over half of all deaths from acute lower respiratory infections in children under 5 years of age in low- and middle-income countries.[11]

Aerosols also have adverse effects on the environment and ecosystems. The acidifying effects of atmospheric deposition of nitrogen and sulphur are well-known: causing major damage to plants, water bodies and buildings, contributing to water and ocean acidification, and affecting nutrient and carbon cycles.[12] Ocean and coastal acidification and eutrophication, caused inter alia by acid rain, leads to coral bleaching and loss of marine life.[13] In addition, nutrients, including nitrates, accumulate in the soil and in water, which result in nitrogen-loving plants thriving and loss in plant species from excessive nitrogen or sunlight deprivation.[14]

But it is mostly for its impact upon cloud formation, weather patterns and the climate that aerosol loading has been included into the planetary boundary framework. Aerosols influence regional precipitation patterns by preventing the formation of certain clouds

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[8] Adam Voiland, 'Aerosols: Tiny Particles, Big Impact' (*NASA Earth Observatory*, 2 November 2010), <https://earthobservatory.nasa.gov/features/Aerosols> accessed 2 November 2019.

[9] World Health Organization, 'Ambient Air Pollution: Health Impacts' (*World Health Organization*, 2019) <https://www.who.int/airpollution/ambient/health-impacts/en/> accessed 2 November 2019.

[10] World Health Organization, *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease* (WHO 2016); WHO Regional Office for Europe, *Health Effects of Particulate Matter* (WHO 2013).

[11] World Health Organization, *Air Pollution and Child Health: Prescribing Clean Air* (WHO 2018) WHO/CED/PHE/18.01, 20.

[12] Heleen A. de Wit, Jean-Paul Hettelingh, Harry Harmens (eds), *Trends in Ecosystem and Health Responses to Long-range Transported Atmospheric Pollutants* (Norwegian Institute for Water Research, May 2016) 9. See also, Diz, chapter xxxx; Stephens, chapter xxxxx n this volume.

[13] Keith A Hunter *et al*, 'Impacts of Anthropogenic SOx, NOx and NH3 on Acidification of Coastal Waters and Shipping Lanes' (2011) 38 (13) Geophys Res Lett L13602.

[14] Samuel M Simkin, Edith B.Allen *et al*, 'Conditional Vulnerability of Plant Diversity to Atmospheric Nitrogen Deposition across the United States' (2016) 113 (15) PNAS 4086. See, also Cooper, chapter xxxx in this volume.

altogether and hence reducing rainfalls[15] or by suppressing light rainfall while intensifying heavy rainfall and lightning.[16] Impacts have to be assessed locally, as geographical variations, that depend on how specific aerosols interact with existing weather patterns, can be considerable. The potentially 'substantial influence [of aerosols] on the Asian monsoon circulation' is one of the core reasons put forward by Rockström *et al* to justify the inclusion of atmospheric aerosol loading in the planetary boundary framework,[17] and has been used as a case study to quantify a regional safe boundary.[18]

In addition, aerosols have been shown to influence the climate. They do so either directly through scattering and absorbing radiation, or indirectly by modifying the optical properties and lifetimes of clouds. Scientific understanding of the effects of aerosols on climate change has improved over the last decade, but uncertainty remains high because the impacts that aerosols have on the climate are difficult to model.[19] Indeed, natural aerosols – dust and sea salt – and some human-made aerosols such as ammonium sulphate, ammonium nitrate and secondary organic aerosols – present in smog and haze – reflect radiation from the sun out into space, therefore creating a net cooling effect.[20] Volcanic eruptions emitting sulphur oxides into the atmosphere also have a short term net cooling effect, the extent of which is more pronounced in the Northern Hemisphere than in tropical regions.[21] Yet, at the same time, other aerosols and gaseous pollutants, such as black carbon, methane and ozone, have a warming effect that was initially expected to be partially offset by the cooling effect of other aerosols, but which appears now to be much more significant.[22] As a result, scientific knowledge remains lacking regarding the medium and long-term impacts of aerosols on the climate.

<3> Overview of applicable instruments and initiatives relevant to the planetary boundary

Identifying the state of law and governance in relation to atmospheric aerosol loading is not an easy task given its highly fragmented nature. Two distinct, yet inter-related, types of law and governance approaches to the issue of atmospheric aerosol loading are identified below: a first route consists of regulating the emissions of aerosols, while a second route governs their sources.

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[15] Hans-F Graf, 'The Complex Interaction of Aerosols and Clouds' (2004) 303 Science 1309, 1310.
[16] Zhangqing Li *et al*, 'Aerosol and Boundary-layer Interactions and Impact on Air Quality' (2017) 4 Natl Sci Rev 810, 810.
[17] Rockström (n 4).
[18] Will Steffen *et al,* 'Planetary Boundaries: Guiding Human Development on a Changing Planet' (2015) 347(6223) Science 1259855-1, 1259855-7.
[19] Rajendra K Pachauri and Leo Meyer (eds), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2014) ('IPCC AR5 Synthesis Report') 44; Olivier Boucher *et al*, 'Clouds and Aerosols' in Thomas F Stocker *et al* (eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2014) ('IPCC AR5 Clouds and Aerosols').
[20] IPCC AR5 Clouds and Aerosols (n 19). See, also Du Toit, chapter xxxx in this volume.
[21] Matthew Toohey *et al.*, 'Disproportionately Strong Climate Forcing from Extratropical Explosive Volcanic Eruptions' (2019) 12 Nat Geosci 100.
[22] IPCC AR5 Synthesis Report (n 19) 44.

<A> Governing air pollutants

The first type of legal approaches designed to govern this planetary boundary are concerned with restricting emissions of aerosols and gaseous pollutants, either through wide-ranging or sector-specific initiatives related to air pollution, or, more indirectly, through initiatives responding to other environmental problems such as climate change.

Wide-ranging responses to air pollution

The problem of atmospheric aerosol loading is addressed by initiatives that do not only concentrate on aerosols but, more generally, seek to limit air pollution and improve air quality. An international treaty on air pollution remains lacking, but high-level political initiatives have multiplied in recent years. Notably, air pollution has been on the agenda of the UN Environment Assembly (UNEA) since its first session,[23] and the 2015 Sustainable Development Goals (SDGs) contain at least nine goals that are relevant to the planetary boundary,[24] with two targets making explicit reference to air quality.[25] The WHO also plays an important role in air quality governance. It regularly publishes air quality guidelines to aid policy-makers to set targets on air pollutants,[26] although domestic air policies, because they have to integrate technical, economic or political considerations, are inevitably laxer.[27] In 2018, the WHO hosted its first conference on air quality and health that led to the adoption of an aspirational goal to reduce deaths from air pollution by two-thirds by 2030.[28] Initiatives of the type of the UNEA, SDGs and WHO are symbolically important because they reveal an emerging consensus on the recognition of air pollution as a global policy issue; however, they have not yet been followed-up by global legally-binding instruments that might constrain states more strongly. Instead, regional initiatives that govern air pollutants have been preferred.

The multilateral instrument of a legally binding nature that is at present possibly best suited to govern this planetary boundary, is a sophisticated regional treaty, the Convention on Long-Range Transboundary Air Pollution (CLRTAP). CLRTAP was adopted under the

[23] UNEA 'Ministerial Declaration' (5 December 2017) UNEP/EA.3/L.19, para 1; and two resolutions on nationally determined ambient air quality standards and air quality monitoring, as well as resolutions relevant to the regulation of specific aerosols and gaseous pollutants or their sources. See UNEA Res 1/7, 'Strengthening the Role of the United Nations Environment Programme in Promoting Air Quality' (27 June 2014) para 2; UNEA Res 3/8, 'Preventing and Reducing Air Pollution to Improve Air Quality Globally' (3 December 2017), para 1(a); UNEA Res 4/10, 'Innovation on Biodiversity and Land Degradation' (28 March 2019); UNEA Res 4/14, 'Sustainable Nitrogen Management' (28 March 2019); UNEA Res 2/24, 'Combating Desertification, Land Degradation and Drought and Promoting Sustainable Pastoralism and Rangelands' (3 August 2016).

[24] UNGA Res 70/1, 'Transforming Our World: The 2030 Agenda for Sustainable Development' (25 September 2015) ('SDGs'), Goal 2 (food security), Goal 3 (health), Goal 7 (sustainable energy), Goal 9 (resilient infrastructure, industrialization and innovation), Goal 11 (sustainable cities), Goal 12 (sustainable consumption and production patterns), Goal 13 (climate action), Goal 14 (marine environment) and Goal 15 (life on land).

[25] SDGs, target 11.6 on reducing the environmental and human health impacts of cities, 'paying special attention to air quality' and target 3.9 on reducing deaths and illnesses from air pollution.

[26] WHO, 'Air Quality Guidelines. Global Update 2005: Summary of Risk Assessment' (2006) WHO/SDE/PHE/OEH/06.02.

[27] For instance, it has been established that 92% of the world's population still live in places where air quality levels exceed the WHO guidelines for $PM_{2.5}$. See WHO, *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease* (WHO 2016).

[28] Geneva Action Agenda to Combat Air Pollution (1 November 2018) <https://www.who.int/phe/news/clean-air-for-health/en/> accessed 14 November 2019.

auspices of the UN Economic Commission for Europe and is only open for ratification to its members (which includes North American countries).[29] It offers a detailed framework to regulate aerosol and gaseous emissions by using multiple protocols that set specific emission reduction targets for sulphur,[30] nitrogen oxides,[31] volatile organic compounds,[32] heavy metals[33] and persistent organic pollutants.[34] The latest protocol, the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, follows a markedly different approach to the previous protocols: instead of adopting a siloed approach, regulating one type of aerosol at a time, it sets national emissions ceilings for four pollutants – sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia, and seeks to limit their broad-ranging environmental impacts.[35] Amended in 2012, the Protocol has become the first binding agreement to target $PM_{2.5}$ (including black carbon) emissions.[36] Assessments of the effectiveness of the Convention vary depending on how it is measured, but the treaty is generally considered to have been successful at reducing certain air pollutants.[37] The detailed air quality framework of the EU has contributed to the implementation of the CLRTAP by setting uniform rules with regard to emission reduction commitments[38] and air quality standards,[39] and by regulating some sources of air pollution, including vehicles and industrial activities.[40] While generally successful at improving air quality, the framework is currently struggling to reduce some air pollutants in Member States, as demonstrated by multiple litigation cases challenging failures by national governments to draw up appropriate air quality plans and to keep within the limit values set for specific pollutants.[41]

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[29] Convention on Long-Range Transboundary Air Pollution (adopted 13 November 1979, entered into force 16 March 1983) 18 ILM 1442 ('CLTRAP') Art 14(1).

[30] Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent (adopted 8 July 1985, entered into force 2 September 1987) 1480 UNTS 215 ('Helsinki Protocol'); Oslo Protocol on Further Reduction of Sulphur Emissions (adopted 14 June 1994, entered into force 5 August 1998) 2030 UNTS 122 ('Oslo Protocol').

[31] Protocol concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes (adopted 31 October 1998, entered into force 14 February 1991) 1593 UNTS 287.

[32] Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes (adopted 18 November 1991, entered into force 29 September 1997) 2001 UNTS 187.

[33] Protocol on Heavy Metals (adopted 24 June 1998, entered into force 29 December 2003) 2237 UNTS 4 ('Aarhus Protocol').

[34] Protocol on Persistent Organic Pollutants (adopted 24 June 1988, entered into force 23 December 2003) 37 ILM 505 ('POPs Protocol').

[35] Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, (adopted 30 November 1999, entered into force 17 May 2005) 2319 UNTS 81 ('Gothenburg Protocol').

[36] Gothenburg Protocol, 'Adoption of amendments of the text of and Annexes II to IX and addition of new Annexes X and XI' (adopted 4 May 2012, entered into force 7 October 2019) C.N.155.2013.TREATIES-XXVII.1.h ('Amended Gothenburg Protocol').

[37] See for instance, for a positive assessment Leen Hordijk and Markus Amann, 'How Science and Policy Combined to Combat Air Pollution Problems' (2007) 37(4) EPL 336; compare with Adam Byrne, 'The 1979 Convention on Long-Range Transboundary Air Pollution: Assessing its Effectiveness as a Multilateral Environmental Regime after 35 Years' (2015) 4(1) TEL 37.

[38] Eg Directive 2016/2284/EU of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC [2016] OJ L344/1.

[39] Directive 2008/50/EC of 21 May 2008 on ambient air quality and cleaner air for Europe [2008] OJ L152/1.

[40] Directive 2007/46/EC of 5 September 2007 establishing a framework for the approval of motor vehicles [2007] OJ L263/1; Directive 2010/75/EU of 24 November 2010 on industrial emissions [2010] OJ L334/17.

[41] See, by way of example, litigation directed at the UK Government's failure to comply with the Air Quality Directive, *R (ClientEarth) v The Secretary of State for the Environment, Food and Rural Affairs* [2013] UKSC 25; R *(ClientEarth) v Secretary of State for the Environment, Food and Rural Affairs (No. 3)* [2018] EWHC 315

Other regions have, albeit less ambitiously, also sought to address the problem of air quality. In Asia, multiple regional intergovernmental cooperative efforts address air pollution,[42] with a particular emphasis on reducing acid rain caused by sulphur oxide emissions[43] and haze due to forest burning,[44] and on coordination and collaboration.[45] In Africa, four United Nations Environment Programme (UNEP)-sponsored policy frameworks on air pollution have been developed to generate and share knowledge and strengthen institutional capacity, but their guidance remains too general to be transformational.[46] In Latin America and the Caribbean, an intergovernmental network on air pollution has been established but has not been formally institutionalized, which has resulted in minimal outputs.[47] In addition, some states have adopted bilateral air quality agreements, such as those in place in North America.[48] While these have successfully reduced aerosol emissions in some instances, their restricted geographical scope offers limited protective coverage to the atmospheric aerosol loading boundary.

Sector-specific responses to air pollution

General approaches to air pollution are complemented by sector-specific responses, with shipping and aviation taking steps to regulate their impacts on air pollution. International shipping is an important sector in the context of atmospheric aerosol loading: having grown by 3.8 per cent between 2000 and 2015,[49] it is responsible for increases in emissions of nitrogen

(Admin); and at the EU level, see eg Case C-336/16 European *Commission v Republic of Poland* [2018] ECLI:EU:C:2018:94.

[42] Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia (22 April 1998) <http://www.rrcap.ait.asia/male> accessed 2 November 2019; Framework Convention on Preservation of Environment for Sustainable Development of Central Asia, Art 8 (adopted 22 November 2006, not in force) <http://www2.ecolex.org/server2neu.php/libcat/docs/TRE/Full/En/TRE-143806.pdf> accessed 2 November 2019.

[43] EANET, 'Joint Announcement on the Implementation of the Acid Deposition Monitoring Network in East Asia' (25-26 October 2000) EANET/IG 2/5/2 rev; EANET, 'Instrument for Strengthening the Acid Deposition Monitoring Network in East Asia' (2010).

[44] ASEAN Agreement on Transboundary Haze Pollution (adopted 10 June 2002, entered into force 25 November 2003) <https://haze.asean.org/?wpfb_dl=32> accessed 2 November 2019 ('ASEAN Haze Agreement').

[45] See for instance the Asia Pacific Clean Air Partnership that coordinates the clean air programmes in the region: UNEP, 'What We Do' (*UN Environment Programme*, 2020) <https://www.unenvironment.org/asia-and-pacific/asia-pacific-clean-air-partnership/what-we-do > accessed 27 March 2020.

[46] Southern African Development Community Regional Policy Framework on Air Pollution (7 March 2008); Eastern Africa Regional Framework Agreement on Air Pollution (23 October 2008); West and Central Africa Regional Framework Agreement on Air Pollution (22 July 2009); North African Framework Agreement on Air Pollution (12-16 December 2011).

[47] 'Regional Plan of Action on Atmospheric Pollution', XIX Meeting of the Forum of Ministers of Environment for Latin America and the Caribbean (14 March 2014).

[48] Agreement of Cooperation between the United States of America and the United Mexican States Regarding Transboundary Air Pollution Caused by Copper Smelters along their Common Border (adopted 29 January 1987, entered into force 29 January 1987) 26 ILM 33; Agreement of Cooperation between the Government of the United States of America and the Government of the United Mexican States Regarding International Transport of Urban Air Pollution (adopted 3 October 1989) 29 ILM 29; Agreement on Air Quality (Canada–US) (adopted 13 March 1991, entered into force 13 March 1991) 1852 UNTS 79, and supplementary protocol and annex on ground-level ozone (7 December 2000).

[49] International Energy Agency, *Tracking Clean Energy Progress 2017* (OECD/IEA 2017) 48.

oxides, volatile organic compounds and particulate matter.[50] A general duty to prevent pollution of the marine environment, including 'from or through the atmosphere', is found in the UN Convention on the Law of Sea,[51] and reproduced in regional law of the sea treaties. More specific obligations to limit aerosol emissions are found in the International Convention for the Prevention of Pollution from Ships (MARPOL)[52], the Annex VI of which sets emission limits on aerosols such as nitrogen oxides and sulphur oxides, creates designated emissions control areas with stricter standards, and adopts technical and energy efficiency measures as well as fuel oil standards.[53]

Similarly, the aviation sector can have a noteworthy impact on this planetary boundary because aircraft emit nitrogen oxides, sulphur oxides, ozone, methane, black carbon, hydrocarbons and water vapour. Since the late 1970s, the International Civil Aviation Organization (ICAO) has been working on limiting and reducing the impact of aviation emissions on local air quality in the vicinity of airports.[54] Air pollution is regulated by volume II of annex 16 of the Chicago Convention on International Civil Aviation that was adopted in 1981 to govern environmental protection. It has since been regularly amended.[55] The ICAO Council is assisted by the Committee on Aviation Environmental Protection established in 1983 to develop international standards and recommended practices. These now include standards for aircraft engine emissions covering smoke and gaseous emissions of hydrocarbons, carbon monoxide and nitrogen oxides, and controls on particulate matter emissions.[56] Yet, despite the recent halt in its growth due to the Covid-19 pandemic, if the civil aviation sector continues to grow by approximately 5 per cent a year,[57] these measures might be lacking in ambition.

Co-benefits of environmental regimes

International initiatives of which the main objective is not explicitly air quality governance, can nevertheless protect this planetary boundary. For instance, international responses to

[50] Naya Olmer, Bryan Comer, Biswajoy Roy, Xiaoli Mao, and Dan Rutherford, *Greenhouse Gas Emissions From Global Shipping, 2013-2015* (International Council on Clean Transportation 2017) 19-20.
[51] United Nations Convention on the Law of the Sea (adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 3, Arts 212(3) and 222. See, also Diz, chapter xxxx; Stephens, chapter xxxx in this volume.
[52] International Convention for the Prevention of Pollution from Ships (adopted 2 November 1973, entered into force 2 October 1983) 1340 UNTS 184.
[53] MARPOL, Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005, revised in October 2008, entered into force 1 July 2010) ('MARPOL Annex VI').
[54] ICAO Assembly Res A40-17 'Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection. General Provisions, Noise and Local Air Quality' (October 2019), Appendix H 'aviation impact on local air quality'.
[55] Convention on International Civil Aviation (adopted 7 December 1944, entered into force 14 April 1947) 15 UNTS 295, Annex 16, volume II.
[56] ICAO, *2019 Environmental Report* (ICAO 2019) 97-99.
[57] Mauro Masiol and Roy M Harrison, 'Aircraft Engine Exhaust Emissions and Other Airport-related Contributions to Ambient Air Pollution: A Review' (2014) 95 Atmos Environ 409-455, 409.

hazardous substances, such as persistent organic pollutants[58] and heavy metals,[59] indirectly protect the planetary boundary because they can be absorbed by fine particulate matter and become aerosolized. Similarly, the recent international attention given to short-lived climate pollutants in the context of climate action – which are responsible for global temperature increases as they trap heat in the troposphere and prevent it from being radiated into space – also benefit air quality. Amongst them, black carbon is an aerosol thought to be the second greatest contributor to climate change after carbon dioxide,[60] and it is a toxic component of global particulate matter air pollution, which is among the top ten leading risk factors for early deaths globally.[61] Black carbon emissions are governed by the Gothenburg Protocol as amended in 2012 to include black carbon within the scope of particulate matter emission reduction targets, making it the first international treaty to regulate this aerosol.[62] The International Maritime Organisation (IMO) and the ICAO are also in the process of designing black carbon policies applicable to their sectors.[63] These are complemented by softer means of cooperation in the form of non-legally binding initiatives – such as the Arctic Council's framework for action on enhanced black carbon and methane emission reductions[64] that adopted a collective, aspirational, regional goal for reducing black carbon emissions[65] – and voluntary partnerships – for instance, the Climate and Clean Air Coalition (CCAC) facilitates cooperation among various stakeholders to improve air quality.[66] As is often the case with instruments and initiatives that focus on limiting aerosol emissions, the approach is target-oriented, offering States some flexibility to decide how to meet specific objectives while encouraging them to apply best available technologies.

<B> Governing pollution sources

A second approach to governing this planetary boundary is to regulate the main sources of aerosols. Legal responses in this category do not necessarily adopt the same command-and-control approach as those that concentrate on reducing emissions. Instead, they favour deep, structural transformations to offer alternatives to the activities responsible for aerosol

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[58] Convention on Persistent Organic Pollutants (adopted 22 May 2001, entered into force 17 May 2005) 2256 UNTS 119. See also POPs Protocol (n 34); Amendments to the Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources (adopted 7 March 1996, entered into force 18 May 2006) Art 5 and Annex III (pollution transported through the atmosphere).

[59] Aarhus Protocol (n 33) Annex I; Minamata Convention on Mercury (adopted 10 October 2013, entered into force 16 August 2017) <www.mercuryconvention.org/> accessed 2 November 2019, Article 8, Annex D.

[60] V Ramanathan and G Carmicheal, 'Global and Regional Climate Changes Due to Black Carbon' (2008) 1 Nat Geosci 221; IPCC, 'Summary for Policymakers', in Valerie Masson-Delmotte *et al* (eds), *IPCC Special Report on the Impacts of Global Warming of 1.5°C* (CUP 2018).

[61] Joshua S Apte *et al*, 'Addressing Global Mortality from Ambient PM2.5' (2015) 49 Environ Sci Technol 8057.

[62] Amended Gothenburg Protocol (n 36) Art 2(5)-(6).

[63] Following the plan of work adopted by the IMO Marine Environment Protection Committee, MEPC 62/24 'Report of the Marine Environment Protection Committee on its Sixty-Second Session' (26 July 2011), para 4.20; ICAO Res A40-17 (n 54) Appendix H, para 5.

[64] Arctic Council, 'Framework for Action on Enhanced Black Carbon and Methane Emissions Reductions' (2015) <http://hdl.handle.net/11374/610> accessed 3 November 2019.

[65] Arctic Council, 'Expert Group on Black Carbon and Methane; Summary of Progress and Recommendations' (2017) 4 <http://hdl.handle.net/11374/1936> accessed 14 November 2019.

[66] See, for instance, Climate and Clean Air Coalition, 'Marrakech Communiqué' (14 November 2016) HLA/NOV2016/03A rev1, committing to reduce black carbon emissions through cleaner diesel fuels and vehicles.

emissions. The emphasis is on building capacity and fostering cooperation in sectors such as transport, energy, or cooking and heating, that produce high levels of aerosol emissions. While the international community logically concentrates on anthropogenic sources of aerosols, it has sometimes also focused on natural aerosols, the emissions of which are exacerbated by human activities that result in unsustainable land and water management as well as land degradation, such as in the case of sand and dust storms.[67]

Major sources of human-made aerosols are fossil fuel combustion and land-use changes. With regards to fossil fuel combustion, a treaty prohibiting fossil fuels and encouraging renewable energy has yet to emerge.[68] Instead, this source of aerosol emissions is indirectly regulated by climate and energy instruments. By aiming to reduce greenhouse gas emissions, international climate treaties implicitly encourage a reduction in fossil fuel use, which also contributes to a decrease in aerosol emissions.[69] Multiple voluntary initiatives also promote access to clean energy and energy efficiency in the context of the Sustainable Energy for All Initiative and Sustainable Development Goal 7.[70]

As for land-use changes – and in particular deforestation for agricultural purposes, international law has remained largely unresponsive, as demonstrated by the repeated failures of the international community to adopt a legally-binding treaty on forest protection.[71] A major exception are the treaties adopted by the Association of Southeast Asian Nations (ASEAN) on the conservation of nature and natural resources[72] and on transboundary haze pollution[73] that both aim to prevent forest fires. However, the language of their provisions is weak,[74] and enforcement can be difficult, as demonstrated by high smog levels in the region due to burning

[67] UNCCD, 'Sand and dust storms' (*UNCCD*) <https://www.unccd.int/actions/sand-and-dust-storms> accessed 10 June 2020.

[68] For such proposals, see Margaretha Wewerinke-Singh, *Thinking Globally, Acting Regionally: The Case for a Pacific Climate Treaty* (Pacific Islands Development Forum & Pacific Islands Climate Action Network 2016), Art 3 on 'phasing-out fossil fuels'; and Anthony Burke and Stefanie Fishel, 'A Coal Elimination Treaty 2030: Fast Tracking Climate Change Mitigation, Global Health and Security' (2020) Earth System Governance 100046.

[69] United Nations Framework Convention on Climate Change (adopted 9 May 1992, entered into force 21 March 1994) 1771 UNTS 107; Kyoto Protocol to the United Nations Framework Convention on Climate Change (adopted 11 December 1997, entered into force 16 February 2005) 2303 UNTS 162; Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016) 55 ILM 740.

[70] See, eg, the Clean Cooking Alliance established in 2010 to accelerate the development and distribution of clean cooking solutions to limit indoor air pollution <https://www.cleancookingalliance.org/> accessed 12 November 2019.

[71] See UNECD 'Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests' (21 April 1992) A/CONF.151/6; UNECD 'Report of the United Nations Conference on Environment and Development' (14 August 1992) UN Doc A/CONF.151/26 (Vol. III) Annex III; and UNGA Res 62/98 'Non Legally Binding Instrument on All Types of Forests' (17 December 2007). For an analysis of how international law protects forests, see Leslie-Anne Duvic-Paoli, 'Trees' in Jessie Hohmann and Daniel Joyce (eds.), *International Law's Objects* (OUP 2018) 504-514.

[72] Agreement on the Conservation of Nature and Natural Resources (adopted 9 July 1985, not in force) <https://environment.asean.org/agreement-on-the-conservation-of-nature-and-natural-resources/> accessed 9 March 2020, Art 6(2)(a).

[73] ASEAN Haze Agreement (n 44) Art 2.

[74] For a detailed analysis of its weaknesses, see Laely Nurhidayah, Zada Lipman and Shawkat Alam, 'Regional Environmental Governance: An Evaluation of the ASEAN Legal Framework for Addressing Transboundary Haze Pollution' (2014) 15(1) Aust J Asian Law 1.

of forest and peat.[75] Land-use changes are also governed by international instruments and initiatives seeking to reduce desertification[76] and combat sand and dust storms.[77]

<4> Challenges presented by the planetary boundary for law and governance

The state of the law and governance in relation to the atmospheric aerosol loading boundary described above, demonstrates that the international community has so far struggled to provide an appropriate response to the problem of atmospheric aerosol loading. We identify below multiple factors that contribute to explaining why protecting this elusive planetary boundary has been so challenging.

<A> Framing disconnect

To start with, international legal responses to the aerosol loading problem are faced with a framing disconnect between the environmental problem that defines the planetary boundary and the policy and legal lexicon used to describe it. The planetary boundary employs the term 'aerosols', a term that will be unfamiliar to policy-makers and lawyers and that is rarely used in legal texts. Instead, the terms 'atmospheric degradation' and 'air pollution' are usually employed by lawyers. Yet, the two terms do not necessarily fit the material scope of the planetary boundary. Atmospheric degradation is broader than aerosol loading and includes not only air pollution, but also ozone depletion and climate change.[78] Similarly, air pollution is not equivalent to aerosol loading since air pollutants include, but are not restricted to, aerosols. Consequently, the law and governance landscape presented above is necessarily a combination of different, ad hoc, regimes that are relevant to the planetary boundary but do not match it perfectly. This might explain, at least in part, why the aerosol loading boundary is one of the lesser known planetary boundaries amongst policy-makers and lawyers.

<B> Scientific complexity and uncertainty

Addressing the governance challenges of this planetary boundary is also difficult because aerosol loading is characterized by high levels of scientific complexity and uncertainty. Pollution, of any type, is generally difficult to regulate because it emanates from different sources, takes different forms, and causes different impacts. Aerosols cannot be approached as

[75] See, eg, Jonathan Watts, 'Malaysia Complains of Smog from Indonesian Forest Fires' *The Guardian* (London, 6 September 2019).

[76] United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (adopted 17 June 1994, entered into force 26 December 1996) 1954 UNTS 3 ('UNCCD'); Sustainable Development Goal 15; UNEA Res 2/24, 'Combating Desertification, Land Degradation and Drought and Promoting Sustainable Pastoralism and Rangelands' (3 August 2016).

[77] See eg, UNCCD Decision 31/COP.13, 'Policy Advocacy Framework to Combat Sand and Dust Storms' (15 September 2017); UNEA Res 2/21, 'Sand and Dust Storms' (3 August 2016); UNGA Res 72/225, 'Combating Sand and Dust Storms' (20 December 2017), inviting the establishment of an inter-agency framework for cooperation. For regional initiatives, see, eg, Economic and Social Commission for Asia and the Pacific Resolution 72/7, 'Regional Cooperation to Combat Sand and Dust Storms in Asia and the Pacific' (24 May 2016).

[78] ILC, 'Protection of the atmosphere - Texts and titles of draft conclusions 1, 2 and 5, and preambular paragraphs provisionally adopted by the Drafting Committee on 13, 18, 19 and 20 May 2015' (22 May 2015) A/CN.4/L.851, draft guideline 1(c).

a single, uniform category because their behaviour in the atmosphere is extremely complex and depends on their chemical composition as well as their geographical location. In addition, the planetary boundary itself is characterized by scientific uncertainty, since it has so far been impossible to quantify it – that is, to recognize a global threshold beyond which humanity would not be operating within a safe zone.[79] In fact, it is one of only two planetary boundaries (alongside 'novel entities') for which quantification has not been possible. The absence of a threshold is problematic because it fails to inspire the sense of urgency which is generally necessary to mobilize policy-makers and civil society.[80]

The planetary boundary is consequently also faced with major knowledge gaps regarding how aerosols interact with each other, and with the climate, and how they damage human health and the environment. A fundamental element of scientific uncertainty relates to the impacts that aerosols have on total radiative forcing estimates, one of the most critical and significant uncertainties in climate change projections.[81] Tackling air pollution may reduce the cooling effect of some aerosols and lead to further surface warming. Yet, climate models remain unable to reliably predict the consequences of reducing aerosols.[82] Although scientific knowledge is improving, the complexity of the interactions has significant implications for decision-makers that lack the scientific basis to make informed and integrated decisions. While global issues such as climate change and biodiversity now benefit from global science-policy interfaces that synthesizes existing knowledge to facilitate decision-making, such a mechanism remains lacking in the case of air pollution. Pursuant to the precautionary principle, the absence of scientific certainty should not preclude decision-makers from taking action, but the lack of scientific clarity regarding the behaviour of aerosols can undermine the design of effective policies.[83] In addition, the evolving nature of scientific knowledge on aerosol loading means that legal instruments (as the CLRTAP model shows), need to be highly adaptive in order to best reflect the latest knowledge.

<C> Multi-level governance

The elusiveness of this particular planetary boundary is also due to the fact that it approaches aerosol loading as a global challenge when it is primarily a localized problem.[84] The rationale for a separate boundary on aerosol loading has in effect been justified in spatially-restricted terms, on the basis of the 'effect of aerosols on *regional* ocean-atmosphere circulation'.[85] This is not to say that atmospheric aerosol loading does not have global impacts: air pollution can have major long-range transboundary effects in other regions or on the global climate. However, scientists have not been able to identify a global safe threshold for the planetary boundary. Instead, they have only been able to define with certainty a planetary boundary for aerosol loading of a regional scale – in relation to the effects of aerosols on monsoon patterns

[79] Rockström (n 4).
[80] Florian Klapproth, 'Time and Decision Making in Humans' (2008) 8(4) Cogn Affect Behav Neurosci 509-524, 519.
[81] IPCC AR5 Synthesis Report (n 19) 44.
[82] IPCC AR5 Clouds and Aerosols (n 19) 576.
[83] See, Collins, chapter xxxx in this volume.
[84] See, Kim and Kotzé, chapter xxxx in this volume on the issue of downscaling.
[85] Steffen (n 18) 1259855-7 (emphasis added).

in South East Asia.[86] While air pollution is now understood as a complex issue that can have regional, hemispheric and global impacts, it has nevertheless been noted that 'the spatial heterogeneity of aerosol loading warrants more geographically specific management'.[87] This scientific reality fits well with the reluctance, mentioned above, of policy-makers towards adopting a global outlook on the governance of air pollution and has resulted in governance initiatives with a regional and local focus.[88] In other words, the global (or *planetary*) outlook of this particular planetary boundary fails to fully acknowledge the complexity of governance between scales.

<D> Political reluctance

The historical reluctance of States to govern the atmosphere presents an additional challenge to this boundary. Air pollution remains a poorly regulated problem at a global level. This does not mean it is completely disregarded by international law. After all, one of the foundational cases of international environmental law – the *Trail Smelter* case[89] – was essentially a case of air pollution. Yet, States have shown little appetite for regulating the issue comprehensively at a global level. Rules of customary international law, including the prohibition to cause transboundary harm, the duty to undertake environmental impact assessments and to cooperate, remain applicable in the context of this planetary boundary, but additional instruments are necessary given the level of specificity required to adequately respond to aerosol pollution. While in 1982 the UNEP Governing Council called for the preparation of a 'global code of conduct with respect to transboundary air pollution, drawing upon existing regional and bilateral experience',[90] the recommendation was never followed through. As a result, to date, no single comprehensive treaty governs the planetary boundary.

Admittedly, air pollution is becoming increasingly important on the international agenda, as evidenced by the recent work of the UNEA and WHO mentioned above. Yet, States generally remain unwilling to find solutions to the gaps within, and between, existing treaty regimes. Notably, the work of the International Law Commission (ILC) on the protection of the atmosphere could have filled such gaps.[91] However, its mandate was significantly restricted with regard to its outcome, which will take the form of guidelines (and not articles), as well as its content, by excluding numerous related topics currently under negotiation (such as long-range transboundary air pollution and black carbon).[92] Similarly, the SDGs do not include a

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[86] Ibid.

[87] Ted Nordhaus, Michael Shellenberger and Linus Blomqvist, *The Planetary Boundary Hypothesis: A Review of the Evidence* (Breakthrough Institute 2012) 30.

[88] UN, 'Agenda 21, Annex II to the Report of the United Nations Conference on Environment and Development (3–14 June 1992)' UN Doc. A/CONF.151/26, Chapter 9, para 9.27(c), encouraging the adoption and implementation of regional air agreements.

[89] *Trail Smelter (United States v. Canada)* (16 April 1938 and 11 March 1941), [1941] 3 RIAA 1905.

[90] UNEP Governing Council Decision 10/21 (31 May 1982).

[91] ILC, 'Report of the International Law Commission to the General Assembly on the Work of its 65th Session' (6 May–7 June and 8 July–9 August 2013) UN Doc A/68/10, 115 ('ILC Report'), para 168. For a critical analysis of the mandate, see Peter Sand, 'The Discourse on 'Protection of the Atmosphere' in the International Law Commission' (2017) 26(3) RECIEL 201.

[92] ILC Report (n 91) para 168.

standalone goal on air pollution, which could have raised the symbolic relevance of air pollution globally and possibly helped adopt a more coordinated approach to the problem.

<E> Legal fragmentation

The scientific impossibility of a one-size-fits-all approach to aerosols and the political reluctance to adopt obligations to prevent atmospheric degradation have resulted in a fragmented legal landscape.[93] Fragmentation is a general problem of international environmental law that has adopted a sectoral approach to environmental problems.[94] The phenomenon is not necessarily negative: specific instruments (either in geographical or material scope) are generally better adapted to local circumstances (environmental, economic and/or technological). Political consensus is also more easily achieved, and ambition raised, when the number of negotiating states is limited, or when the scope of the problem to be solved is limited.

However, this particular planetary boundary arguably cannot be protected in a homogenous manner without a holistic approach to aerosol loading. A first difficulty arises from the nature of aerosols: they often clump together and form complex mixtures, which means that a siloed legal approach – regulating air pollutants individually – is unable to account for the effects of their interactions.

The second challenge relates to the consequences of fragmentation: regulation does not only vary depending on the aerosol, but one aerosol might even fall under the scope of multiple legal sources applicable to different members. That is for instance the case of sulphur dioxide emissions (a source of major health problems and which is responsible for acid rain), that are regulated by a patchwork of regional and bilateral treaties.[95] While generally speaking these instruments have successfully reduced sulphur dioxide emissions,[96] such a piecemeal approach dilutes responsibility, which, in turn, limits accountability.

A third and related problem arising from fragmentation is geographical: significant portions of the planet are not covered by a legally-binding transboundary agreement, and some do not even fall under any regional air pollution networks.[97] While various regional air pollution arrangements exist, they are at various stages of development and often largely aspirational.[98] They are predominantly scientific networks, such as the Acid Deposition Monitoring Network in East Asia, or political endeavours, such as the Southern African

[93] See, also Piselli and Van Asselt, chapter xxxx in this volume.
[94] Rakhyun E Kim and Klaus Bosselmann, 'International Environmental Law in the Anthropocene: Towards a Purposive System of Multilateral Environmental Agreements' (2013) 2 TEL 285, 286.
[95] Helsinki Protocol (n 35); Oslo Protocol (n 35); Agreement between the Government of Canada and the Government of the United States on Air Quality (adopted 13 March 1991, entered into force 13 March 1991) Annex I(1); MARPOL Annex VI (n 53) regulation 14 (sulphur dioxide and particulate matter).
[96] See, for instance, *Canada-United States Air Quality Agreement Progress Report 2016* (2017), 4-7, noting the major reductions in sulphur dioxide as a result of the Canada-US Agreement on Air Quality.
[97] Such as the Middle East and Oceania. For the geographical coverage of the main existing regional air pollution networks, see figure 1 in CLRTAP Executive Body, 'Strengthening Cooperation with Regional Air Pollution Networks and Initiatives outside the Convention. Submitted by the secretariat of the Global Atmospheric Pollution Forum' (12–16 December 2011) Informal document No 12.
[98] Werner Scholtz, Jonathan Verschuuren, 'Introduction', in Werner Scholtz, Jonathan Verschuuren (eds), *Regional Environmental Law: Transregional Comparative Lessons in Pursuit of Sustainable Development* (Edward Elgar 2015) 1-17, 16.

Development Community Regional Policy Framework on Air Pollution,[99] that remain 'soft' in nature and often suffer from implementation deficits. Atmospheric aerosol loading cannot therefore be governed in a homogenous manner because levels of cooperation are uneven across regions and regional forums have operated so far largely in isolation. Overall, while a complex web of legal instruments protects the planetary boundary, this is under extremely limited circumstances given their restricted material and spatial scope, thereby leaving substantial gaps in the governance of the planetary boundary.

<F> Non-treaty-based approaches

Political resistance towards a comprehensive framework has also resulted in the multiplication of non-treaty-based approaches to air pollution governance. For instance, traditional approaches to regulating black carbon through legally-binding instruments have been met with limited success at the IMO and the ICAO, while the amendment to the Gothenburg Protocol covering black carbon emissions has been slow to enter into force. Conversely, voluntary initiatives have multiplied, for instance at the Arctic Council and through the CCAC. These voluntary initiatives can have substantial advantages to the extent that they might address some of the shortcomings of the more formal, treaty-based approaches.

First, consensus is generally slow to develop around legally-binding instruments and rely on the existence of a common understanding of the problem and proposed solutions that are often the result of voluntary cooperation. Second, international treaties are not always sufficiently flexible to adapt to the rapid evolution of scientific knowledge over the health and environmental impacts of air pollutants, whereas voluntary initiatives are. Third, multi-stakeholder initiatives facilitate the involvement of non-State actors, and their participation is often central to facilitate implementation. For instance, the CCAC now includes 67 countries, 18 intergovernmental organizations and 57 non-governmental organisations (NGOs).[100] Similarly, *BreatheLife*, a joint campaign started in 2016 led by the WHO, UNEP and the CCAC, seeks inter alia to mobilize cities and subnational actors to commit to achieving WHO Air Quality Guidelines by 2030. Due to their largely aspirational qualities, these initiatives have an important role in mobilizing stakeholders and building capacity. But without rigorous monitoring, reporting or a compliance process, their ability to provide a sufficiently ambitious response to the planetary air quality crisis remains uncertain.

<5> Concluding remarks and recommendations

The chapter has highlighted major gaps in our legal and policy response to atmospheric aerosol loading. Our conclusions are, however, not all entirely negative. For example, air pollution – and, therefore, aerosol loading – has recently been given a more important status on the international agenda, including at the UNEA, WHO and UN General Assembly. Nevertheless, the framework offered by the planetary boundary is not necessarily helpful to mobilize the

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[99] Southern African Development Community Regional Policy Framework on Air Pollution (n 46).
[100] Climate and Clean Air Coalition, 'Partners' <https://www.ccacoalition.org/en/partners> accessed 2 November 2019.

international community. Atmospheric aerosol loading remains one of the lesser known planetary boundaries in legal and policy circles, and the framework offered by the atmospheric aerosol loading planetary boundary is facing noteworthy difficulties. First, its global, planetary scope seems to be unable to always account for the localized impacts of atmospheric aerosol loading. Second, it is extremely difficult to make sense of the exact relationship between this planetary boundary and the other boundaries given the complex interactions between aerosol loading and other boundary concerns such climate change, ozone, and freshwater. Third, by concentrating only on aerosol loading and not more broadly on air pollution, the planetary boundary finds itself ill-at-ease with existing legal frameworks. The framework therefore struggles to raise awareness and to adequately mobilize policy-makers.

This chapter concludes with five general recommendations on how to better respond to the problem of atmospheric aerosol loading, while acknowledging that the challenges identified in section 4 remain substantial hurdles to the governance of this planetary boundary. A first fundamental step towards better protecting the planetary boundary lies in the gathering of solid scientific data. Indeed, further progress on the regulation of the planetary boundary is conditional on developing a common knowledge base that would be able to provide clear policy options to support well-informed governance action. Data on air quality is improving, but remains difficult to gather in low and medium-income countries.[101] Even when the data is available, difficulties remain regarding how to communicate it to policy-makers[102] and the general public.[103] Gathering scientific information to improve the quality and spatial coverage of existing data, using an Earth system science approach to facilitate inter- and multi-disciplinary collaborations, and making existing knowledge widely accessible, are all indispensable to the governance of the planetary boundary.

Second, attention should be given to strengthening existing instruments and initiatives. We have seen that the existing legal framework is too fragmented to offer holistic protection of the planetary boundary. However, even when a legal instrument offers partial protection to the planetary boundary, its effects are limited if emission reduction targets lack ambition and/or are not properly implemented – the regular breaches of EU air quality legislation is just one prominent example.[104] The influence of existing air quality networks and agreements might be strengthened if they were able to better coordinate their work and share scientific knowledge, best practices and policy failures. Enhanced cooperation could take different forms, including informal coordination between individual states to foster mutual learning, memoranda of understanding between different agreements, or even the creation of a global confederation of networks.[105] By doing so, existing intergovernmental networks could offer a more uniform coverage of this planetary boundary, thereby possibly overcoming some of the challenges arising from legal fragmentation.

[101] Nicole Wetsman, 'Air-pollution Trackers Seek to Fill Africa's Data Gap' (2018) 284 Nature 556.
[102] See, for instance, Sheila Jasanoff, *The Fifth Branch: Science Advisers as Policymakers* (HUP 1990) 101-122.
[103] R Beaumont, RS Hamilton, N Machin, J Perks, ID Williams, 'Social Awareness of Air Quality Information' (1999) 235(1-3) Sci Total Environ 319.
[104] Yulia Yamineva and Seita Romppanen, 'Is Law Failing to Address Air Pollution? Reflections on International and EU Developments' (2017) 26(3) RECIEL 189, 195-197.
[105] 'Strengthening Cooperation' (n 97) para 73.

Thirdly, informal cooperative arrangements might be the most politically viable way forward. Naturally, the adoption of a global air pollution treaty would offer a more comprehensive response to atmospheric aerosol loading, but such a development is at present highly unlikely. Alternatively, progress can be achieved through informal means of cooperation facilitated by international organisations or NGOs. For instance, the Global Atmospheric Pollution Forum that brought together regional networks, international organisations and various stakeholders, successfully provided opportunities to strengthen exchanges between regions. Similarly, political consensus is more easily reached thanks to the work of soft law initiatives focusing on issues that are geographically or materially restricted in scope, such as in the case of black carbon in the Arctic.

Fourthly, it might be possible to build on existing synergies between air pollution and other environmental issues to benefit from the political mobilisation that already exists in these areas. While the interactions between the atmospheric aerosol loading boundary and other boundaries are complex, they could be used as an advantage. In particular, it has now become more apparent that climate change and air quality are tightly connected: this means that the political mobilization in the climate regime can have important co-benefits for air quality. Certain aerosols can be regulated via the climate regime, for instance by including short-lived climate pollutants in nationally determined contributions.[106] Likewise, recognizing the impacts of air pollution on biodiversity (for instance, forest degradation due to acid rain) in the context of ongoing discussion about the post-2020 biodiversity legal framework, might also help address the problem more systemically.

Finally, the fragmented nature of air pollution governance offers opportunities to undertake legal experimentation at a smaller scale and to evaluate best practices. For instance, the CLRTAP, and in particular the multi-pollutant and multi-effect approach of its Gothenburg Protocol, provide a template for intergovernmental cooperation that could be replicated elsewhere. Despite its regional scope, the CLRTAP aims to be viewed as a global leader,[107] and its results are closely monitored in other regions.[108] Overall, better integration at all levels – between science and policy, between legal regimes, between different scales of governance – and the sharing of experience gained, could help alleviate the significant discrepancies that remain between the major risks posed by atmospheric aerosol loading and existing multilateral legal and policy responses.

[106] For an analysis of the extent to which current nationally determined contributions cover short-lived climate pollutants, see Katherine Ross *et al*, *Strengthening Nationally Determined Contributions to Catalyze Actions That Reduce Short-Lived Climate Pollutants* (World Resources Institute 2018).
[107] CLRTAP Decision 2018/5, 'Long-term strategy for the Convention on Long-range Transboundary Air Pollution for 2020-2030 and beyond' (2018), para 4.
[108] UNECE, 'Entry Into Force of Amended Gothenburg Protocol is Landmark for Clean Air and Climate Action' Press Release (4 October 2019).