South Asian Regional Cooperation on Sustainable Nitrogen Management

NITROGEN POLLUTION IN SOUTH ASIA: SCIENTIFIC EVIDENCE, CURRENT INITIATIVES AND POLICY LANDSCAPE

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Message from the Director-General of SACEP

I'm pleased to be a part of this policy paper summarizing scientific evidence, current initiative and policy landscape jointly published by South Asia Cooperative Environment Programme (SACEP) and UKRI GCRF South Asian Nitrogen Hub (SANH) across the region.

South Asia is one of the global hotspots for nitrogen pollution and it is the second highest region in the globe in terms of nitrogen fertilizers use. Being the most populous (nearly 2 billion people) and economically, the fastest growing region of the world, with a distinct socio-economic-cultural and climatic profile, there is growing demand for more consumer goods and food production. Agricultural activities followed by energy and industry are the major source of nitrogen pollution in the region. Nitrogen pollution creates impacts on greenhouse balance, climate change, human health, ecosystem and coastal habitats of South Asia. These damaging impacts are insufficiently addressed, and each has been treated in isolation for policy development.

This issue has been recognized in the region and multiple activities have been undertaken. Efforts by SACEP member countries have led to adoption of UNEA 4 resolution on Sustainable Nitrogen Management SACEP in partnership with SANH to develop Regional Policy Framework on Nitrogen Management.

I believe this assessment report will provide key information to address the sustainable Nitrogen management issues in South Asia.

Finally, I would like to render my heartfelt thanks and gratitude to all SANH experts, scientists and government agencies for developing this important and valuable policy paper which will ultimately help the region in managing nitrogen sustainably.

Dr. Md. Masumur Rahman
Director General
South Asia Cooperative Environment Programme (SACEP)
Colombo, Sri Lanka, 2021

Message from the Director of the South Asian Nitrogen Hub

I am exceptionally pleased to welcome this important contribution to advancing our understanding of nitrogen-relevant policies in South Asia. It is a unique achievement, drawing on the contributions from many partners of the UKRI GCRF South Asian Nitrogen Hub (SANH) across the region, and with major inputs from the South Asia Cooperative Environment Programme (SACEP). The report contributes to the work that SANH is doing in establishing and following up the UNEA-4 Nitrogen Resolution to highlight nitrogen's role in the climate change and biodiversity challenge, including through implementing the Colombo Declaration. SANH with SACEP have championed the Global Roadmap for Sustainable Nitrogen Management (2020-2022) as a contribution to the UNEP/GEF International Nitrogen Management System (INMS). SANH is pleased to be able to help work towards open societies and conflict resolution by bringing together all eight countries of South Asia through nitrogen as an integrator for environmental diplomacy.

Members of SANH are also hard at work in developing further the necessary science, research and technology to underpin the development of research-led agronomic, genetic and industrial solutions for circular nitrogen management. SANH scientists have identified key nitrogen threats in forests and coral reefs where new scientific data are needed to inform both climate and biodiversity policies, as well as raising awareness, including through the Nitrogen Massive On-line Open Course (N-MOOC), now translated into eight South Asian languages. Such actions and the resulting awareness are being amplified through the #Nitrogen4NetZero initiative in preparation for the 26th Conference of Parties (COP26) of the Climate Convention in Glasgow 2021.

In this context, I am very pleased to see the publication of this joint report and commend it not only to South Asian governments but across the world, since the report is path-breaking in a global as well as a regional context.

Prof Mark Sutton
Director UKRI GCRF South Asian Nitrogen Hub
Edinburgh, October, 2021

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GLOSSARY AND ABBREVIATIONS

ECOLEX	ECOLEX is an information service on environmental law, operated jointly by FAO, IUCN and UNEP. https://www.ecolex.org/p/about/
Eutrophication	When a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of algae
FAOLEX	A comprehensive and up-to-date legislative and policy database, one of the world's largest online repositories of national laws, regulations and policies on food, agriculture and natural resources management. http://www.fao.org/faolex/en/
Hypoxia	Low oxygen conditions. In good quality water, oxygen levels are approximately 7 ppm (0.0007%),
ING-SCON	Indian Nitrogen Group established under the Society for Conservation of Nature https://www.scon-india.org/
INI	International Nitrogen Initiative https://initrogen.org/
INMS	International Nitrogen Management System https://www.inms.international/
IPCC	Intergovernmental Panel on Climate Change https://www.ipcc.ch/
N_r	Reactive Nitrogen
N_2O	Nitrous oxide
NO_x	Nitrogen oxides, including nitric oxide (NO) and nitrogen dioxide (NO_2)
NH_3	Ammonia
NO_3^-	Nitrate
N_2	Di-Nitrogen, that exists naturally in the atmosphere
NUE	Nitrogen use efficiency
PM	Particulate Matter. $PM_{2.5}$ can be formed from the chemical reactions of gases such as sulphur dioxide (SO_2) and nitrogen oxides.
Policies	The policy documents collected are variously called Legislation, Acts, Laws, Ordinances, Plans, Strategies, Regulations, Statute, Standards, Rules, Orders, Codes, Frameworks, and Guidelines.
SDG	Sustainable Development Goals
SACEP	South Asia Co-operative Environmental Programme http://sacep.org/
SANC	INI South Asian Regional Nitrogen Centre
SANH	South Asia Nitrogen Hub https://sanh.inms.international/
UNEA	United Nations Environment Assembly https://www.unep.org/environmentassembly/about-united-nations-environment-assembly
UNEP	United Nations Environment Programme https://www.unep.org/
UNEP-GPNM	United Nations Environment Programme-Global Partnership on Nutrient Management https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-partnership-nutrient

REPORT OVERVIEW

The Sustainable Nitrogen Management Resolution was adopted in the 4th UN Environment Assembly (UNEA) held in March 2019, moved under the leadership of India. Spearheaded by Sri Lanka, in October 2019, the 'Colombo Declaration' was adopted by a group of member states with an ambition to halve nitrogen waste by 2030. The declaration urges countries to make comprehensive assessments of nitrogen policy, its management, and scientific aspects to move towards sustainable nitrogen management. This report contributes directly towards these actions for South Asia.

The report has two key features. Firstly, it provides an overview of current nitrogen emissions and trends, drivers and impacts to explain **why sustainable nitrogen management is a globally important issue, as it is for South Asia**. Secondly, it contains a **summary of the collection and analysis of 966 nitrogen related policies from South Asia**. Until now little has been known about the nitrogen policy landscape for the region. Assessing nitrogen-related policies is crucial to identify the gaps and opportunities for managing nitrogen. An analysis of this kind provides an essential building block to understanding the quality of policies currently in place and to determine what is needed for the future. The policy database itself provides a valuable resource for South Asia governments and the wider scientific community. This report was developed by the South Asia Co-operative Environmental Programme (SACEP) and the UKRI GCRF South Asian Nitrogen Hub to contribute towards building a nitrogen policy arena for South Asia.

SACEP is an inter-governmental organization, established in 1982 by the governments of South Asia to promote and support regional protection, management and enhancement of the environment. SACEP eight member countries include Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka.

The South Asian Nitrogen Hub (SANH) is a UKRI GCRF funded research partnership that brings together 32 leading research organisations and project engagement partners from South Asia and the UK. SANH is working towards enabling South Asia to 'adopt and champion a strategic approach to nitrogen management, as a key step towards the Sustainable Development Goals'. SANH aims to provide relevant scientific insights, identify barriers to change, and demonstrate the economic benefits of tackling nitrogen pollution.

EXECUTIVE SUMMARY

1. This report provides an assessment of South Asia nitrogen emission trends and drivers, and a unique assessment of 966 nitrogen related policies, valid in 2019, from South Asia.
2. Human interventions that convert nitrogen to its reactive form (N_r) have been essential for sustaining the global population. Whilst nitrogen is essential for life, excess N_r can cause catastrophic harm to people and the environment.
3. Activities such as agriculture, transport, industry, energy production, sewage processing, and waste management have contributed to excessive N_r, impacting water and air quality, the climate, ecosystems, and soil.
4. South Asia (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka) is a major global nitrogen emission hot spot. Therefore, how nitrogen is managed in South Asia has global implications.
5. Sustainable nitrogen management would contribute to the attainment of all 17 of the UN Sustainable Development Goals (SDGs).
6. South Asia has been among the earliest to recognise the nitrogen threat and to act to mitigate it.
7. This report, along with an open access nitrogen policy database, provides a valuable resource not only for policy makers in South Asia but also the global scientific community.

THE SOUTH ASIA NITROGEN CHALLENGE:

8. South Asia is a global hotspot for the main nitrogen compounds: nitrogen oxide, nitrous oxide and ammonia, with emission levels above global averages.
9. Nitrous oxide has a global warming potential about 300 times that of carbon dioxide, while nitrogen oxide is 10 times more powerful.
10. South Asia contains some of the most polluted world cities, in terms of particulate matter, ($PM_{2.5}$ containing N_r), accounting for the largest number of global deaths and disability due to air pollution.
11. Nitrogen oxide emissions have risen rapidly in the South Asia region, approximately doubling since 2000. The largest contributing source is electricity and heat generation, followed by road transportation and manufacturing and construction.
12. Nitrous oxide and ammonia emissions in South Asia are steadily increasing. The main source of nitrous oxide is direct emissions from managed soils; ammonia emissions are closely linked to excessive commercial fertilizer applications.

NITROGEN POLICY FINDINGS:

13. The South Asia nitrogen-relevant policy database provides descriptive information.[1] Based on the text only, policies were further classified by sector, sink, policy type, and other indicators of quality. The analysis focused on policies with high/medium relevance and scope.
14. Water was the most common single environmental sink identified, followed by ecosystems, climate, and air. Soil was the least common sink, despite both managed and unmanaged soils being a major N_r emission source.

[1] The policy title, year of establishment, URL source (if available), type (legislation, policy, regulation, miscellaneous), country, territorial division (national or sub-national), language, and responsible ministry (if applicable).

15. Agriculture was the most common single sector identified in the policies. Transport, energy, waste and industry were less frequently featured.
16. The policy type 'framework' was the most common, followed by data and methods, research & development (R&D) and regulatory and economic elements (considered 'core policies' with tangible actions towards N_r management). Commerce and Pro-nitrogen were the least common types. Over half of the policies featured multiple policy types.
17. Most policies were classified as having a potentially positive impact (environmental focus), followed by mixed/neutral impact, with fewest policies classified as having potentially negative impacts, that is, that might promote unsustainable N_r practices.
18. Policies rarely referred to pollution types (point source or non-point source), representing a potential policy gap.
19. The findings suggest that only a small proportion of policies have attempted to integrate across multiple sectors and sinks, while also proposing a range of policy instruments.

POLICY RECOMMENDATIONS:

20. Reducing nitrogen waste is possible and a highly desirable policy goal limiting adverse environmental effects, with co-benefits for food production and the wider economy.
21. Policy actions at multiple levels are vital to mitigate localised and transboundary effects.
22. Key experts reveal barriers to nitrogen policy formulation include a lack of awareness of the N_r threats, a lack of data and reliable scientific assessments, poor coordination between ministries and departments, and limited engagement with wider stakeholders.
23. In choosing sectors to prioritize for action,
    - Current levels of N_r pollution (e.g., excessive fertilizer in agriculture, biomass burning and 'dirty' industry and vehicles) should be high priorities.
    - Fast-growing/emerging N_r source sectors (e.g., human, animal and industrial waste) and areas where quick results are achievable, are also candidates for urgent action.
24. There is scope to increase 'core policies', that is, regulatory and/or economic instruments to provide quantifiable limits and/or incentives to support sustainable N_r management.
25. Support for 'research and development' and the use of 'green technologies' for N_r can provide financial rewards and environmental co-benefits. For example, the use of neem coated urea reduces costs from excessive fertilizer application.
26. Existing experience and best practices could be starting points, if optimized to local conditions and needs. Mutual learning within the region, can help fill policy gaps.
27. Some policies indicate favourable policy features (multiple sinks and sectors and policy instruments) – a desirable direction for future policy. More integrated policies and integration across policies would help address nitrogen issues systematically.
28. South Asia can be world-leading in addressing the sustainable N_r management challenge. The foundations for catalysing further regional and international cooperation and actions to improving nitrogen management in South Asia have already been laid.

A. INTRODUCTION: REACTIVE NITROGEN THREATS TO HUMAN HEALTH AND THE ENVIRONMENT

Nitrogen is a significant issue globally and for South Asia. Human interventions, and the production of reactive nitrogen (N_r), have led to nitrogen pollution, harmful to human health and the environment. It has been estimated that during the last century global N_r production has more than doubled as a result of human activity (Sutton et al., 2013; Erisman et al., 2011). This section summarises the nitrogen challenge as part of a balanced natural cycle with benefits, but that in excess has led to increasingly negative effects.

Nitrogen (N) is everywhere and invisible. Almost 80% of the Earth's atmosphere consists of nitrogen in its unreactive form (as N_2), which is harmless. **Some compounds of N_r are part of important natural cycle processes** that transform N_2 into N_r, such as biological N-fixation and lightning activity. Eventually these compounds are transformed back to N_2. Many N_r compounds in the soil help plant growth and are essential nutrients for food production.

Human interventions, however, have caused N_r to accumulate mainly through the production of ammonia (NH_3) via the Haber-Bosch process, fixation by leguminous plants, and fossil fuel and biomass burning. Accumulation that exceeds the neutralizing capacity of the natural nitrogen cycle (Figure 1) causes a variety of problems. Excess N_r contributes to respiratory and cardiovascular illness, causes acid rain, soil degradation, ground and surface water pollution, coastal algal blooms, eutrophication,[2] and dead zones.[3]

The main N_r compounds of concern are Nitrogen oxides (NO_x), ammonia (NH_3) and nitrous oxide (N_2O) in air, and nitrates in water. They have been accumulating in our environment over several decades, affecting our health and local environment, in addition to their contributions to climate change. South Asia is a hot spot for all three compounds emitted to the air (Sutton et al., 2017).

Excess N_r can cause a range of beneficial and negative effects (Galloway et al., 2003). These effects can be summarized under the acronym **'WAGES'**, referring to effects on **water**, **air**, **greenhouse gases**, **eco-systems** and **soil** (Sutton et al., 2013). These effects are summarised in Box 1.

[2] Eutrophication is characterized by excessive plant and algal growth which can be due to the increased availability of nutrient fertilizers (Shindler, 2006). The rate and extent of eutrophication has accelerated due to human activities with excess reactive nitrogen, and other nutrients, entering water bodies.

[3] For a detailed review of literature on the health impacts of reactive nitrogen, see Gupta et al. (2017).

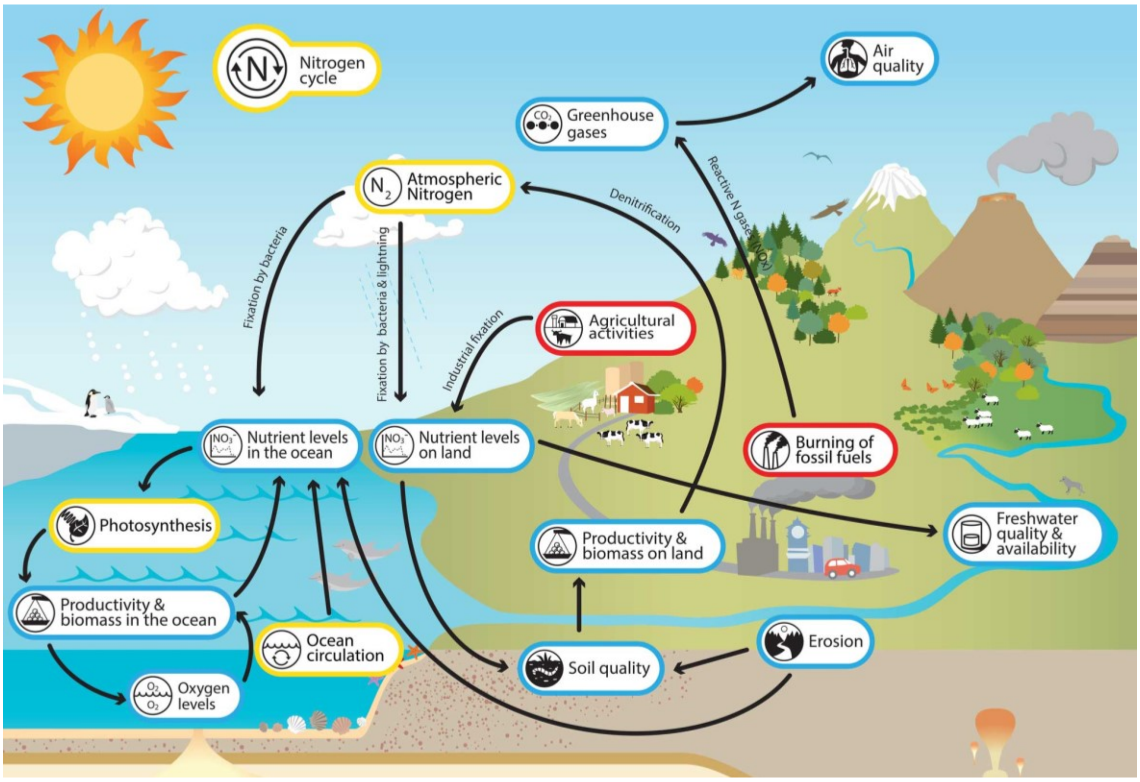


Figure 1. A system model for the nitrogen cycle. Source: University of California (2018)

Box 1. Summary of Reactive Nitrogen (N_r) effects	
Water	Nitrate (NO_3-) and nitrite (NO_2-) are naturally occurring as part of the nitrogen cycle (WHO, 2011). Nitrites, nitrates, and ammonium (NH_4+) as well as dissolved organic nitrogen can enter marine and fresh-water ecosystems as water pollution affecting soil pH and water quality. This can enter surface and ground waters through surface run-off and leaching through soil. Sources of excess N_r in the soil and water include excreta from animals and humans, and fertilizer products. Water pollution by nitrogen can have adverse effects on human and animal health. A prolonged dietary exposure of nitrate from water and/or bioaccumulation in food and animal/fish feed can increase the risk of specific cancers, birth defects, or other adverse health effects (Ward et al., 2018). Babies and young infants are particularly vulnerable. Nitrate does not normally cause health problems unless it is reduced to nitrite (NO_2-). Eutrophication, that is, over-enrichment with minerals and nutrients, is another impact of excess N_r. This induces excessive growth of algae leading to algal blooms, creating dead zones, killing aquatic life.
Air	N_r contributes to air pollution threatening human health. Nitrogen compounds can combine to exacerbate environmental impacts. NO_2 (Nitrogen dioxide) and NH_3-

	(ammonia) in the air can react to form particulate matter (PM), constituting up to half of $PM_{2.5}$ and PM_5, causing serious respiratory, cardiovascular and other diseases from prolonged exposure, and can lead to premature deaths. The World Health organisation (WHO) reports that PM affects more people than any other pollutant (WHO, 2021). Airborne and waterborne nitrogen pollution are not entirely distinct as air pollution compounds can be deposited into the water, land, and soil. Similarly, nitrogen pollution that is waterborne can convert into gas.
Greenhouse Gases (GHGs)	Disruption of nutrient cycles has both climate warming and cooling effects. The greenhouse gas nitrous oxide (N_2O) is the longest lasting warming component, while NO_x leads to further warming by reducing plant carbon dioxide (CO_2) uptake. According to the IPPC (2007) N_2O has a global warming potential about 300 times higher than CO_2, while NO_x is 10 times more powerful. As a side effect N_2O is now the main cause of stratospheric O_3 depletion, increasing the risk of skin cancer. By contrast, atmospheric N_r deposition promotes plant growth and CO_2 up-take, and N_r contributes to water-soluble particulate matter (PM), both of which contribute cooling effects.
Ecosystems	Different ecosystems will respond to nitrogen pollution in different ways (Sala et al., 2000). N_r can cause acidification and eutrophication in ecosystems but the impact depends on several factors (Erisman et al., 2013). Species of high conservation and food value which are naturally adapted to 'few nutrients', for example, are threatened by eutrophication. 5-15% of current global biodiversity loss is linked to Atmospheric N_r deposition (Sala et al., 2000). In addition soil nutrient shortages limit productivity and can force farmers to seek additional agricultural land, leading to agricultural encroachment further threatening ecosystems. Land-use change, associated with food production, is the biggest driver of biodiversity loss.
Soil	Too much N_r input can lead to soil acidification, particularly in agricultural ecosystems with intense rates of fertilization. While this can be mitigated, the effect tends to deplete essential soil bases in natural soils while mobilizing toxic metals, risking vegetation health and freshwater fish populations. Excessive use of nitrogenous fertilizer is costly and wasteful. By contrast, insufficient nutrient availability in agriculture leads to loss of soil fertility and can exacerbate soil erosion.

The United Nations Environment Programme (UNEP) report *Frontiers 2018/19* identified N_r as one of the five emerging threats facing our planet (UNEP, 2019). The report highlights that the accumulation of N_r has made the nitrogen cycle one of the most anthropogenically altered elemental cycles on earth (Sutton et al., 2019). Activities such as agriculture, sewage treatment, waste burning and fuel burning for power, transport and industry produce far more nitrogen compounds than through the natural cycle of nitrification and denitrification. Nitrogen has also been flagged as exceeding planetary boundaries, therefore already operating in a high-risk zone (Steffen et al., 2015).

Nitrogen pollution threatens the environment in multiple ways with knock on effects for society and the economy. For example, the combined cost to ecosystems, climate and health was estimated at over €70 billion per year to the European Union (EU) alone (Brink et al., 2011). Most of these costs were attributed to the impacts on human health. It was further reported that by 'halving nitrogen waste' by 2030, as called for in the Colombo declaration, could save US$100 billion annually (Sutton et al., 2021). These savings could contribute to post-coronavirus disease 2019 (COVID-19) economic recovery and multiple Sustainable Development Goals (SDGs) (see Sutton et al., 2021). In the recent 8th International Nitrogen Initiative Conference (INI2020) it was highlighted that Sustainable Nitrogen management, would contribute to the attainment of all 17 of the UN (SDGs) by 2030.

Summary of Section A:

- Nitrogen is an essential element for life, yet reactive Nitrogen (N_r), through human interventions, has become overly abundant.
- Excess N_r causes pollution which effects water, air, greenhouse gases, eco-systems and soils (WAGES).
- South Asia is experiencing severe environmental pressure, compounded by ineffective nitrogen management.
- Tackling nitrogen and halving nitrogen waste could save billions annually, benefiting ecosystems, climate and human health.
- Sustainable nitrogen management would contribute to attaining all 17 SDGs.

B. NITROGEN EMISSION TRENDS, DRIVERS AND IMPACTS IN SOUTH ASIA

South Asia has one of the fastest growing economies in the world, yet economic progress has been coupled with increased pressure on natural resources and the environment (UNEP, 2021). Ecosystem services are under severe pressure due to air pollution, depletion of water quality and quantity, dwindling forests and coastal resources, and soil degradation all issues that are exacerbated by nitrogen pollution. South Asia contains several global hotspots for N_r pollution, both in its larger cities and across the Indo-Gangetic Plain. This section provides an **overview of current nitrogen emissions, trends, drivers and impacts for the three main N_r pollutants nitrogen oxides (NO_x), nitrous oxide (N_20) and ammonia (NH_3).** These findings outline why sustainable nitrogen management in South Asia is an important issue regionally and globally.

Whilst South Asian countries have their own country level nitrogen data, for comparative purposes in this report the major international analysis of nitrogen emissions, sources and trends are sourced by the **Emissions Database for Global Atmospheric Research (EDGARv5.0**). Data refer up to 2015 and are provided for each South Asia country and for the region. The emission data are provided in the following order: nitrogen oxides (NO_x), nitrous oxide (N_20) and ammonia (NH_3). For each nitrogen compound the emissions status in 2015 is provided, along with emission changes between 2000 and 2015 further standardised by per 1000 capita, and then the main sector sources are listed.

B.1 Nitrogen oxides (NO_x)

Nitrogen oxide emissions from South Asia make up a major proportion of global emissions, and relative to the rest of the world, South Asian emission levels have risen between 1970 and 2015 (Appendix 4 Figure 2). Figure 2 shows the hot spots of nitrogen oxide (NO_x) emissions, with major concentrations coming from the towns and cities in the Indo-Gangetic plain and in south India (see also Decina et al., 2020). The contributions of the main shipping routes are also clear. Tables 1, 2 and 3 show the main sources and trends of NO_x emissions in South Asian countries in 2015.[4]

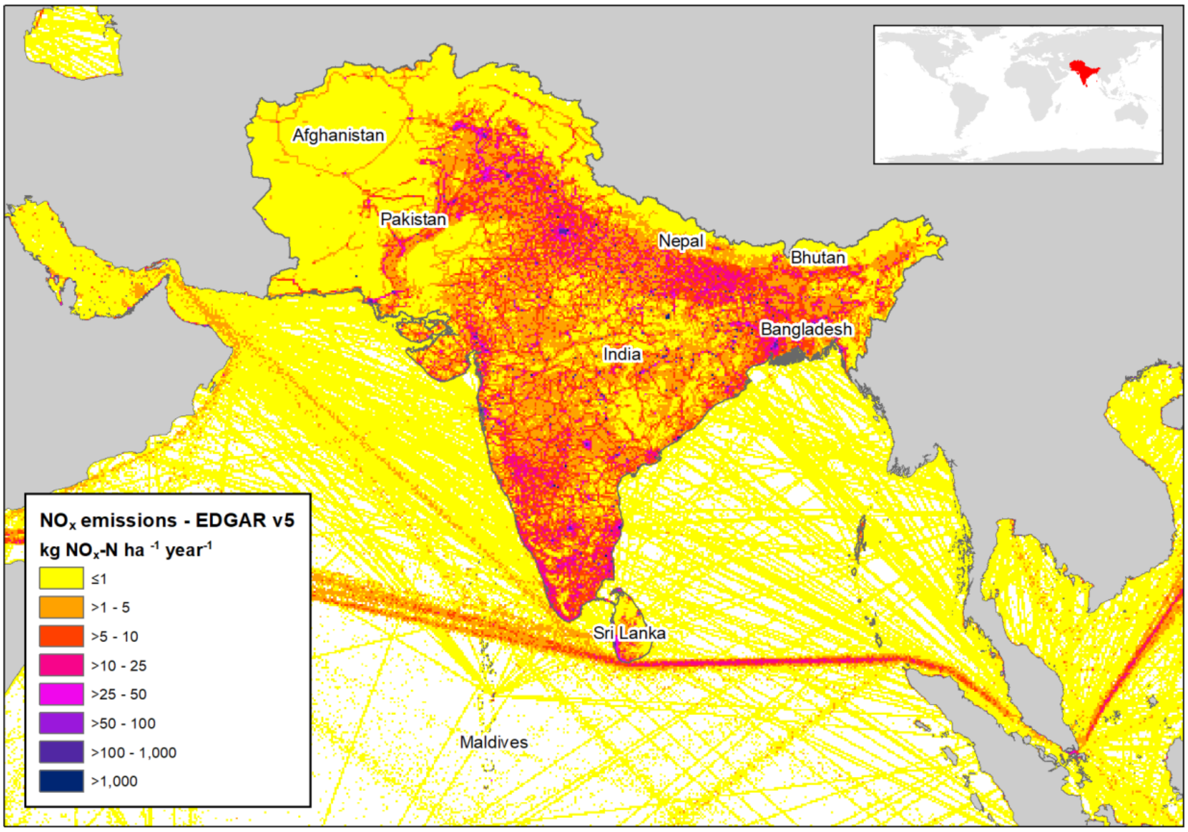
Table 1 shows that India was the major contributor to NO_x emissions in the region, but on a per capita basis, Maldives, Bhutan and Sri Lanka show higher figures (details in Appendix 4 Table 1). It also shows that in all South Asian countries, NO_x emissions have been rising rapidly, approximately doubling since 2000 in the region, with a 107% increase in NO_x emission observed in 2015 as compared to 2000. The greatest relative increases in NO_x

[4] Detailed tables can be found in Appendix 4, Tables 1 and 2, and Figure 5.

emission were observed in Afghanistan (+668%), Bangladesh (+228%), and Maldives (+169%).

Table 2 shows that overall, in South Asia, electricity and heat generation (at 37%) is the largest contributor to NO_x emissions, followed by road transportation (27%) and manufacturing and construction (21%) (Appendix 4 Table 1). Table 2 also shows that in most of the countries road transport, and electricity and heat production sectors are the major contributors to NO_x emissions. In Bhutan, India, Nepal, Pakistan and Sri Lanka, manufacturing and construction also make substantial contributions. In Nepal and Bhutan, a major source of NO_x is 'Other sources', which refers mostly to residential combustion (use of biomass for cooking and heating).

Figure 2: Nitrogen oxide (NO_x) emissions across South Asia, 2015



Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa et al (2019a)
The darker purple to blue colours indicate high concentrations of NO_x per hectare per year.

Table 1: Nitrogen oxide (NO_x) emissions in South Asia, 2000-2015

Country	Total emission (Gg year^{-1})			Per 1000 capita emission (kg year^{-1})		
	2000	2015	% Change	2000	2015	% Change
Afghanistan	11	83	668	529	2,420	357
Bangladesh	158	519	228	1,238	3,321	168
Bhutan	4	7	63	6,768	9,609	42
India	5,109	10,420	104	4,835	7,953	64
Maldives	4	10	169	14,317	21,050	47
Nepal	52	87	67	2,172	3,228	49
Pakistan	740	1166	58	5,199	5,844	12
Sri Lanka	125	178	43	6,657	8,522	28
Total South Asia	6,203	11,304	107	4,259	6,822	60

Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al. (2019a)

Table 2: Main sectors of country specific nitrogen oxide (NO_x) emissions (Gg year^{-1}), 2015

Country	Main sectors by relative contributions
Afghanistan	Road Transport (50%) Electricity and heat production (20%) Water-borne transport (10%) Direct soil (Emissions from managed soils +manure in pasture) (8%)
Bangladesh	Electricity and heat production (43%) Road Transport (16%) Other sources (7%) Water-borne transport (6%) Direct soil (Emissions from managed soils +manure in pasture) (6%)
Bhutan	Other sources (35%) Manufacturing Industries and Construction (22%) Electricity and heat production (18%) Road transport (16%)
India	Electricity and heat production (39%) Road Transport (25%) Manufacturing Industries and Construction (22%)
Maldives	Road Transport (47%) Electricity and heat production (40%) Water-borne transport (8%)
Nepal	Road Transport (32%) Manufacturing Industries and Construction (27%) Other sources (25%) Direct soil (Emissions from managed soils +manure in pasture) (9%)
Pakistan	Road Transport (40%) Electricity and heat production (23%) Manufacturing Industries and Construction (19%) Other sources (7%) Direct soil (Emissions from managed soils +manure in pasture) (6%)
Sri Lanka	Road Transport (50%) Electricity and heat production (26%) Manufacturing Industries and Construction (15%)
South Asia	**Electricity and heat production (37%)** **Road Transport (27%)** **Manufacturing Industries and Construction (21%)**

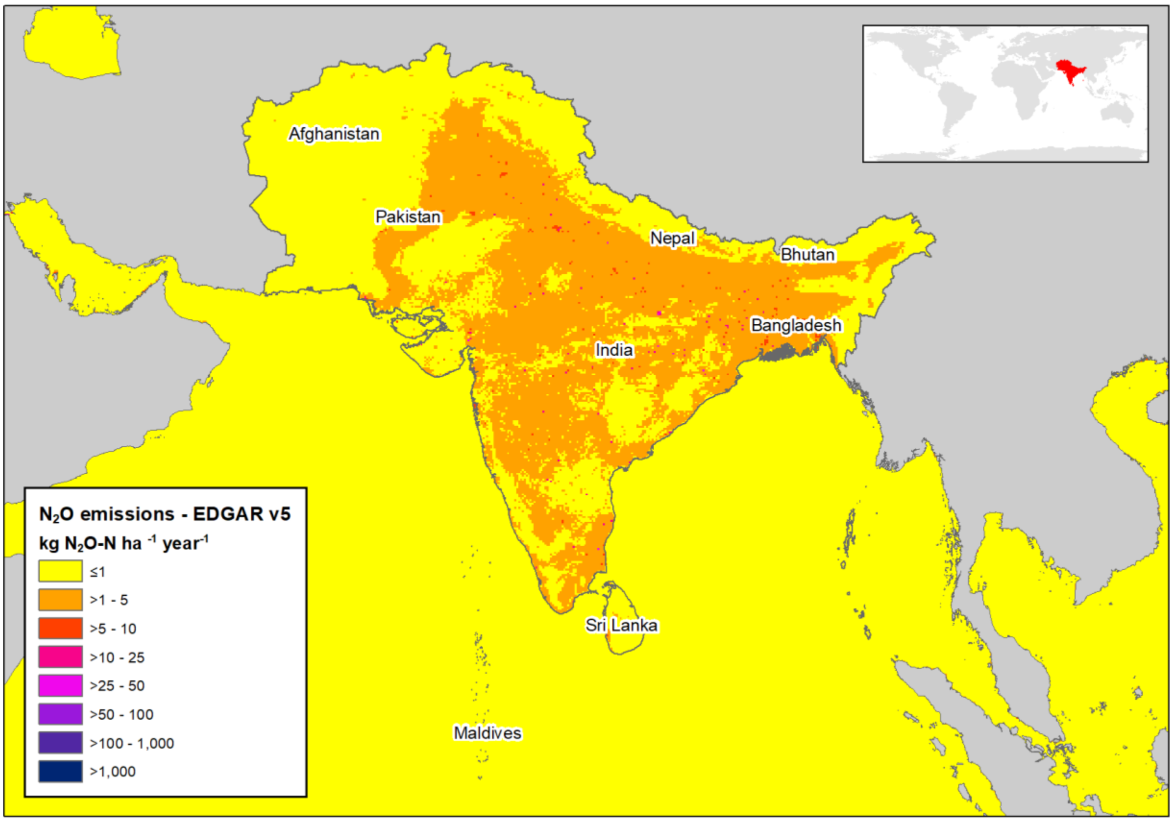
Source and detailed notes: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al. (2019a). This table includes only those sectors with at least 7% contribution to national totals. ‘Other sources’ refers mostly to residential combustion (using wood and crop residues for cooking). See Appendix 4 Note on EDGAR methodology for compiling N_2O and NO_x data, and Appendix 4, Table 1.

B.2 Nitrous oxide (N_2O) emissions

Nitrous oxide emissions (N_2O) from South Asia make up a major proportion of global emissions, and relative to the rest of the world, South Asian emission levels have risen between 1970 and 2015 (Appendix 4 Figure 6). Table 3 shows that India was the major contributor to N_2O emissions in the region, but as with NOx, on a per capita basis, Nepal, Pakistan and Bhutan show higher figures (details in Appendix 4 Table 3).

Trends of N_2O emissions in South Asian countries are also shown in Table 3. Within South Asia, emissions of N_2O have grown at very different rates between 2000 and 2015. A 36% increase in N_2O emission was observed in the whole South Asia region in 2015 as compared to 2000. The greatest increase in N_2O emissions, on a per capita basis, was observed in Maldives.

Figure 3: Nitrous oxide (N_2O) emissions across South Asia, 2015



Note: EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa, et al. (2019b). For more detail see Appendix 4 Figure 6, which shows areas within South Asia that experience N_2O emissions greater than global average emissions between 1970 and 2015. By 2015 all the Indo-Gangetic plain, for example, had emissions well above global averages, whereas in 1970 parts of this area showed lower levels relative to global averages.

Table 3: Nitrous oxide (N_2O) emissions in South Asia, 2000 and 2015

Country	Total emission (Gg year^{-1})			Per 1000 capita emission (kg year^{-1})		
	2000	**2015**	**% Change**	**2000**	**2015**	**% Change**
Afghanistan	9.58	13.83	44	461	402	-13
Bangladesh	49.85	67.30	35	390	431	10
Bhutan	0.51	0.66	7	863	902	5
India	499.71	673.56	35	473	514	9
Maldives	0.04	0.09	135	143	187	31
Nepal	13.58	18.46	36	567	683	20
Pakistan	98.73	143.22	45	694	718	4
Sri Lanka	4.96	6.27	26	264	300	13
Total South Asia	677.96	923.37	36	465	505	9

Note: EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa et al (2019b)

Table 4 shows that the main sources of N_2O in South Asia are direct N_2O emissions from managed soils (63%), indirect N_2O emissions from managed soils (9%), and indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3 (8%).[5] Maldives shows very different patterns of emission from the rest of South Asia, because agriculture plays a small part in its economy. India is the largest source of N_2O emissions, but on a per capita basis, Bhutan, Pakistan and Nepal are larger emitters (Appendix 4 Table 3). It should be noted that emissions have decreased slightly, on a per-capita basis, in Afghanistan and Bhutan – despite absolute increases for both countries, because population growth has outstripped the growth in emissions.

[5] For more detail on how these categories are defined, see Appendix 4, note on EDGAR methodology

Table 4: Main sectors of country specific nitrous oxide (N_2O) emissions (Gg year^{-1}) 2015

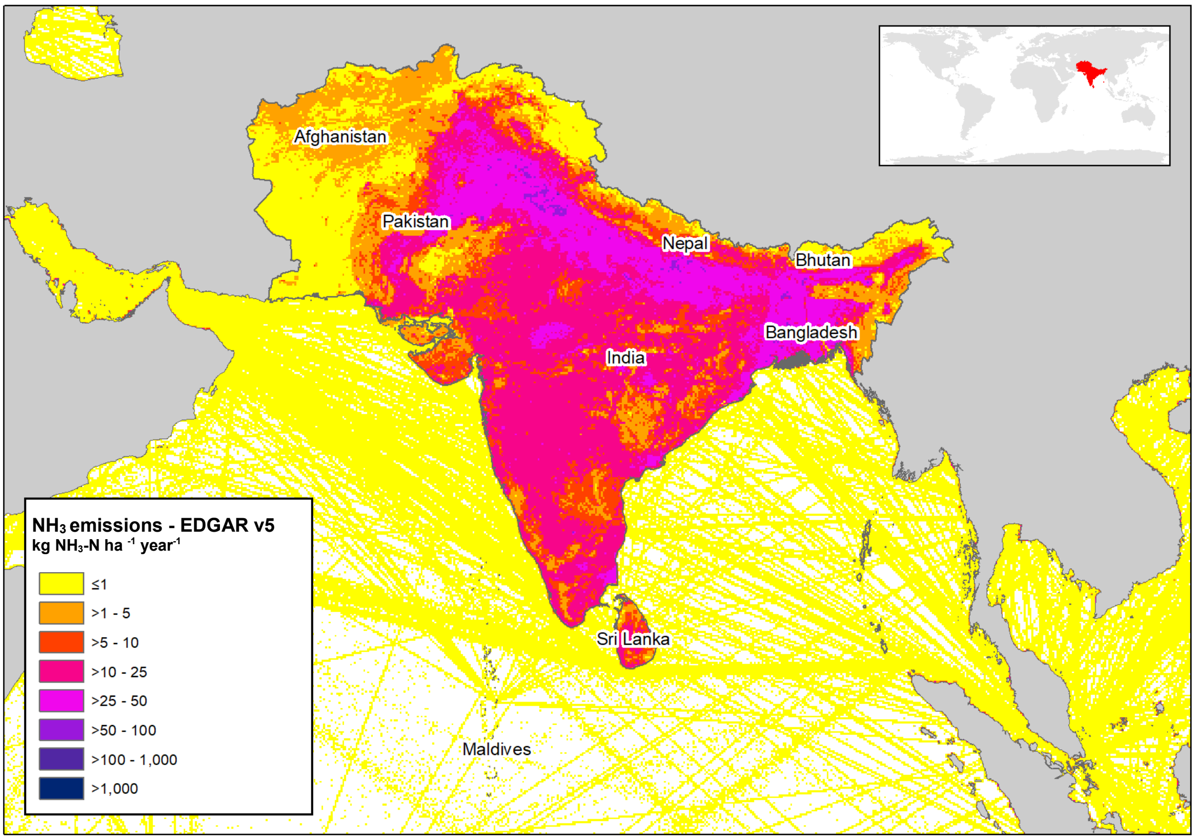
Country	Main sectors by proportionate contributions
Afghanistan	Direct N_2O Emissions from managed soils (75%) Indirect N_2O Emissions from managed soils (13%)
Bangladesh	Direct N_2O Emissions from managed soils (69%) Indirect N_2O Emissions from managed soils (9%) Other sectors (9%)
Bhutan	Direct N_2O Emissions from managed soils (38%) Other sectors (30%) Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3 (19%) Indirect N_2O Emissions from managed soils (7%)
India	Direct N_2O Emissions from managed soils (60%) Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3 (9%) Indirect N_2O Emissions from managed soils (8%)
Maldives	Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3 (56%) Wastewater Treatment and Discharge (20%) Road Transportation (10%)
Nepal	Direct N_2O Emissions from managed soils (61%) Other sectors (12%) Indirect N_2O Emissions from managed soils (11%)
Pakistan	Direct N_2O Emissions from managed soils (71%) Indirect N_2O Emissions from managed soils (9%)
Sri Lanka	Direct N_2O Emissions from managed soils (47%) Indirect N_2O Emissions from managed soils (18%) Wastewater Treatment and Discharge (10%) Other sectors (8%)
South Asia	**Direct N_2O Emissions from managed soils (63%)** **Indirect N_2O Emissions from managed soils (9%)** **Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3 (8%)**

Source and detailed notes: EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa et al. (2019b). This table includes only those sectors with at least 7% contribution to national totals. 'Other sectors' refers mostly to residential combustion (using wood and crop residues for cooking). See Appendix 4 Note on EDGAR methodology for compiling N_2O and NO_2 data, and Appendix 4 Table 3.

B.3 Ammonia (NH_3) emissions

Ammonia emissions are closely linked to commercial fertilizer applications and South Asia is a global hotspot (Appendix Figures 2, 7 & 8). Using the FAO region definitions, application rates for 2017 ranged from 15 kg/ha in Africa to over 213 kg/ha in East Asia. South Asia was on par with the European Union at about 94 kg/ha, above World and OECD averages of 71 and 75 kg/ha, respectively, but use rates have been growing faster than in the rest of the world (Appendix 4 Table 5). Figure 4 shows the distribution of NH_3 emissions across the region, and how closely it mirrors the areas under crop production.

Figure 4: Ammonia (NH_3) emissions across South Asia, 2015



Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al (2019a). For more detail, see Appendix Figure 7.

The main sources and trends of NH_3 emissions in South Asian countries are shown in Tables 5 and 6. Table 5 shows that India was the major contributor to NH_3 emissions in the region. On a per capita basis, Bhutan, Nepal and Pakistan have higher emissions, and Maldives, with its limited agricultural sector, has much lower levels. Van Damme and others (2018) identified gaps in the EDGAR ammonia inventories, stating that improvements were needed to monitor anthropogenic ammonia sources accounting for the rapid evolution of such sources over time.

Table 5 also shows a 36% increase in NH_3 emission in the South Asia region in 2015 as compared to 2000. The highest increases in NH_3 emission were in Afghanistan, Pakistan and Maldives, with the lowest increase in Sri Lanka.

Table 6 shows that agriculture is the major source of NH_3 emission except in Maldives and Bhutan where the 'other' sector, the consumption of biomass and fossil fuels (LPG and kerosene) in the residential and commercial/ institutional settings, is the major source.

Table 5: Ammonia (NH_3) emissions in South Asia, 2000 and 2015

Country	Total emission ($Gg\ year^{-1}$)			Per 1000 capita emission ($kg\ year^{-1}$)		
	2000	**2015**	**% Change**	**2000**	**2015**	**% Change**
Afghanistan	49.67	78.65	58	2,390	2,357	-1
Bangladesh	385.28	502.21	30	3,018	3,250	8
Bhutan	7.37	8.93	21	12,470	12,420	0
India	4301.86	5,795.37	35	4,072	4,473	10
Maldives	0.04	0.06	50	143	146	2
Nepal	107.11	149.93	40	4,474	5,572	25
Pakistan	867.88	1,231.76	42	6,097	6,307	3
Sri Lanka	59.20	75.40	27	3,153	3,627	15
Total South Asia	5,778.41	7,842	36	3,967	4,345	10

Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al. (2019a).

Although the environmental impacts of reduced pollutants, such as ammonia (NH_3) are less well known than that of oxidised nitrogen pollutants (NO_x), pollution caused by high levels of ammonia are more likely to exceed critical loads, especially when it is deposited dry rather than wet (Hicks et al., 2011).

Table 6: Main sectors of country-specific ammonia (NH_3) emissions (Gg year^{-1}) 2015

Country	Main sectors by relative contributions
Afghanistan	Direct soil emissions from managed soils (79%) Manure management (9%)
Bangladesh	Direct soil emissions from managed soils (60%) Other sectors (13%) Urea application (11%) Manure management (11%)
Bhutan	Other sectors (71%) Direct soil emissions from managed soils (15%)
India	Direct soil emissions from managed soils (60%) Other sectors (14%) Urea application (12%)
Maldives	Other Sectors (30%) Main Activity Electricity and Heat Production (21%) Solid fuels (17%)
Nepal	Direct soil emissions from managed soils (47%) Other sectors (35%) Manure management (11%)
Pakistan	Direct soil emissions from managed soils (63%) Other sectors (13%) Manure Management (11%)
Sri Lanka	Direct soil emissions from managed soils (49%) Other sectors (22%) Urea application (14%)
South Asia	**Direct soil emissions from managed soils (60%)** **Other sectors (14%)** **Urea application (11%)**

Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al (2019a). This table includes only those sectors with at least 7% contribution to national totals. 'Other sectors' refers mostly to residential combustion (using wood and crop residues for cooking). See Appendix 4 Table 6 for the full results.

B.4. Overview of N_r emissions

Taking all three main N_r pollutants together, the following picture emerges. Appendix Figures 5, 6 and 7 show how, relative to global trends, emissions of the three compounds NO_x, N_2O and NH_3 have remained above global means, and in some parts of the region, have grown further relative to global means. The per capita rates for Afghanistan, Bhutan and Maldives are stable or marginally declining, suggesting no increase in emissions per head. Appendix Figure 8 summarizes the data for the same compounds, showing the strong upward trends in total emissions for all sector sources.

South Asia is one of a small number of global sites of very high levels of NO_2 pollution, along with Europe, the Atlantic seaboard of the United States, East Asia and parts of sub-Saharan Africa (Appendix 4 Figure 1). South Asia is one of an even smaller group of regions where ammonia (NH_3) is also emitted in large quantities (Appendix 4 Figure 2); in combination, the two nitrogen compounds (NH_3 and NO_2) contribute to very high levels of disability and death from poor air quality. According to WHO (World Health Organization 2016), most of the world's cities with the highest levels of $PM_{2.5}$ pollution are in South Asia, which accounts for the largest number of deaths and disability due to air pollution globally (Appendix 4 Figures 3 and 4).

South Asia is also a global hotspot of N_r pollutants on coastal water quality. UNESCO has recently documented coastal hypoxia and oxygen minimal zones all over the world, including South Asia (Appendix 4 Figure 9) (Isensee et al., 2018). South Asia contains many coastal sites where anthropogenic nutrients have exacerbated or caused oxygen declines to very low levels, as well as oxygen-minimum zones at 300 m of depth below the ocean surface. The combined and increasing in South Asia effects of N_r and other pollutants on coastal water quality can be seen through the extent of eutrophication, contributing to coral death hypoxia and eutrophication of water bodies.

Excess N_r needs to be addressed in policy yet the treatment of the different of the nitrogen compounds requires nuance. For policy, recognising ratios of oxidised nitrogen (NO_x and N_2O) and Ammonia (NH_3) that enter the environment is important as the main sources vary, therefore warranting different policy response (European Commission, 2013). Furthermore, the compounds impact the environment in different ways and concentrations vary across location and time. These differences do not detract from the overall response to reduce global nitrogen emissions, but policies can distinguish between the needs and measures required to manage nitrogen oxides and ammonia. More research is required to understand the relative impacts of the different nitrogen compounds (Hicks et al., 2011).

Summary of Section B:

In South Asia, nitrogen pollution is high and rising. Nitrogen compounds impact the environment and human health both directly and indirectly.

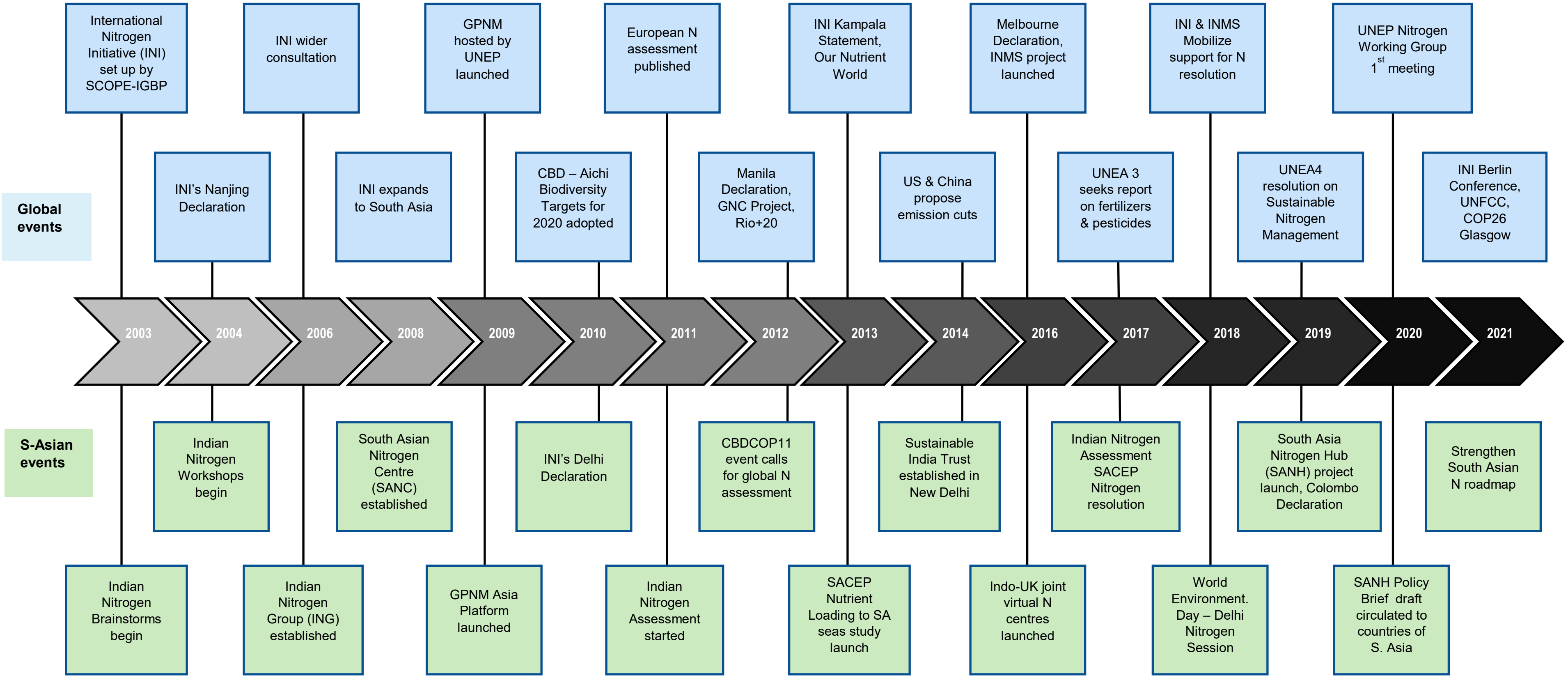
- Nitrogen oxides (NO_x) had the greatest overall rise in emissions between 2000 and 2015 for the South Asia region at 107%. Electricity and heat generation was the largest contributor to NO_x emissions, followed by road transportation and manufacturing and construction. NO_x and ammonia (NH_3) cause air pollution, and nitrates cause water pollution.
- Nitrous Oxide (N_2O) has 300 times the global warming potential of carbon dioxide (CO_2), and emissions have risen by 36% in South Asia between 2000 and 2015. The main source of N_2O emissions in the region is from ‘managed soils’ at 63%.
- In South Asia, ammonia (NH_3) emissions have increased by 36% between 2000 and 2015. Ammonia emissions are closely linked to commercial fertiliser applications. South Asia has the highest fertiliser use growth rate globally, at 50% between 2002 and 2017, over double the world average.
- Nitrogen dioxide (NO_2) and NH_3 can react to form particulate matter (PM), constituting up to half of $PM_{2.5}$ and PM_5, which pose great health risks. According to the WHO, South Asia contains some of the most polluted cities in terms of $PM_{2.5}$ accounting for the largest number of deaths and disability globally due to air pollution.
- Nitrogen pollution is increasingly problematic both for the environment and human health. Policy action at multiple levels, local, provincial, national to international scales, is vital to help mitigate both localised and transboundary effects.
- The treatment of the different of the nitrogen compounds requires nuance, policies can distinguish between the needs and measures required to manage nitrogen oxides and ammonia.

C. SOUTH ASIA INITIATIVES ON REACTIVE NITROGEN

Fortunately, South Asia has been proactive in recognizing nitrogen issues (Figure 5) (see Raghuram et al. 2020; Raghuram et al., 2021). The South Asian Nitrogen Centre (SANC) of the International Nitrogen Initiative (INI) was established in New Delhi in 2008. Together with the Indian Nitrogen Group established under the Society for Conservation of Nature (ING-SCON), it reviewed the status of nitrogen at many levels (Galloway et al., 2008) and hosted the INI's 5th International Nitrogen Conference in New Delhi in 2010. This was attended by over 350 delegates from 36 countries including most of the South Asian countries. A Delhi Declaration was adopted. This was followed by two national brainstorming workshops held by ING-SCON in New Delhi, India, in February and March 2012 with the support of the Ministry of Earth Sciences, Government of India. A special side event (ID: 2776) was then held during the Conference of Parties (COP11) to the Convention of Biological Diversity (CBD) at Hyderabad, India, in October 2012. The event titled '*The challenge to produce more food & energy with less pollution: Towards a Global Nitrogen Assessment'* was organized by INI-SANC in association with the United Nations Environment Programme-Global Partnership on Nutrient Management (UNEP-GPNM) and ING-SCON.

In 2013, the South Asia Co-operative Environment Programme (SACEP) commissioned a study on the nutrient pollution of the coastal and marine systems in South Asia, as an input document for a sub-regional workshop on nutrient management under the Bay of Bengal Large Marine Ecosystem (BOBLME) project. This scoping study outlined the nitrogen losses to freshwater, coastal and marine environments; identified the critical marine habitats affected; and recommended technological, managerial and policy measures through regional coordination (SACEP, 2014). The acceptance of this scoping study, entitled "Nutrient loading and eutrophication of coastal waters of the South Asian seas" by the SACEP Governing Council (a ministerial level decision making body for SACEP) was a key milestone in the intergovernmental recognition of N_r as an important aspect of nutrient loading at the South Asian level. It also revealed the knowledge gaps and laid the foundation for a South Asian nitrogen assessment. South Asia also figured in the UNEP-GPNM commissioned report entitled '*Our Nutrient World'* as a Global Overview on Nutrient Management (Sutton et al., 2013), which received extensive media coverage and scholarly citations internationally. Its highlights were presented at the 6th International Nitrogen Conference of INI in Kampala, Uganda and a Kampala Declaration was adopted (Sutton et al., 2020).

Figure 5: Timeline of global and South Asian developments toward global cooperation on sustainable nitrogen management



Source: Raghuram et al. (2021)

Over the next 3 years, building on the success of the UNEP-GPNM 'Global nutrient cycle' project based on nutrient pollution in Chilika Lake in India and Manila Bay in the Philippines, UNEP facilitated a Global Environment Fund (GEF) project granted to INI. Entitled 'Towards International Nitrogen Management System' it incorporated six regional demonstrations including South Asia. As its project partner, SACEP facilitated the nomination of national governmental representatives in this project and hosted the first meeting of South Asian partners at Malé, Maldives, in September 2017. A draft resolution on 'sustainable nitrogen management' was adopted by the SACEP Governing Council. It was based on the Indian Nitrogen Assessment (Abrol et al., 2017), a SACEP scoping study, and other emerging evidence from the region.

Over the following year (2018), SACEP mobilized the support of its member countries for leading this resolution in the UN. The government of India and Bangladesh formally submitted it in 2018 for the 4th UN Environment Assembly (UNEA-4). It was eventually tabled and negotiated by Indian diplomats with the scientific support of INI and was adopted unanimously in UNEA-4 in March 2019 (resolution attached in Appendix 3). This was a historic moment for regional cooperation through SACEP and overall South Asian leadership on the global stage.

A more extensive partnership on N_r research and policy was approved for a South Asian Nitrogen Hub (SANH) funded by UK Research and Innovation (UKRI) under the Global Challenges Research Fund (UKRI-GCRF).[6] This brought together 40 institutions from all eight South Asia countries along with the UK, led by Prof. Mark Sutton of the UK Centre for Ecology & Hydrology. Through the INMS and SANH projects, further consultations and workshops were held throughout 2019 in Kathmandu, Nairobi, Dhaka, Malé, New Delhi and Chennai. They culminated in the launch of a UNEP global nitrogen campaign at a high-level summit hosted by the Sri Lankan government in Colombo in September 2019. The Colombo Declaration (see Appendix 4) on the implementation of the UN resolution on sustainable nitrogen management was adopted. The 'Colombo Declaration' commits to an ambition to halve nitrogen waste by 2030. The declaration urges countries to take comprehensive assessments of nitrogen policy, its management, and scientific aspects to move towards sustainable nitrogen management. This report contributes directly towards these actions for South Asia.

Sri Lanka is also the first country to announce its commitment to halving nitrogen waste, in accordance with the Colombo declaration, as part of its updates to its nationally determined

[6] https://www.ukri.org/wp-content/uploads/2020/10/UKRI-22102020-GCRF-Hub-booklet-June-2019.pdf

contributions (NDC's) to the United Nations Framework Convention on Climate Change (UNFCCC).[7]

These initiatives have further strengthened the UNEP-INI-INMS-SACEP partnership and South Asian leadership on nitrogen has generated wider international support.

Summary of Section C

In the last two decades, several initiatives have taken place in South Asia to tackle N pollution. Early actions include the establishment of the South Asian Nitrogen Centre (SANC) of the International Nitrogen Initiative (INI) in 2008.

Events have since taken place in parallel both at the global and regional level. Key actors include the various environmental agencies of the UN, with SACEP driving regional cooperation.

In 2019 the most recent and significant event was the passing of the 'Colombo Declaration on Sustainable Nitrogen Management'. Member states of UNEP endorsed a proposed road map for action to halve nitrogen waste by 2030.

The initiatives that have taken place to date lay the foundations for catalysing further regional and international cooperation and actions to improve Nitrogen management in the South Asia region.

[7] Sri Lanka, Ministry of Environment (2021)

D. EXISTING NITROGEN-RELATED POLICIES IN SOUTH ASIA

South Asian countries have many policies, regulations, and legislation that are likely to impact levels of nitrogen pollution. As part of the **actions towards building 'the nitrogen policy arena for South Asia',** the South Asian Nitrogen Hub (SANH) collected and analysed Nitrogen related policies from the region. Until now, little has been known about the nitrogen policy landscape for the region. Assessing nitrogen-related policies is crucial to identify the gaps and opportunities for managing nitrogen in the region. An analysis of this kind provides an essential building block to understanding what policies currently are in place to determine what is needed for the future.

This section **provides a summary of 966 nitrogen related policies from South Asia** focused mostly at the national level. A summary of the policy data collection approach is firstly provided. Secondly, the regional policy results are described based on the classifications: relevance, scope, pollution target source, policy type, sink and sector. Policy quality was further assessed and discussed by considering policy integration.

The database of nitrogen-related policies from South Asia collected for the South Asian Nitrogen Hub (SANH) 2020-2021 provides a valuable resource for South Asia governments and the wider scientific community[8]. Details for each policy included in the database are the policy title, year of establishment, URL source (if available), text type (legislation, policy, regulation, miscellaneous), country, territorial division (national or sub-national), language, and responsible ministry (when applicable) in addition to the classifications.

D.1 Data Collection approach

This work builds on from an initial global nitrogen policy assessment conducted by Kanter and others (2020). This global database identified 2,726 policies directly related to nitrogen, across 186 countries derived from the ECOLEX database. From the global database a total of 56 policies for South Asia were collected. By adjusting the data collection approach and using multiple online data sources, SANH identified a total of 966 policies (i.e., pieces of legislation, regulations, or other interventions related to nitrogen) for South Asia (Table 7). The search involved collecting policies from multiple sources including the FAOLEX database, which is maintained by FAO. For the region, 55% of policies were sourced from FAOLEX. In addition, policies were collected from other sources, including government and ministry websites, which

[8] For access to the 'Nitrogen-relevant policies from South Asia collected by the South Asian Nitrogen Hub (SANH) 2020-2021' database please contact: anastasia.yang@ed.ac.uk

contributed 45% of collected policies. The policies were collected during 2020-2021 and relate to policies operative on 31 December 2019.

The SANH approach further differed from the global study by **including those policies directly and 'indirectly' related to nitrogen management**. Indirectly relevant policies include those that can potentially influence how N_r enters the environment, even if nitrogen is not the focus of the policy. Additional sectors were also included in the policy search such as forestry, and urban development and tourism and an option for others. Collected policies featured those that could have potentially positive, negative or mixed/neutral impacts on N_r. For example, those that have measures to 'mitigate' N_r pollution, such as air pollution standards, and those that may 'exacerbate' N_r issues, such as subsidies for synthetic chemical fertilizers.

Table 7: Number of nitrogen-related interventions by South Asian governments per country and for the region, including main data sources and the policies selected for relevance and scope to nitrogen management

Country	Collected from FAOLEX database	Collected from other web sources	Total Number of policies *valid at end of 2019	Policies selected for relevance & scope
Afghanistan	79	7	86	55
Bangladesh	67	120	188	120
Bhutan	31	29	61	39
India	69	123	192	136
Maldives	20	20	40	29
Nepal	63	45	109	66
Pakistan	136	39	175	98
Sri Lanka	61	54	115	106
South Asia	**526**	**439**	**966**	**649**
Percentages	**55%**	**45%**	**100%**	**67%**

Note: policies were collected from multiple sources including: FAOLEX listings (http://www.fao.org/faolex/en/) corroborated and updated by SANH partners. ECOLEX listings, from https://www.ecolex.org/, were used by Kanter et al. (2020)

Source: Nitrogen-relevant policies from South Asia collected for the South Asian Nitrogen Hub (SANH) 2020-2021

D.2 Classification

Policies identified for further analysis were those classified as having greater relevance and (potential) impact for nitrogen management. Relevance was assessed as *high, medium* or *low.* 533 policies (55%) were classified as having *high* relevance. A total of 197 policies

(20%) were classified as having medium relevance. Policies with *low* relevance, a total of 236 (24%), were not included for further analysis in this report. The boxes in the following tables provide classification definitions.

Relevance	Classification definition
High relevance	Policies directly targeting N_r e.g., vehicle emissions' regulations limiting levels of NO_x. Policies were identified as high relevance if they had one or more of the 29 key words as outlined by Kanter et al. (2020), such as 'nitrogen' or 'ammonia'. A caveat was that a small number of policies may contain a key word, such as climate change, but may directly focus on nitrogen per se. Nonetheless, such policies, are considered likely, even if inadvertently, to have direct implications for nitrogen management.
Medium relevance	Indirectly nitrogen relevant policies that still had clear relevance to nitrogen, e.g., policies that did not contain any of the key words, but contained their synonyms. For example, they refer to global warming rather than climate change, or they did not refer to fertilizer but incentivized agricultural inputs to promote productivity.
Low relevance	Policies more distantly related to N_r management such as 'seed' policies, food safety, or road expansion policies. These policies do not contain key words or related synonyms but may potentially have indirect implications for N_r pollution. For example, some seed policies encourage particular crops or seed types that could affect N_r pollution because of their implications on fertiliser use. Likewise, road expansion policies encourage more cars, potentially increasing NO_x emissions unless mitigated by other policy initiatives and measures

Policies were also **classified by impact scope** – large, medium and small – to distinguish the scale of possible impact of a policy on N_r use. 374 (39%) of policies have a *high* impact scope. 345 (36%) of policies have a *medium* impact scope. 247 (26%) of policies have a *small* impact scope, and these policies were not included in further analysis.

Impact scope	Definition
Large scope	Includes nation-wide policies such as an agricultural policy with wide and direct implications for N_r management.
Medium scope	Policies that encompass a large area (national) but indirectly focused on N_r management e.g., a fauna and flora protection act, or sub-national level plans with fairly direct implications for nitrogen management, such

	as the Master Plan for Agricultural Development in the Southern Region of Bangladesh.
Small scope	Policies that focus on only a small spatial area i.e. less than provincial. These may be area/zone specific, and/or with minor implications for nitrogen management, e.g., plant quarantine rules. Such policies with a small spatial scale may nonetheless represent important interventions that may impact N_r management in different sinks.

In sum, the analysis in this report focuses only on those policies with *high* or *medium* relevance and *large* or *medium* impact scope. Selected policies totalled 649, comprise 67% of the database (see Table 7).

SANH further classified policies by economic sectors, environmental sinks and policy type. These classifications indicate if a policy is directed towards a particular sector, or toward multiple sectors, and/or where they are targeted towards environmental protections and a particular sink, or multiple sinks. The classification for policy type identifies the type of policy instrument being applied or advocated. Further details on these classifications are outlined below.

D.2.1 Economic sectors

Economic sectors mostly followed the definitions set out by Kanter et al. (2020), with some slight adjustments. ***Transport, energy, agriculture, waste***, and ***industry*** were common between the SANH and Kanter et al. (2020) approaches, as well as an option for **multiple sectors.** Policies classified as *multiple* indicate integration across sectors, often necessary to deal with nitrogen management. A code for ***sector not included*** was applied when the policy had no reference to a sector and referred only to environmental sink(s). Additional sector options include ***urban development and tourism, land use change, food*** and an option for ***'other'*** for example health policies with N_r management implications.

For Economic sectors, Table 8 shows that the most common classification was *multiple,* i.e. referring to two or more sectors, with 200 policies (31% of the selected policies). The *agriculture* sector was the second most common classification, with 135 policies (21%). This is perhaps not as large as would have been expected, given that agriculture is such a substantial part of South Asian economies and land use (except for Maldives). Following this, policies classified as '*sector not included'* were the most common, i.e., 10% of all policies only focused on environmental sink(s).

All the other sectors (*energy, food, industry, land use change, transport, urban development & tourism, waste and other*) were at 8% or below. Whilst policies on these sectors were less commonly found they address some of the highest emitting sources of N_r pollution for South

Asia (see section B). The sectors emitting the most significant sources vary by country and indicate possible policy gaps and opportunities, where nitrogen needs further attention.

Table 8: Selected* Nitrogen-related South Asian policies by sector and sink

	Environmental sink								
Sector	**Air**	**Climate**	**Eco-system**	**Soil**	**Water**	**Multiple**	**Sink not included**	**Total**	**% of total**
Agriculture		4	5	3	7	28	88	135	21
Energy	5	9	1			2	26	43	7
Food						7	18	25	4
Industry	3					2	14	19	3
Land Use Change			17	1	1	13	11	43	7
Other	1		2		4	3	20	30	5
Transport	9	1			1	2	13	26	4
Urban Dev. & Tourism					5	3	6	14	2
Waste					15	16	20	51	8
Multiple	9	13	18	1	28	99	32	200	31
Sector not included	6	8	11	1	23	14	0	63	10
Total	33	35	54	6	84	189	248	649	100
% of total	5	5	8	1	13	29	38	100	

Source: Nitrogen-relevant policies from South Asia collected for the South Asian Nitrogen Hub (SANH) 2020-2021. *Selected policies include those classified with high-medium relevance and large-medium scope.

D.2.2 Environmental sinks

An environmental sink refers to a reservoir that takes up a nitrogen compound, or where nitrogen loads can accumulate and can have an impact. A policy was classified as having a particular sink only if the policy objective or content mentioned one or more sinks, therefore not based on assumed nitrogen environmental links or impacts. **Policies classified for environmental sinks** followed those classifications outlined by Kanter et al (2020) including: ***water, air, ecosystems, climate, soil,* and *multiple* sinks and *sink not included*** i.e., where the policy refers only to sector/s

For environmental sinks the most common classification was for sinks *not included*, with 38% focused only on sectors (Table 8). These 248 policies have implications for the environment and yet currently do not specifically consider the environment. This is another policy gap that needs attention, especially if these sector-based policies are not linked to or supplemented by other policies that aim to mitigate or minimise negative environmental impacts.

In contrast, the second most common classification is *multiple* sinks. These policies indicate a favourable direction for policy because N_r impacts affect multiple sinks (see Section A). Policies that represent integration across sinks are those that recognise that sinks are not isolated from each other. The third most common classification for a single sink was for *water* (13%) including policies related to water laws, water quality, drinking water, river conservation plans etc. For *ecosystem, climate* and *air,* classifications were at 8% or below. *Soil* was the least common sink referred to even though N_2O and NH_3 emissions come from managed and unmanaged soil.

D.2.3 Policy Type

The policy type classification distinguishes between several different policy mechanisms that can impact environmental pollutants. The classification was originally derived from the OECD's 'Database on Instruments used for Environmental Policy' and developed further by Kanter et al. (2020) to ***regulatory, economic, framework, data and methods, research & development (R&D), commerce*** and ***pro-Nitrogen*.** SANH further adjusted this approach to allow for multiple policy types to be identified e.g., having *framework* elements as well as *data and methods*.

For policy type, indicating the policy instruments being proposed, 549 policies were classified as having a ***framework*** element, by far the most common policy type found within the database (see Table 9). The second most common policy type was ***Data & Methods****,* with 173 policies. ***Research & Development (R&D)*** was the next most common instrument, included in 154 policies. The Colombo Declaration calls on member states to promote R&D around nitrogen management, therefore such policies are considered to be valuable. ***Regulatory*** **and** ***economic*** policy elements are the fourth most common. 145 policies included regulatory policy elements and 110 policies were classified as having economic elements. These policies are considered 'core policies' because they are most likely to have a direct impact on N_r pollution. Nonetheless all policies included in the database potentially can have indirect declarative effects that are hard to identify or measure. The least common policy types were ***commerce*** and ***Pro-N*.** 54 policies included commerce elements and 36 policies were identified in the SANH database as *pro-nitrogen*.

Policy Type	Classification definition
Framework	Policies that are broad in reach and scope. Framework-type measures delegate authority or responsibility relevant to nitrogen regulation or set broad goals and objectives on reducing or limiting nitrogen pollution.
Data & methods	Policies refer to monitoring and evaluation, and may also enforce, prescribe, or define data collection or data reporting protocols. Monitoring is a key element in the implementation of policies to assess their effectiveness. Therefore, policies on data and methods are desirable for nitrogen-related policies.
Research & Development (R&D)	Policies that advocate for research and development in relation to nitrogen, directly or indirectly. In addition, this classification includes some policies that allocate funding and/or provide mechanisms for R&D into N_r pollution or develop processes and technologies that reduce nitrogen emissions to the environment.
Regulatory	These include tools and instruments include those that set quantifiable limits or restrictions on nitrogen production, consumption and loss. Such policies include broader strategies if they identify quantifiable targets that could have impacts on nitrogen management. For example, standards tend to have a quantitative element (such as pollution concentration limits), whereas other regulatory elements could be applied more qualitatively (such as bans on product use or certain activities).
Economic	Policies include financial incentives and signals to spur quantifiable improvements in nitrogen management and mitigation, including, e.g., the provision of licences for effluent discharge in wastewater.
Commerce	Refers to policies that aim to that regulate fertilizer production and/or trade. Examples include labelling, registration and classification, quality assessments, and sewage sludge or manure processing.
Pro-Nitrogen	Nitrogen policies that primarily focus on increasing agricultural production, often via subsidies or other incentives for increased fertilizer use. Where policies include language similar to ecological or responsible use of fertilizer, such policies were still considered as pro-nitrogen unless this concern was a major component.

For over half (53%) of the selected policies, SANH identified multiple policy elements. Policies with multiple instruments are regarded as more comprehensive. The Intergovernmental Panel on Climate Change (IPCC), amongst others, advocates applying a combination of policy instruments to secure better environmental outcomes than is possible from individual policy instruments delivered on their own (Gupta et al., 2007, p.765).

Of the 273 agricultural policies in the SANH database, very few contained core policies i.e., included *regulatory* elements (17) or involved *economic* tools (24) (see Table 9). By far the largest number of policies included *framework* elements (117). *Commerce* and *Pro N* were mostly associated with *agriculture* but still low numbers, at 21 and 23 respectively. Likewise, 42 agricultural related policies had *R&D*, higher again here than in the other sectors, with the exception of multiple.

Table 9: Selected* Nitrogen-related South Asian policies by sector and policy type

	Policy Types								
Sectors	**Regulatory**	**Economic**	**Framework**	**Data & methods**	**R&D**	**Commerce**	**Pro-n**	***Total***	***% of total***
Agriculture	17	24	117	29	42	21	23	273	22
Energy	3	11	37	7	12	4	2	76	6
Food	2	2	24	2	5	2	4	41	3
Industry	3	3	18	2	4	2	0	32	3
Land Use Change	15	6	34	5	6	1	1	68	6
Transport	9	2	22	8	3	6	0	50	4
Urban Dev. & Tourism	2	4	12	3	1	0	0	22	2
Waste	20	9	39	19	1	1	0	89	7
Other	8	6	25	8	3	3	0	53	4
Multiple	54	39	170	73	60	14	6	416	34
No sector included	12	4	51	17	17	0	0	101	8
Total	**145**	**110**	**549**	**173**	**154**	**54**	**36**	**1221**	**100**
% of total	**12**	**9**	**45**	**14**	**13**	**4**	**3**	**100**	

Source: Nitrogen-relevant policies from South Asia collected for the South Asian Nitrogen Hub (SANH) 2020-2021.
Note: A policy could be coded multiple times by policy type, hence policy types add up to more than 649.
*Selected policies are those classified with high-medium relevance and large -medium scope.

D.3 Policy quality

Policy quality is usually assessed in terms of the impact of the policies, as indicated by changes in the scale of pollution. This paper deals only with a policy's intent (as expressed in the text of a policy document) and the likelihood that the tools it proposes will have the envisaged effects. The quality of nitrogen related policies is assessed here by considering three main aspects: impact direction; existence of pollution source targets; and level of integration i.e., whether multiple sinks, sectors and/or policy types have been considered.

D.3.1 Direction of impact

For **direction of impact,** policies could be coded as *positive, negative* or *mixed/ neutral*. 403 of the selected policies (62%) were classified as having a potentially *positive* impact on nitrogen management. The second most common classification was for *mixed* or *neutral* impact, at 32% (209) of the selected policies. The least common category was policies likely to increase N_r pollution (6% of the 649 selected policies). Considering the environment within a policy is an important yet first step; to ensure in practice those considerations or conditions are being met needs further action. Therefore, whilst a significant number of policies are classified as being potentially positive or even mixed, the effectiveness of those policies to achieve positive impacts on N_r management will require further assessment.

Impact scope	Definition
Positive	Policies promote a reduction in N_r pollution and/or improved nitrogen management, whether directly or indirectly. This included policies that were environmentally oriented, e.g., environmental standards, and water quality control policies.
Mixed /neutral	Polices that have intentions that could have both positive and negative implications (e.g. a policy that aims to enhance food production but also considers environmental impacts), or if the policy is potentially neutral in its impacts.
Negative	Policies that could potentially cause excess N_r and had no environmental considerations in place e.g. those that promote synthetic fertiliser use or fossil fuels but mention no mitigation measures.

Table 10: Selected* Nitrogen-related South Asian policies by sink and policy type

Environmental Sinks	Policy Type							Total	%
	Regulatory	Economic	Framework	Data & Methods	R&D	Commerce	Pro-N		
Air	18	8	22	16	2	4	0	70	6
Climate	5	7	32	11	11	1	0	67	5
Ecosystem	8	4	50	8	15	1	3	89	7
Soil	0	1	6	0	2	0	2	11	1
Water	20	13	71	27	14	0	0	145	12
Multiple	52	35	158	70	64	10	14	403	33
Sink not included	42	42	210	41	46	38	17	436	36
Total	**145**	**110**	**549**	**173**	**154**	**54**	**36**	**1221**	**100**
%	**12**	**9**	**45**	**14**	**13**	**4**	**3**	**100**	

Source: Nitrogen-relevant policies from South Asia collected for the South Asian Nitrogen Hub (SANH) 2020-2021.
Note: A policy could be coded multiple times by policy type, hence policy types add up to more than 649.*Selected policies are those classified with high-medium relevance and large-medium scope.

D.3.2 Environmental sink and policy type

We compared policy type classifications with environmental sink and sector classifications (Tables 9 and 10) to further examine policy characteristics. Table 10 displays the **cross tabulation of sinks and policy type**. The number of *framework* policies classified as 'sink(s) not included', is 210, counting the policies that were sector-based only. In Table 9, *agriculture* emerged as the most common single sector type policy associated with *framework*, a total of 117 policies, whereas the *multiple* sector classification is most common for *framework* policy types, with a total of 170. *Framework* policy types were secondly associated with *multiple* sinks. This indicates policies with broader objectives i.e., 'umbrella' type policies, often including strategies or action plans, and less likely to be legislative, such as Bangladesh's National 3R Strategy for Waste Management 2010, or Bhutan's National Biodiversity Strategies and Action Plan 2014.

D.3.3 Pollution source Type

Pollution source types were assessed to identify whether a policy targeted, or even showed awareness of, the different types of sources of N_r pollution, non-point source (NPS) and point source. A total of 78 policies (12%) referred to targeted point source pollution. NPS was less commonly recognised, with only 35 policies (5%). However, more policies (152, or 23%) recognised both pollution types. Such policies indicate useful examples for N_r management as they recognise the differences of pollution sources and the requirements to measure and mitigate these different types. It was, however, more common for policies not to refer to any pollution types or to the differences between the two. These policies were classified as unspecified and totalled 199 (31%). In the SANH database, 29% were coded as non-applicable (NA).

Impact scope	Definition
Point source pollution	Where nitrogen pollution is discharged directly into water or into the atmosphere at one or a few 'discrete points', making it easier to control and monitor.
Non-point source (NPS)	Covers pollution that comes from many land, air or water sources and can be carried overland, underground, or in the atmosphere, making the pollution difficult to measure and control.
Both pollution sources	Polices was classified as this if it referred to point source and NPS.
Non-applicable (NA)	This was applied to policies that had 'indirect' nitrogen relevance and/or those policies that were classified with a negative impact direction.

D.3.4 Policy integration

To assess the overall **degree of policy integration** the sinks, sectors and policy type were examined. It was recognised in the earlier results that *multiple* was a common classification for sinks and sectors. A total of 99 selected policies (15%) were classified as both *multiple* sink and *multiple* sector. These policies stand as progressive examples for having integrated objectives. Policies were further assessed to see if they had an 'integrated approach,' i.e., if they had been associated with multiple policy instruments. It was earlier noted that for policy type the majority were classified as having multiple interventions. However, only 61 of the selected policies, (9%), were found to have multiple sinks, multiple sectors and multiple policy instruments. It is encouraging that some policies in South Asia met this criterion, yet a potential policy gap is also visible. Certainly, these 61 policies indicate a higher policy quality and desirable direction for future policy. There appears to be a considerable policy gap, since the vast majority of policies collected do not indicate this level of integration. Integrated policies are essential to address nitrogen management systematically.

D.4 Conclusion

South Asian nitrogen-related policies are typically qualitative in nature and rarely set quantitative targets for reduction. Very few policies try to manage N_r pollution in a measurable way. Examples from this latter group are policies on water quality, where limits have been set for acceptable levels of ammonium (NH_{4+}) in ground water or industrial effluent, and on air quality, with limits on NO_x released to the atmosphere from transport or industry. Efforts to ban crop residue burning since the late 2010s are the first to attempt to manage N_r pollution in air quality emitted by the agriculture sector. Otherwise, typically there are aspirations or goals to 'encourage' more sustainable practices that might result in less N_r pollution, such as greater availability and use of bio-fertilizers, increased soil testing, changes to tilling practice and use of cover crops. In most cases, how these goals would be achieved still needs to be developed.

The SANH database provides an initial overview of the current nitrogen policy landscape for South Asia, allowing the identification of those policies that deal with nitrogen directly and providing an opportunity to pinpoint where there are gaps. In addition, there are opportunities for shaping existing policy, especially for indirectly nitrogen-relevant policies, where minor amendments could further specify nitrogen links to have a greater impact in promoting sustainable N_r management. 'More' policies may not necessarily be 'better' policies, but when policies are 'few' this indicates a potential for development to proactively manage nitrogen pollution.

Summary of Section D:

- Until now, little has been known about the nitrogen policy landscape at national and regional levels for South Asia. To address this knowledge gap **966 nitrogen related policies from the region, operative at the end of 2019, were collected and analysed** by the South Asia Nitrogen Hub (SANH).
- The texts of these policies were **classified by sector, environmental sink, policy type, and other indicators of policy quality**.
- A total of 649 policies were found to have high or medium relevance and large or medium scope with reference to nitrogen management.
- **Water was the most common single environmental sink** identified, followed by ecosystems, climate and air. Soil was the least common sink.
- **38% of policies focused only on sectors.** These policies have implications for the environment and yet currently do not specifically consider it. This is a policy gap that needs attention, especially if these sector-based policies are not linked to or supplemented by other policies that aim to mitigate or minimise negative environmental impacts.
- **Agriculture was the most common single sector** for the policies in the region. Transport, energy, waste and industry were each more minor policy sector types. These reflect emerging sectoral sources of nitrogen pollution that likely need further attention in nitrogen related policy interventions.
- **The policy type framework was the most common** (45%) followed by data and methods, R&D, regulatory and economic. Commerce and Pro-N were the least common policy types.
- South Asian nitrogen-related **policies are typically qualitative in nature and rarely set quantitative targets for reduction**. Very few policies try to manage N_r pollution in a measurable way.
- It was **rare for policies to refer to any pollution types** (neither point source nor non-point source), representing a policy gap.
- The findings suggest that a **small proportion of policies have attempted to integrate across multiple sectors and sinks, while also proposing a range of policy instruments.** Overall, integrated policies are lacking in the region and having more of these in place would help address nitrogen issues systematically.

E. CONCLUSIONS AND POLICY IMPLICATIONS

This report outlines the impacts, trends, and drivers of nitrogen pollution/waste in south Asia, providing an overview of the regions nitrogen related policies and their characteristics. The assessment highlights that excess N_r, is a significant problem that needs requires national and international cooperation and commitment to resolve. Nitrogen emissions are increasing across all south Asia countries, and for the region, exceeding in most case global averages, underlining that more still needs to be done. This section outlines some of the findings from this assessment, elaborating on the challenges and barriers for policy and action, and on existing technologies and alternative practices already under consideration by South Asian governments.

E.1 Policy findings

The policy analysis highlights potential gaps and opportunities in the current policy landscape. For example, there is scope to increase 'core policies,' i.e., regulatory and/or economic instruments to provide quantifiable limits and/or incentives to support sustainable N_r management. Furthermore, some policies indicate favourable policy features (multiple sink, sector, and policy instruments) – a desirable direction for future policy. More integrated policies and integration across policies would help address nitrogen issues systematically.

Reducing nitrogen waste is possible and a highly desirable policy goal that can limit adverse environmental effects and health impacts, with co-benefits for food production and the wider economy. Existing experience and best practices could be starting points, if optimized to local conditions and needs. Countries can learn from each other which approaches work best in the region, and how to fill any gaps. The South Asia region can be world-leading in addressing the challenge of sustainable N_r management. Efforts so far lay the foundations for catalysing further regional and international cooperation and actions to improving nitrogen management in South Asia.

E.2 Key challenges

For South Asian governments a key challenge is how to meet increasing food and transport demands to support larger, wealthier populations while in parallel stabilizing and/or reducing nitrogen pollution. Nevertheless, opportunities for policy development exist for each of the main source sectors that create nitrogen pollution (agriculture, combustion, water/sewage, transport, tourism, urban development, food, industry and energy). As South Asian economies develop further, the importance of controlling pollution from industrial and energy generation sources that support this development will grow in relative importance. Some clean technology is already cost-comparable to older iterations that serve the same purpose. South Asia could potentially leap-frog 'traditional' development pathways and demonstrate global leadership in creating green economies and societies. Box 2 provides a summary of barriers to effective nitrogen policy formulation as reported by South Asia governments.

Box 2. Barriers to new nitrogen policy formulation

SACEP circulated a questionnaire to South Asian governments, and the responses identified barriers to new nitrogen policy formulation. They include:

Knowledge, awareness and engagement

- A lack of awareness, among the public as well as among legislators and other policymakers, of the threats posed by nitrogen pollution to the environment and to human and animal health.
- A limited range of stakeholders engaged in N_r reduction efforts.
- Lack of awareness on sustainable nitrogen management at all levels to improve the efficiency of nitrogen policies in an integrated manner.
- Strengthening capacities of stakeholders for nitrogen management.

Data and research

- A lack of data and reliable scientific assessments that can be used to enhance public and policy-maker awareness of these threats.
- Improving monitoring and understanding the status of nitrogen pollution and its management through regional and national N_r assessment, such as this report and national reports for all eight South Asian countries.
- Improve research to better understand the impacts of products, tools, machinery, and approaches on nitrogen pollution in a wide variety of sectors and settings like understanding nutrient use efficiency (NUE) of water-soluble fertilizers compared with conventional fertilizers and machineries for effective delivery of fertilizers.

Policy gaps

- Poor or no co-ordination mechanisms between ministries or departments for integrated responses to nitrogen threats.
- Coordination (sharing knowledge/best practice) within countries (between ministries and departments) and across South Asia, to minimise cross-border effects and improve coordinated efforts for sustainable nitrogen management.
- A major hurdle is the increase in cost of producing alternatives including efficient products such as sulphur and neem coated urea.
- Absent or insufficient incentives for nutrient recovery and recycling.
- Lack of regionally appropriate guidance for better nitrogen management.

E.3 Sectors and sources

Different compounds of N_r are lost from different sectors of human activity, as Tables 1 to 6 have shown. These activities are often overseen by different ministries or departments in each South Asia country. The main sources of N_r loss include mineral fertilizers and manure management in crop and livestock production, aquaculture, power generation, industry, mining, transport, solid and liquid waste, biomass burning. These multiple sources therefore require the commitment of **all relevant ministries** to reduce N_r pollution in their respective sectors and ideally requires **inter-ministerial coordination**. Policies dealing with N_r threats should involve, e.g., departments of health, power generation, transport, industry, urban planning, agriculture and waste management fisheries, food standards, pollution control, and sanitation. Ministries of the environment cannot by themselves take forward policies to reduce wastage of N_r: collaboration between departments is essential

Fossil fuel consuming sectors such as energy, transport and industry release more NO_x than other nitrogen compounds, while agriculture mainly releases ammonia (NH_3) and nitrous oxide (N_2O) to air, and nitrites and nitrates to water. This allows different **ministries to act as nodal agencies to manage different nitrogen compounds** and reduce environmental accumulation from their sectors. Despite the difficulties involved, comparing the scale or impact of different forms of N_r pollution is crucial, to permit comparison to global levels and trends, qualitative assessments of significance and selection of pollutants to address quickly -- as can be seen from the report findings.

Considering that nitrogen losses follow different growth rates over time in different sectors, policy interventions **need to address not only the predominant sector for each nitrogen compound emitted, but also the fastest growing sector(s**) such as domestic wastewater, and transport, for each nitrogen compound. Similarly, while chemical fertilizers have always been the single largest source of N_2O in the region, their growth rates have been very low whereas the contribution of domestic wastewater, navigation and aviation grew several times faster (Bhattacharya et al., 2017; Winiwarter et al., 2018). Data reliability varies across the South Asian countries and there is an ongoing need to explore how this can be improved.

In choosing sectors to prioritize for action:

- Current levels of N_r pollution (e.g., excessive fertilizer in agriculture, biomass burning and 'dirty' industry and vehicles) should be high priorities.
- Fast-growing/emerging N_r source sectors (e.g., human, animal and industrial waste) and areas where quick results are achievable, are also candidates for urgent action.

E.4 Solutions and alternatives

South Asian governments are already considering actions via **existing technologies and alternative practices** to tackle the N_r issues including:

- **Improved management of sewage and solid waste**, including nutrient recovery, promotion of city compost and organic fertilizer and recycling of nitrogen for use as fertilisers, which could reduce chemical fertiliser use by as much as 40%.
- **Raising nitrogen use efficiency (NUE)** across South Asia. Even a 10% increase in nitrogen use efficiency can result in massive savings. Fertilizer product research needs to be intensified to improve on sustained nitrogen release materials to meet crop nitrogen demands and minimize nitrogen losses (see Móring et al., 2021; Jat and Gerard, 2014).
- **Reductions in vehicular emissions** can be addressed through improved public transport and a transition to electric mobility.
- **Introducing and incentivising technology and approaches to reduce nitrogen waste/pollution** like use low NO_x burners in industrial boilers, NO_x capture and utilisation (NCU) technology that focuses on extracting N_r from waste combustion streams and use of cattle dung as manure, and providing low cost and regular supplies of less polluting alternative sources of cooking fuel.
- **Implementation of emission standards** like NO_x (400 mg N m^{-3}), effluent standards of Ammoniacal Nitrogen (50 mg-l^{-1}), Nitrate (10 mg l^{-1}) and setting goals to cut consumption of nitrogen-based fertilisers.
- **Banning of crop residue burning**, a key contributor to winter smog in many parts of the Indo-Gangetic plain.
- **Promoting integrated nutrient management** through soil tests and leaf colour chart apps.
- **Using 'clean' renewable energy**, particularly zero-emission technologies such as wind and solar energy.

SACEP and SANH see this report as a first step in a journey towards a South Asia roadmap positioning South Asia as a global leader in N_r management. Efforts to reduce nitrogen waste will reap financial, health and environmental benefits. These will flow from evidence-based decision making. SANH is mobilizing a wide range of environmental scientists and emissions modellers, along with social and policy scientists, to provide cutting-edge research that is targeted towards providing contributions to improved evidence-led N_r management in the region.

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Appendix 1: Relevant International Conventions and Networks and acronyms

1. Rio Conventions, 1992
   a. United Nations Framework Convention on Climate Change (UNFCCC) https://unfccc.int/
   b. United Nations Framework Convention on Climate Change (CBD) https://www.cbd.int/convention/
   c. United Nations Convention to Combat Desertification (UNCCD) https://www.unccd.int/
2. Global Partnership on Nutrient Management, 2009 (GPNM): https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-partnership-nutrient
3. Manila Declaration on Nutrient Pollution, 2012: https://www.unenvironment.org/resources/report/manila-declaration

South Asian regional agreements/programmes and mechanisms

1. South Asia Co-operative Environment Programme (SACEP) http://sacep.org/
2. South Asian Seas Programme (SASP) http://www.sacep.org/programmes/south-asian-seas
3. South Asia Environment and Natural Resources Information centre (SENRIC)
4. South Asia Coral Reef Task Force (SACRTF) http://www.icran.org/management-sacrtf.html
5. Malé Declaration on control and prevention of air pollution and its likely transboundary effects http://www.sacep.org/programmes/male-declaration
6. South Asia Biodiversity Clearing House Mechanism https://www.cbd.int/financial/asia.shtml
7. Colombo Declaration, 2019 tps://web.archive.org/web/20200812202815/https://papersmart.unon.org/resolution/node/286/ See also: https://www.thegef.org/news/colombo-declaration-calls-tackling-global-nitrogen-challenge

Scientific Networks involved in research on reactive nitrogen and its effects

1. INMS: International Nitrogen Management System http://www.inms.international/
2. SANH: South Asian Nitrogen Hub, under the UK Global Challenges Research Fund https://gtr.ukri.org/projects?ref=NE%2FS009019%2F1

3. INI: International Nitrogen Initiative, with its South Asian Nitrogen Centre https://initrogen.org/content/about-ini
4. INCOM, Interconvention Nitrogen Co-ordination Mechanism, process in development see: https://www.inms.international/unep-nitrogen-working-group-first-ebriefing
5. TFRN, Task Force on Reactive Nitrogen (under the Convention on Long-range Transboundary Air Pollution) http://www.clrtap-tfrn.org/
6. INA, International Nitrogen Assessment. https://www.inms.international/registration-ina-2

Appendix 2: Text of the Resolution on Sustainable Nitrogen Management, UNEA-4

United Nations Environment Assembly of the United Nations Environment Programme,
Fourth session, Nairobi, 11–15 March 2019
https://papersmart.unon.org/resolution/uploads/k1900699.pdf

Sustainable nitrogen management[1]

The United Nations Environment Assembly,

Recognizing the multiple pollution threats resulting from anthropogenic reactive nitrogen, with adverse effects on the terrestrial, freshwater and marine environments, contributing to air pollution and greenhouse gas emissions, while acknowledging the benefits of nitrogen use for food and energy production,

Recognizing also that global crop production in the world and the world's food security is dependent on nutrients, including nitrogen and phosphorus resource use,

Noting that global economy-wide nitrogen use is extremely inefficient with over 80% of anthropogenic reactive nitrogen lost to the environment,[2] which leads to water, soil and air pollution that threatens human health, wellbeing and ecosystem services and contributes to climate change, due to increases in greenhouse gas emissions, and stratospheric ozone depletion,

Recognizing the existing actions already taken by countries as part of national action plans and intergovernmental agreements related to water quality, air quality, climate and biodiversity,

Acknowledging that current policies related to reactive nitrogen in many countries are fragmented and incoherent,

Realizing that intersectorally incoherent approaches on global nitrogen cycle are resulting in unquantified trade-offs between different forms of nitrogen pollution and contributing to barriers to the adoption of policies for cleaner water, cleaner air, climate mitigation and adaptation and biodiversity protection,

Noting the initiatives of the Global Partnership on Nutrient Management (GPNM) and the recent establishment of the International Nitrogen Management System as a science support system for policy development across the nitrogen cycle, including working with regional groups and actors to allow regional perspectives to be developed within the global

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[1] The present document is being issued without formal editing (UNEP/EA.4/L.16). A version edited by UNEP Secretariat of Governing Bodies (UNEP/EA.4/Res.14) is also available in five languages: https://www.unep.org/environmentassembly/proceedings-report-ministerial-declaration-resolutions-and-decisions-unea-4

[2] Sutton et al. (2013) *Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management.* Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

context; also acknowledges the work done within UNECE Convention on Long-Range Transboundary Air Pollution and its Taskforce on Reactive Nitrogen,

Noting also the initiative taken by South Asia Cooperative Environment Programme (SACEP) and the International Nitrogen Management System focussed on the South Asia Seas region, towards development of a globally coherent approach for sustainable nitrogen management during its deliberations in Male in September 2017,

Calls on the Executive Director of the United Nations Environment Programme to:

(a) Consider the options to facilitate better coordination of policies across the global nitrogen cycle at the national, regional and global levels, including consideration of the case to establish an intergovernmental coordination mechanism on nitrogen policies, based primarily on existing networks and platforms and consider the case for developing an integrated nitrogen policy, which could enhance the gravity of common cause between multiple policy domains,

(b) Support exploration of the options, in close collaboration with relevant UN bodies, including the Food and Agriculture Organization, and multilateral environmental agreements as appropriate for better management of the global nitrogen cycle, and how these could help achieve Sustainable Development Goals, including sharing of assessment methodologies, relevant best practices and guidance documents and emerging technologies for recovery and recycling of nitrogen and other such nutrients,

(c) Coordinate existing relevant platforms for assessments of the multiple environmental, food and health benefits of possible goals for improved nitrogen management, while ensuring coordinated management of the relevant datasets to allow development of the integrated and sustainable nitrogen management approach and identify current information gaps, including in quantifying the net economic benefits for food and energy production, freshwater, coastal and marine environmental quality, air quality, greenhouse gas mitigation and stratospheric ozone depletion mitigation, underpinned by the development of reference values,

(d) Facilitate with relevant UN bodies, including the Food and Agriculture Organization, and as appropriate multilateral environmental agreements the promotion of appropriate training and capacity for policy makers and practitioners for developing widespread understanding and awareness of the nitrogen cycling and opportunities for action,

(e) Support member states with sharing and making available existing information and knowledge in the development of evidence based and intersectorally coherent approach to domestic decision-making towards sustainable nitrogen management where appropriate,

(f) Report on the progress achieved in the implementation of this resolution in UNEA-6.

Appendix 3: Text of the Colombo Resolution, October 2019[3]

Colombo Declaration

on Sustainable Nitrogen Management

We, the Member States of the United Nations Environment Programme (UNEP) participating in the Ceremonial Launching of the United Nations Global Campaign on Sustainable Nitrogen Management, 'Nitrogen for Life', held in Colombo, Sri Lanka,

Recognizing the relevance of Nitrogen and the need for national coordination between different Ministries such as Environment, Agriculture, Health, Education and Science as well as agencies and other stakeholders, in addressing Sustainable Nitrogen Management using the Whole of Society approach,

Acknowledging that Nitrogen is not just another problem, but rather it must be part of the solution for many of our environmental challenges, as it is an essential element for building structures of living organisms and as a critical element for the survival of all living things,

Recognizing that unreactive di-nitrogen is extremely abundant in the atmosphere and is converted naturally to reactive forms through lightning and biological nitrogen fixation, which cycle through roots of plants into food chains and made available to life, health and environment,

Appreciating agricultural wisdom and traditional best practices of ancient civilizations relevant for sustainable nutrient management, as this has descended over generations,

Noting that human activities continue to fertilize soils with reactive nitrogen in order to sustain global food and feed production,

Reaffirming the resolution on Sustainable Nitrogen Management (UNEP/EA.4/Res.14), adopted at the Fourth Session of the United Nations Environment Assembly (UNEA-4), emphasizing that global economy–wide nitrogen use is currently inefficient with extremely large proportion of anthropogenic reactive nitrogen lost to the environment,

Concerned that mismanagement and overuse of nitrogen has negative effects on land, water, biodiversity, human health and air, leading to worsening of climate change impacts,

Recognizing the International Nitrogen Initiative's commitment, made at the 'Our Ocean Conference 2018' in Bali, Indonesia, to support a Global ambition to halve nitrogen waste by 2030, which would offer quantified co-benefits for water quality, air quality, biodiversity, human health, climate resilience, food and livelihoods,

Acknowledging the efforts of the United Nations Environment Programme, the Global Environment Facility and the International Nitrogen Initiative, in the establishment of the International Nitrogen Management System to link science and policies on sustainable nitrogen management, including contributions from the Global Partnership on Nutrient Management, the South Asia Cooperative Environment Programme and the 'GCRF South

[3] Permanent download available at: https://web.archive.org/web/20200812202815/https://papersmart.unon.org/resolution/node/286/

Asia Nitrogen Hub' established with support from the Global Challenges Research Fund of UK Research and Innovation,

Noting the outcome of the Fourth Session of the International Nitrogen Management System, held at UNEP in Nairobi on 29-30 April 2019 as a follow-up to the UNEA-4 resolution (UNEP/EA.4/Res.14) and the proposed 'Roadmap for Action on Sustainable Nitrogen Management 2020-2022',

1. Endorse the proposed Roadmap for Action on Sustainable Nitrogen Management 2020-2022, including its activities as one of the instruments to establish an Inter-convention Nitrogen Coordination Mechanism and secretariat to better facilitate communication and coherence across nitrogen policies, consistent with mandates of existing conventions and MEAs,
2. Call upon UN agencies and other international organizations, development partners, philanthropic agencies, academic and civil society organizations, to support the implementation of this Declaration, through the establishment of mechanisms of cooperation to mobilize human, financial and technical resources, including capacity building and transfer of know-how and technology, for this purpose;
3. Agree that countries should consider, in line with their national circumstances and where relevant, to:

   3.1 Develop and implement comprehensive policies on Sustainable Nitrogen Management;

   3.2 Develop national roadmaps for sustainable nitrogen management, with an ambition to halve nitrogen waste by 2030;

   3.3 Conduct comprehensive assessments on quantitative and qualitative nitrogen cycling covering scientific aspects, policy, regulation and implementation;

   3.4 Promote innovation on anthropogenic nitrogen use and recycling, emphasizing the opportunities for the circular economy;

   3.5 Sensitize the citizens to understand the natural nitrogen cycle and how anthropogenic activities alter its balance;

   3.6 Identify the best of descended traditional agricultural wisdom and assess the opportunities offered for nitrogen management, where appropriate mainstreaming it through policy, implementation and regulatory channels;

   3.7 Cooperate to submit a joint resolution to the Fifth Session of the United Nations Environment Assembly; and

   3.8 Report on the progress of implementing this Colombo Declaration at the Sixth Session of the United Nations Environment Assembly;
4. Request the UNEP Executive Director to:

   4.1 Facilitate the implementation of the Colombo Declaration, and the Roadmap for Action on Sustainable Nitrogen Management, 2020-2022,

   4.2 Catalyze a global comprehensive analysis of global nitrogen budgeting, impacts and solutions, including valuation of natural nitrogen fixation.

Done on 24th October 2019 in Colombo, Sri Lank

Appendix 4: Supplementary Figures and Tables

Note on EDGAR methodology for compiling nitrous oxide (N_2O) and nitrogen dioxide (NO_2) data

EDGAR uses the IPCC category classification and utilizes emission factors from IPCC methodologies (for CO_2, CH_4, N_2O) and for the tier 2 emission factors (NH_3, NO_2, BC, OC etc.) from the European Monitoring and Evaluation Programme (EMEP) of the European Environment Agency. An individual nation's 'other sectors' or 'other sources' differ. The following excerpts from national reports from countries outline what is included in their 'other sectors'. Although they refer mainly to CO_2, the activities are the same for emissions in their reporting of N_2O and NO_2.

1. National Inventory Report (NIR) of the Islamic Republic of Afghanistan (2019)

2.2.1.4 Other Sectors and Not Specified (IPCC subcategory 1.A.4 and 1.A.5)

GHG emissions occur from fuel combustion for heating and cooking purposes in

- Commercial and institutional buildings (1.A.4.a)
- Residential buildings and households (1.A.4.b)
- Agriculture/Forestry/Fishing/Fish Farms (1.A.4.c)

Stationary combustions are boilers (< 50 MW), pumps, stoves, fireplaces, cooking, etc. Mobile combustions are gardening equipment's and vehicles, fire trucks, sewage trucks, Snow mobiles, etc.

The national energy statistics do not provide a split of fuel used in this sector. The UN energy statistics and FAO statistics provided the amount of fuel used in this sector. All solid biomass fuels such as wood, charcoal, crop residues or animal dung are allocated to this sector.

Furthermore, based on expert judgment GHG emission from waste burned in households for cooking and heating was estimated."

2. Third National Communication of Bangladesh to UNFCCC (2018)

"Residential and Commercial: As can be seen from Figure 3.9, the commercial sector consumes mainly natural gas and diesel from the stand-by generators in the case of a power outage, while the residential sector consumes LPG, [Liquid Petroleum Gas] natural gas and kerosene. While natural gas and LPG are used mainly for cooking, kerosene is mainly used by rural households for lighting. It is worth pointing out that residential households, especially in the rural areas of Bangladesh, also use a significant quantity of biomass as cooking fuel. Since CO_2 emission of biomass is not counted, it is reported separately as a memo item.

Agriculture: The main fuel consuming activity is water pumping using diesel pumps for irrigation. The quantity of diesel consumed in the agriculture sector is a lumped figure reported by BPC [Bangladesh Petroleum Corporation] as per their supply to outlets and depots designated for agricultural diesel pumps. In the absence of data, it was assumed that 33% of the diesel consumed in the agriculture sector was used for irrigation, and the rest in operating other farm equipment such as power tillers, tractors and rice/wheat threshers and for running fishing boats."

3. Bhutan Third National Communication to UNFCCC (2021)

"2.12.7 Other sectors [1A4]

Energy use in this subcategory includes the consumption of biomass and fossil fuels (LPG and kerosene) in the residential and commercial/ institutional sectors. Hydropower generated electricity provides for most of the energy needs. Electricity generated from hydropower meets most of the energy demand in Bhutan, and biomass is used as source of energy for cooking and space heating, especially in rural areas. In contrast, LPG is used mainly for cooking and kerosene for space heating in urban areas. The emission is estimated based on the Energy Directory 2005 ratio of fuel usage and results in an emission of 37.68 Gg of CO_2 e in 2015."

4. India's 3rd Biennial Update Report to UNFCCC (2021)

"Other sectors (1.A.4)

This subcategory includes GHG emissions from fossil fuels burnt in commercial and institutional buildings, in homes and in activities related to agriculture, forestry, fisheries and the fishing industry. Cooking, lighting, space heating and cooling, refrigeration, and pumping characterize the residential, commercial, and agriculture sectors included in this category. In 2016, the other sectors together emitted 2,13,490 Gg of CO_2e, of which approximately 60 per cent was contributed by the residential sector, about 32 per cent by the commercial sector and rest 8 per cent by the biomass burnt for energy (non-CO_2 GHGs) and agriculture/fisheries sectors put together."

5. Maldives First Biennial Update Report (2019)

"3.7.2.1.3 Other sectors

Energy combustion in 'Other sectors' are from as those explained in 3.6.4.4. Largest emission (43%) is from fisheries mobile combustion. Second largest is the LPG usage by the residential use, which is 30% and tourism sector LPG usage contributes to 27% of the emissions."

6. Nepal's Second National Communication on Climate Change (2014)

"(B) GHG Emission from Energy Use in Residential Sector

Energy use in residential sector: The residential sector accounts almost 89% (about 301.1 million GJ) of the total energy consumption of Nepal in 2000/01. The consumption is primarily for cooking, lighting, heating and other household purposes. Usage of LPG as the primary source of cooking by households in urban Nepal exceeded consumption of the same by rural households. Biomass fuels such as fuel wood, crop residues, and animal dung continue to be the dominant fuels used by rural households.

GHG emission: In 2000/01, the residential sector emitted 4854.75Gg of CO2equivalent, of which 750.49 Gg was in the form of CO2 emission, mainly from fossil fuel use in the residential sector. The CH4 and N2O emission was 163.26 Gg and 2.18 Gg respectively. The CH4 emission is found to be driven by the biomass consumption in the residential sector. The residential sector emitted 55 Gg, 2719 Gg and 326 Gg of NO_X, CO and NMVOC respectively. The high amount of emission of the pollutants is attributed to the heavy biomass burning in this sector.

(C) GHG Emission from Energy Use in Commercial Sector

Energy use in commercial sector: The commercial sector accounts almost 1.2% (about 4.128 million GJ) of the total energy consumption of Nepal in 2000/01. In the commercial sector, key activities include lighting, cooking, space heating/cooling, pumping, running of equipments and appliances.

Sources of energy for the sector are grid-based electricity, LPG, kerosene, diesel, agricultural residue and fuel wood. The commercial and institutional sectors also seek extensive use of captive power generation across the country due to frequent power shortages in various seasons. These power generation units generally run on diesel. In the urban sector, the important sources of energy are kerosene and LPG.

GHG emission: In 2000/01, the commercial sector emitted 164.05 Gg of CO_2 equivalent, of which 150.66 Gg was emitted as CO_2, 0.49 Gg as CH4 and 0.01 Gg as N_2O. It also emitted 8 Gg of CO and 1 Gg of NMVOC.

(D) GHG Emission from Energy Use in Agriculture Sector

Energy use in agricultural sector: The energy for agricultural sector came from two types of sources – electricity and petroleum. In the year 2000/01, the agricultural sector consumed about 3.152 million GJ of energy. About 96% of the total energy used in agricultural sector came from petroleum products especially diesel fuel. Only 4% was derived from electricity.

GHG emission: In 2000/01, the agricultural sector emitted 224.2 Gg of CO_2 equivalent, of which 223.57 Gg was in the form of CO_2 emission, mainly from high-speed diesel use."

7. Pakistan's 2nd National Communication to UNFCCC (2019)

"2.3.7 Other Sectors- Residential, Commercial, & Agriculture (1A4)

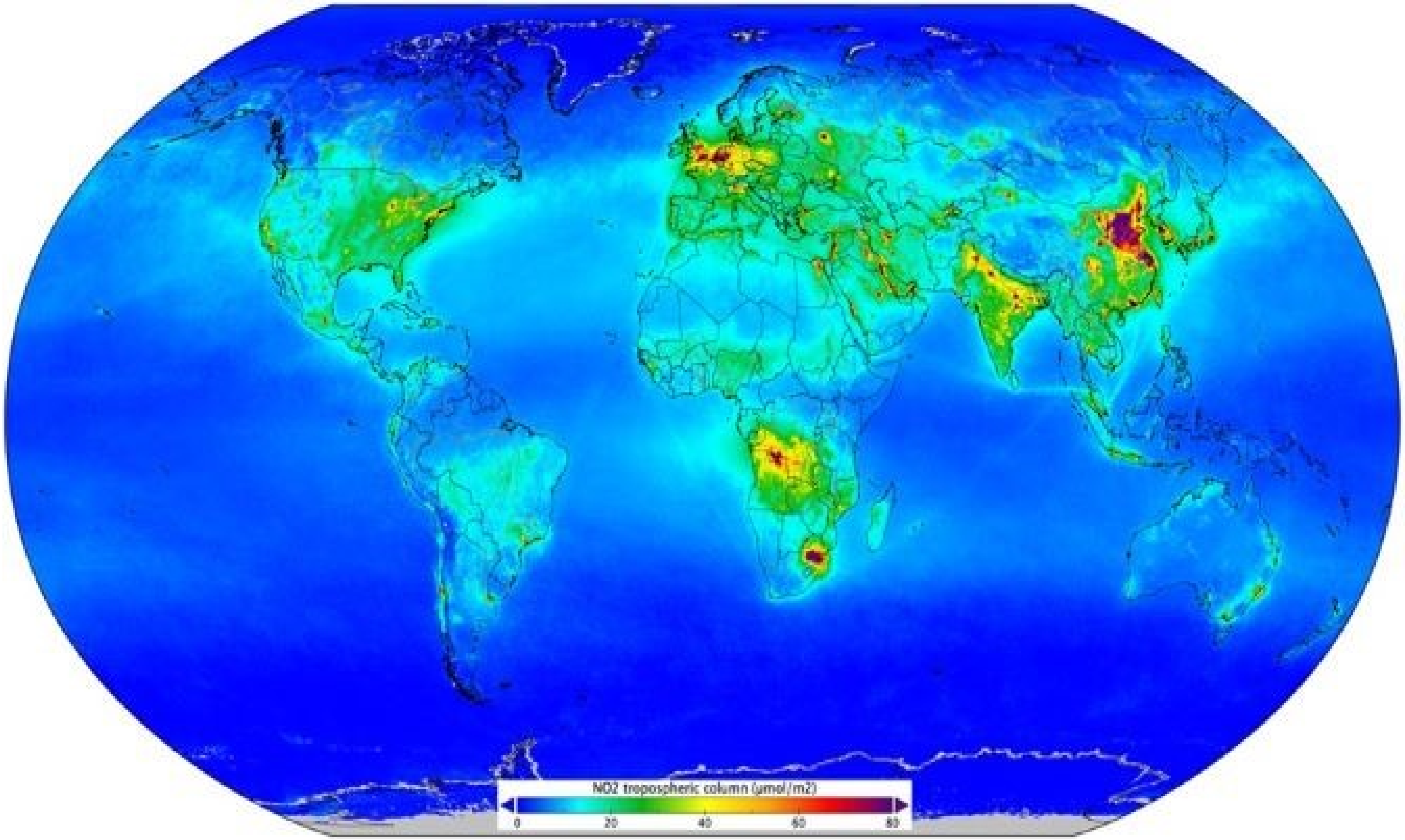
Cooking, lighting, space heating and cooling, refrigeration, and pumping activities are characterized in the residential, commercial, and agriculture sectors included in this category. The fuels consumed are electricity (for lighting, heating, cooling, and pumping), liquefied petroleum gas (LPG; for cooking), kerosene (for lighting and cooking), diesel (for generating power for pumping and lighting), and coal, charcoal, and fuel wood (for cooking). In the year 2015, these sectors together emitted 42.457 Mt of CO_2 – eq, which is 23% of the total CO_2 – e.g., from the energy sector. This excludes the GHG emissions due to grid use of electricity. Almost 60% of the total GHG emissions from the category 1A4 are from the residential sector (15.554 Mt CO_2 – eq). The residential sector has a rural and urban spread, where it combusts both fossil fuel as well as biomass. Biomass still comprises a substantial amount of fuel mix used in rural Pakistan. CH_4 from biomass combustion in the residential sector is reported in the energy sector; however, CO_2 from biomass is reported as a memo item and is not included in the national totals in accordance with the IPCC Guidelines. The commercial, residential, and agriculture sectors also witness extensive use of captive power generated from diesel use. This source is scattered, and a systematic collection could not be carried out. The fuel consumption in these private generator sets could be substantial. Lack of data for this consumption is a gap area that requires further research and capacity to improve the inventory estimates in Pakistan."

8. Sri Lanka's Second National Communication on Climate Change (2012)

2.2.5 Household and Commercial Sector

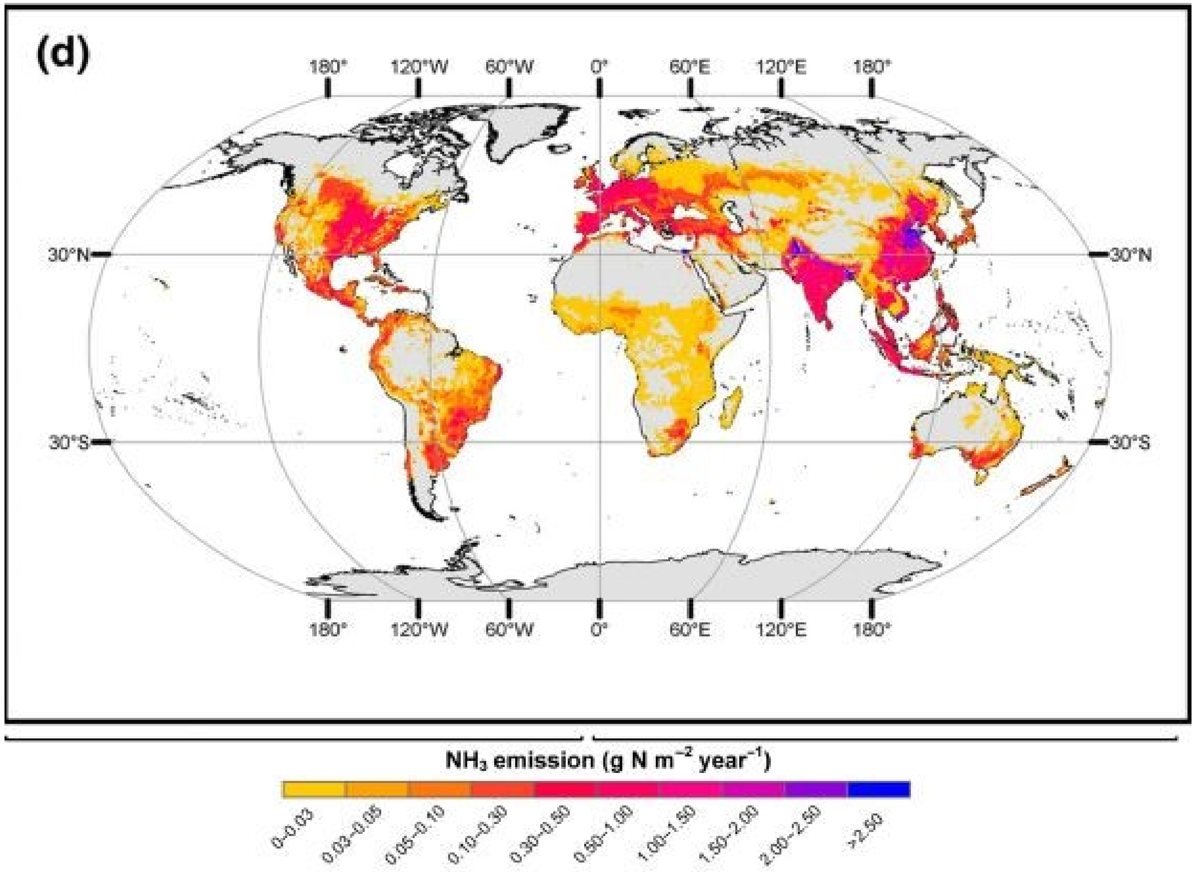
According to the 2001 National Census taken in 18 districts (excluding the conflict area), Sri Lanka had 4.05 million households, out of which 80% used firewood for cooking, 14.8% used LPG, and 3.1% used kerosene (C&SD, 2001). Further, nationally 63.6% of households used electricity for lighting, which varied from 85% in urban areas to 38% in estate areas. The rest of the households used kerosene for lighting. The Sri Lanka Energy Balance 2000 gives the LPG, kerosene and biomass consumption figures in the household and commercial sector in 2000 as 122.71 kt, 225.79 kt and 9,609 kt, respectively. However, in the Energy Balance (SLSEA, 2008) statement, the biomass consumption in household and commercial sector for 2000 has been revised to 8,350 kt. Table 2.11 gives the emissions from this sector based on these consumption figures calculated using Tier 1 emission factors.

Appendix Figure 1: Global map of nitrogen dioxide (NO_2) atmospheric pollution



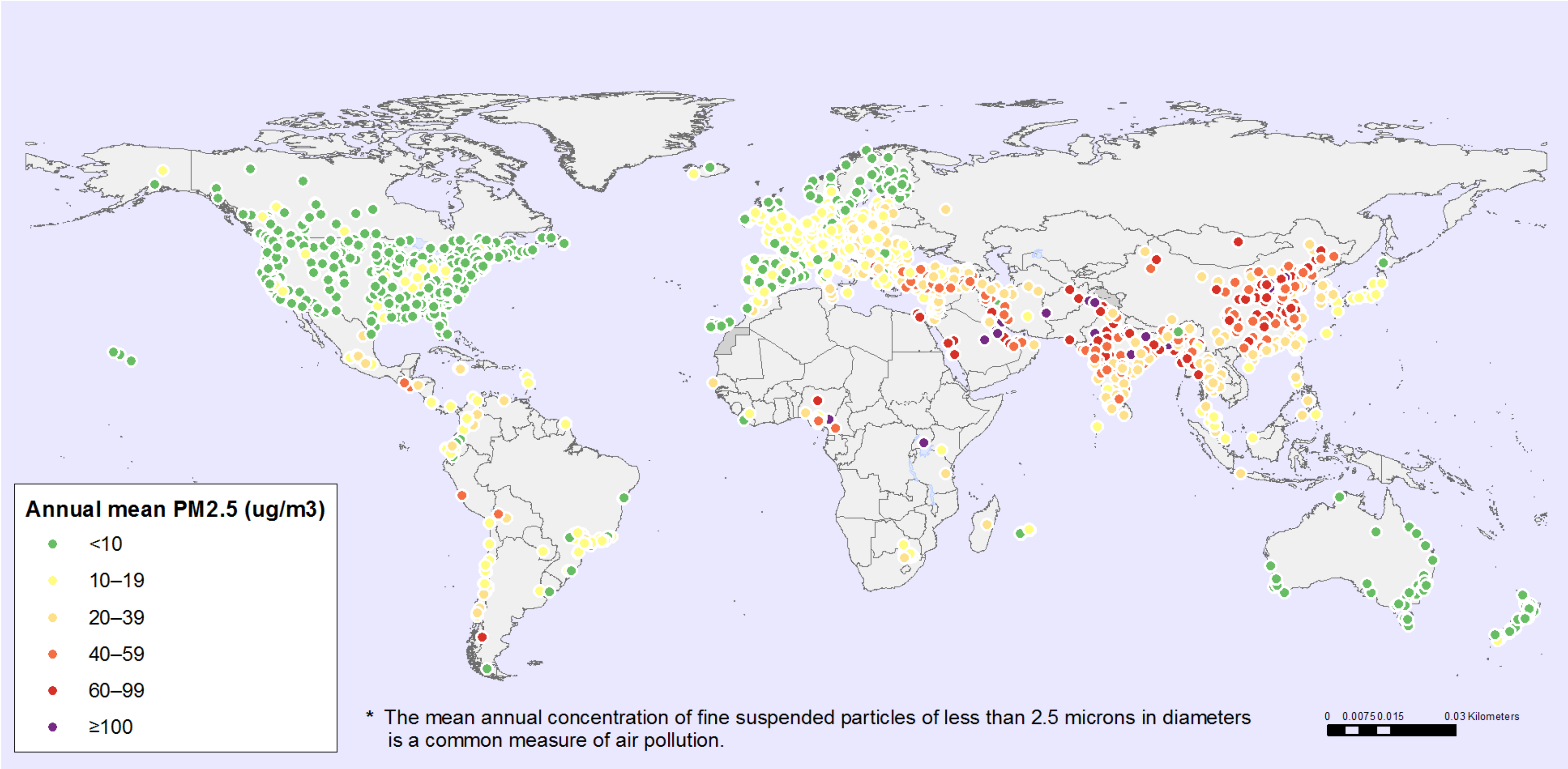
Source: European Space Agency (2019)
Note: Low levels of pollution are dark blue running to dark red for highest levels. Measurements gathered by the Copernicus Sentinel-5P mission between April and September 2018 have been averaged to reveal nitrogen dioxide in the atmosphere. The data were averaged and gridded on a regular latitude-longitude grid of about 2 x 2 km. Nitrogen dioxide pollutes the air mainly as a result of traffic and the combustion of fossil fuel in industrial processes. It has a significant impact on human health, contributing particularly to respiratory problems.

Appendix Figure 2: Global map of Ammonia (NH_3^-) emissions



Source: Xu et al. (2018)

Appendix Figure 3: Concentration of Particulate matter (PM) 2.5 in nearly 3000 urban areas, 2008-2015

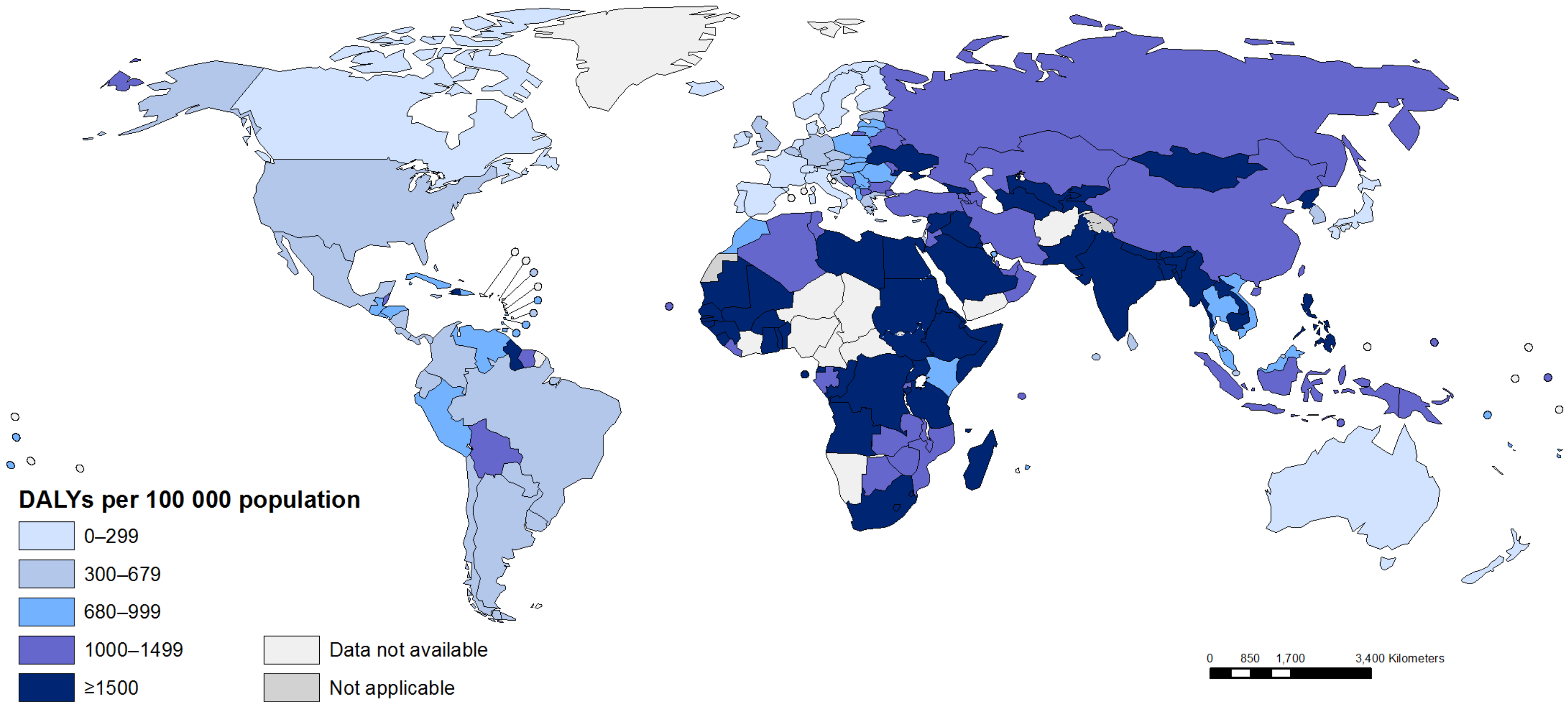


The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Information Evidence and Research (IER)
World Health Organization

World Health Organization

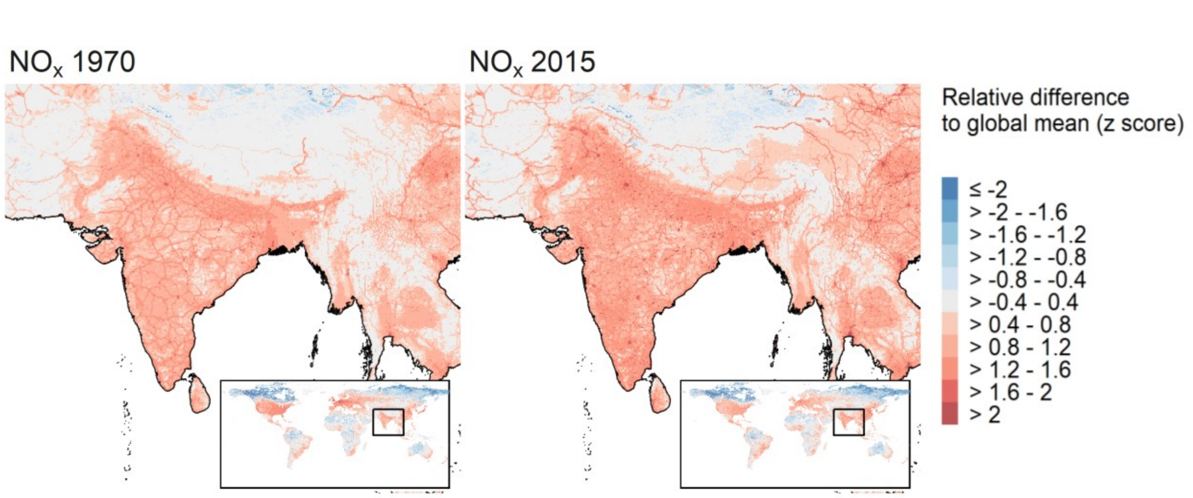
Appendix Figure 4: Disability-adjusted life years (DALYs) attributable to atmospheric pollution per 100,000 population, 2016



Source: World Health Organization (2018)

Note: DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with a health condition or its consequences

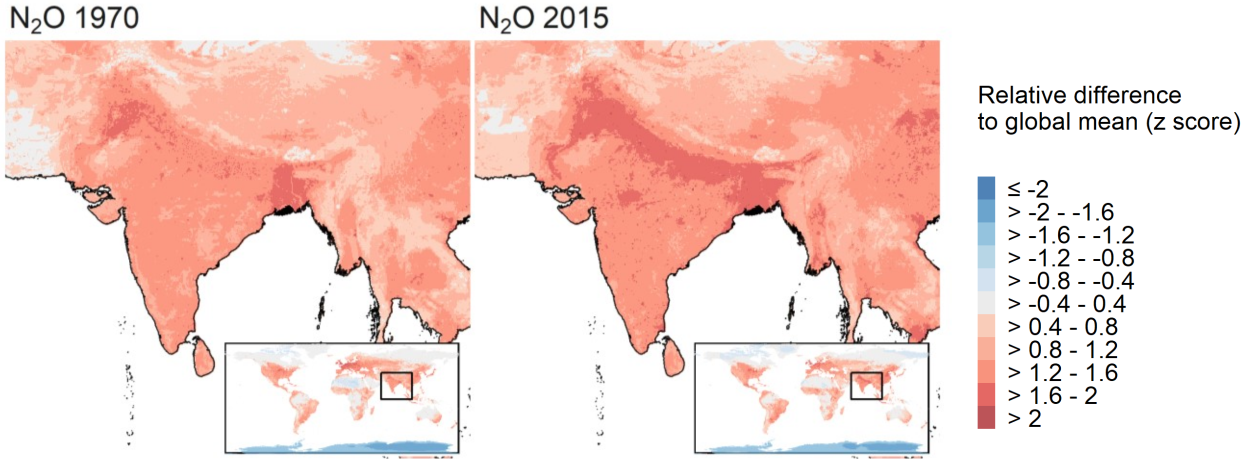
Appendix Figure 5: Terrestrial Nitrogen oxide (NO_x) emissions across South Asia relative to global means, z-scores 1970 and 2015



Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al (2019a)

Z-score is the number of standard deviations by which the value of a raw score is above or below the mean value of what is being observed or measured. Raw scores above the mean have positive standard scores, while those below the mean have negative standard scores.

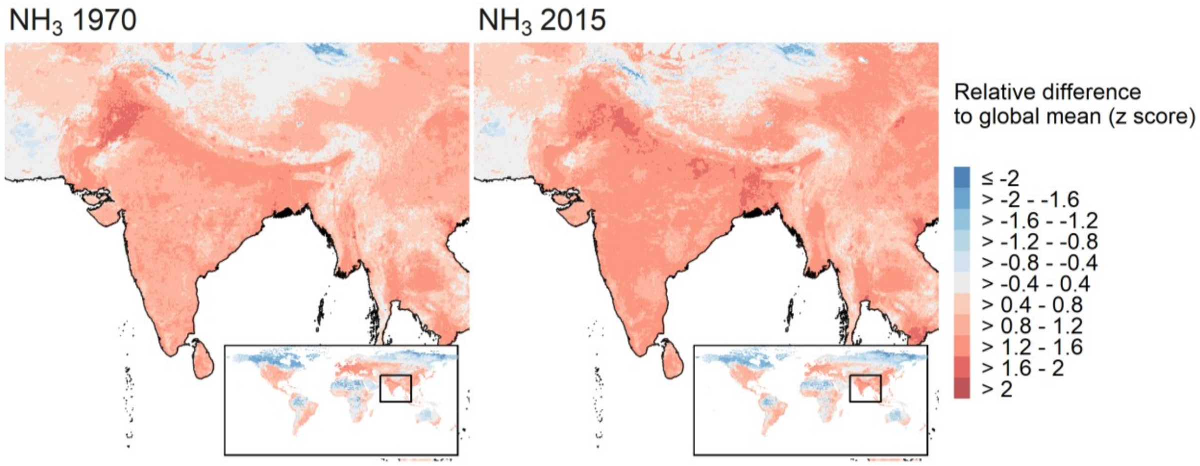
Appendix Figure 6: Terrestrial nitrous oxide (N_2O) emissions across South Asia relative to global means, z-scores 1970 and 2015



Note: EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa, et al (2019b)

Z-score is the number of standard deviations by which the value of a raw score is above or below the mean value of what is being observed or measured. Raw scores above the mean have positive standard scores, while those below the mean have negative standard scores.

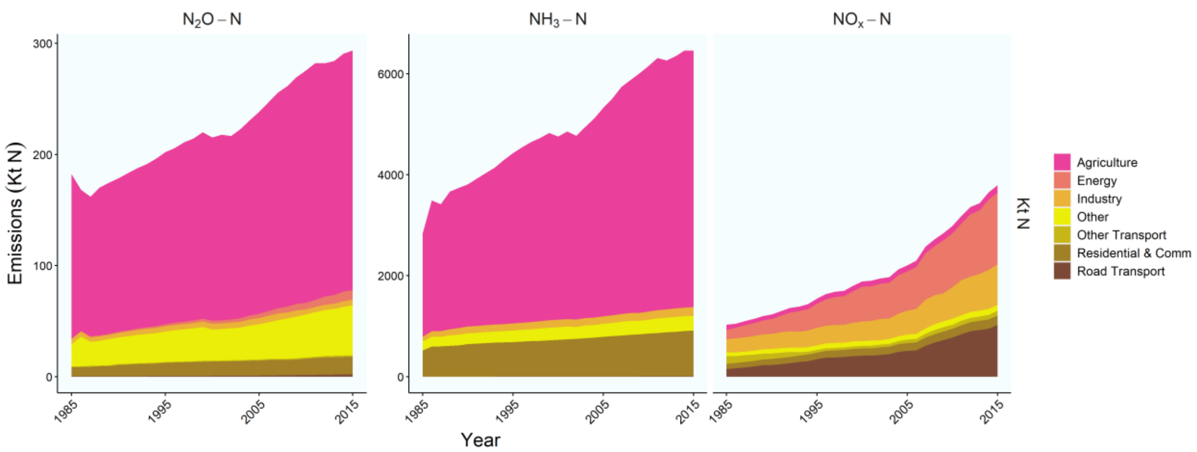
Appendix Figure 7: Terrestrial ammonia (NH_3) emissions across South Asia relative to global means, z-scores 1970 and 2015



Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al (2019a)

Z-score is the number of standard deviations by which the value of a raw score is above or below the mean value of what is being observed or measured. Raw scores above the mean have positive standard scores, while those below the mean have negative standard scores.

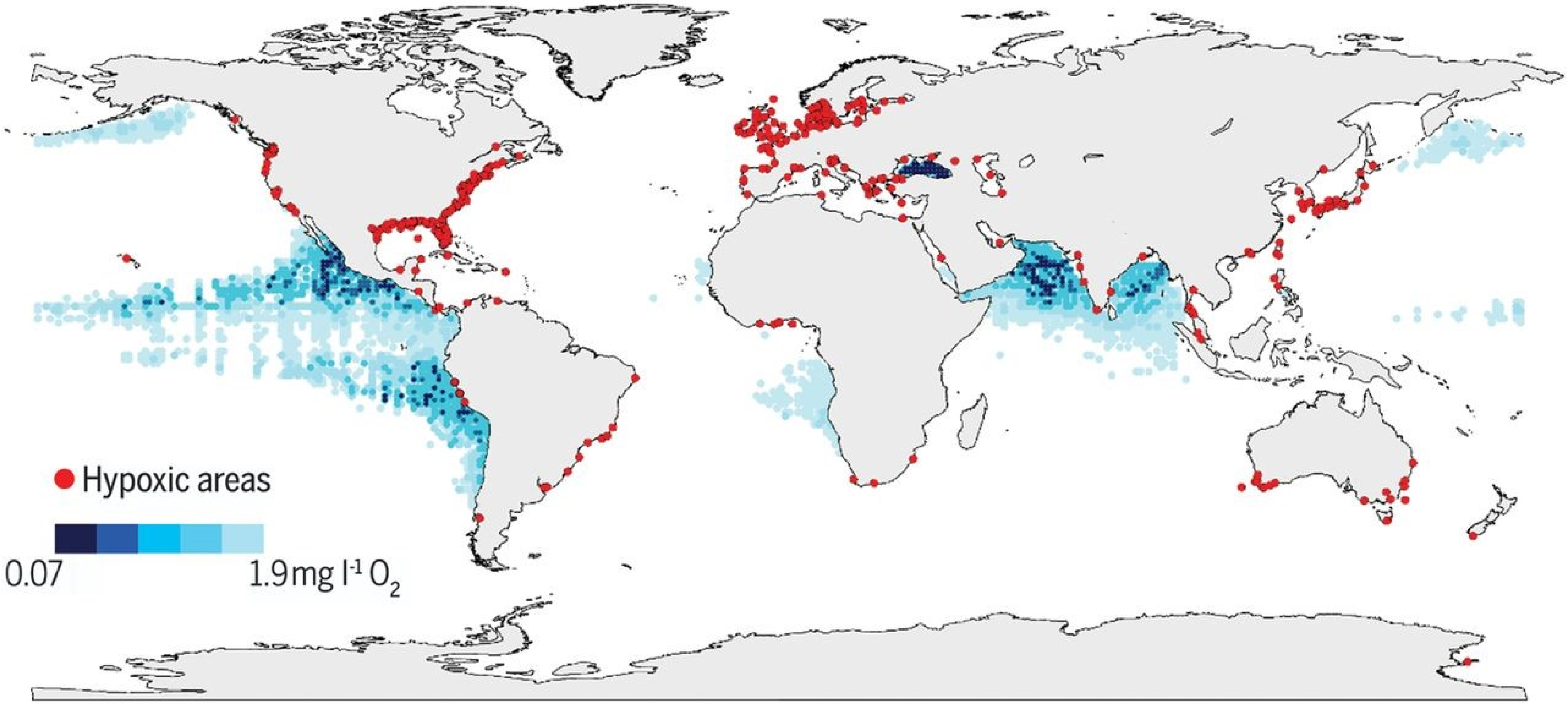
Appendix Figure 8: Nitrogen emission (NO_x, NH_3 and N_2O) trends from 1985 to 2015, showing the different sectoral sources for South Asia (regional total) in kt N



Source: Yang et al. (under review)

Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa et al. 2019a and EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa et al. 2019b.
The Y axes for NO_x and for NH_3 are common and is different for N_2O (as a Greenhouse Gas)

Appendix Figure 9: Low and declining oxygen levels in open ocean and coastal waters



Source: Breitburg et al. (2018)

Appendix Table 1: Nitrogen oxide (NO_x) emissions (Gg $year^{-1}$) in South Asia by sector for the year 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka	South Asia Total	South Asia (%)
Electricity and Heat Production	16.3	221.9	1.3	4096.7	3.79		263.5	46.4	**4650**	**37.29**
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		0.6		25.3			2.7	0.0	**29**	**0.23**
Manufacturing Industries and Construction	2.1	74.7	1.5	2267.1	0.18	28.2	217.2	26.6	**2618**	**20.99**
Civil Aviation	0.9		0.0	20.4	0.08		1.3	0.0	**23**	**0.18**
Road Transportation no resuspension	41.2	83.8	1.1	2649.5	4.47	23.8	468.7	88.8	**3361**	**26.96**
Railways		14.6		141.9			13.4	2.0	**172**	**1.38**
Water-borne Navigation	8.5	32.6	0.2	56.8	0.77			3.7	**103**	**0.82**
Other Transportation	2.2	NULL	0.1	2.1	0.20				**5**	**0.04**
Other Sectors	1.2	37.6	2.5	475.8	0.05	22.1	83.6	7.0	**630**	**5.05**
Non-Specified	0.4	NULL	0.0	47.1	0.01	NULL	0.1	0.4	**48**	**0.38**
Solid Fuels	0.0	0.0	0.0	1.0	0.00	0.0	0.1	0.0	**1**	**0.01**
Oil and Natural Gas		NULL		0.3					**0**	**0.00**
Chemical Industry	0.1	0.8		13.1			3.8	NULL	**18**	**0.14**
Metal Industry			0.0	2.8					**3**	**0.02**
Other				3.1			0.1	0.0	**3**	**0.03**
Manure Management	0.5	2.2	0.0	20.9		0.9	7.1	0.1	**32**	**0.25**
Emissions from biomass burning	3.1	16.6	0.1	261.1	0.00	4.6	29.5	0.2	**315**	**2.53**
Direct soil emissions from managed soils +manure in pasture	7	34	0	322	0.00	8	74	3	**448**	**3.59**
Other (fossil fuel fire 1995)				13					**13**	**0.10**
Incineration and Open Burning of Waste					0.03				**0**	**0.00**
Total emissions in Gg $year^{-1}$	**83**	**519**	**6.99**	**10420**	**10**	**87**	**1166**	**178**	**12469**	**100**
Population (millions) 2014	34.41	156.26	0.73	1310.15	0.45	27.02	199.43	20.91	1827.85	
Total NO_x emissions per million inhabitants	2.42	3.32	9.61	7.95	20.97	3.23	5.84	8.52	6.82	

Source: Crippa et al. 2019a; Population figures from World Bank

Appendix Table 2. Percent change in Nitrogen oxide (NO_x) emissions in South Asia from different sectors between 2000 and 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Electricity and Heat Production	1146	591	88	110	91	-100	42	3
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		-1		-18			13	-93
Manufacturing Industries and Construction	513	358	54	104	-11	75	96	77
Civil Aviation	452		-33	178	-29		12	-98
Road Transportation no resuspension	3089	242	326	167	385	165	66	78
Railways		168		88			-9	81
Water-borne Navigation	2813	172	253	43	274			265
Other Transportation	1799		130	-18	144		-100	
Other Sectors	81	46	26	31	97	33	41	-1
Non-Specified	91		-18	101	-12			-53
Solid Fuels	68	23	466	18	47	57	37	-37
Oil and Natural Gas	-100			1107			-100	
Chemical Industry	120	-50		6			65	
Metal Industry			700	271				
Other				161				
Manure Management	80	39	-11	17		40	86	18
Emissions from biomass burning	132	21	21	14	-47	14	24	23
Direct soil Emissions from (managed soils +manure in pasture)	41	37	-11	35		39	41	37
Other (fossil fuel fire 1995)				0				
Incineration and Open Burning of Waste					131			
Overall percentage change	**668**	**228**	**63**	**104**	**169**	**67**	**58**	**43**

Source: Crippa et al. 2019

Appendix Table 3: Nitrous oxide (N_2O) emissions (Gg $year^{-1}$) in South Asia from different sectors for the year 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka	South Asia Total	South Asia %
Electricity and Heat Production	0.020	0.096	0.001	26.025	0.002		0.429	0.096	**26.67**	**2.89**
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		0.001		0.073			0.007	0.000	**0.08**	**0.01**
Manufacturing Industries and Construction	0.007	0.149	0.018	12.833	0.000	0.083	1.221	0.322	**14.63**	**1.58**
Civil Aviation	0.007		0.000	0.168	0.001		0.010	0.000	**0.19**	**0.02**
Road Transportation	0.081	0.215	0.002	5.059	0.009	0.045	1.186	0.164	**6.76**	**0.73**
Railways		0.348		3.381			0.319	0.048	**4.10**	**0.44**
Water-borne Navigation	0.009	0.034	0.000	0.059	0.001			0.004	**0.11**	**0.01**
Other Transportation	0.002		0.000	0.002	0.000				**0.00**	**0.00**
Other Sectors	0.110	5.884	0.195	36.353	0.007	2.183	4.847	0.502	**50.08**	**5.42**
Non-Specified	0.001		0.000	0.395	0.000		0.000	0.003	**0.40**	**0.04**
Solid Fuels	0.012	0.016	0.003	0.415	0.000	0.001	0.039	0.004	**0.49**	**0.05**
Oil and Natural Gas	0.000	0.000	0.000	0.003	0.000		0.000		**0.00**	**0.00**
Chemical Industry				1.016			0.012		**1.03**	**0.11**
Other Product Manufacture and Use	0.010	0.049	0.000	0.394	0.000	0.009	0.057	0.006	**0.53**	**0.06**
Manure Management	0.063	0.545	0.004	8.101		0.383	2.625	0.042	**11.76**	**1.27**
Emissions from biomass burning	0.092	0.480	0.003	6.966	0.000	0.128	0.817	0.005	**8.49**	**0.92**
Direct N_2O Emissions from managed soils	10.440	46.347	0.250	407.194	0.001	11.341	102.367	2.947	**580.89**	**62.91**
Indirect N_2O Emissions from managed soils	1.854	6.358	0.048	56.476	0.000	2.079	12.503	0.302	**79.62**	**8.62**
Indirect N_2O Emissions from manure management	0.186	0.614	0.006	4.609		0.221	0.610	0.030	**6.28**	**0.68**
Wastewater Treatment and Discharge	0.540	2.978		43.774	0.016	0.951	8.764	0.639	**57.66**	**6.24**
Indirect N_2O emissions from atmospheric deposition of nitrogen in NO_x and NH_3	0.394	3.182	0.125	60.038	0.046	1.033	7.411	1.154	**73.38**	**7.95**
Other				0.225					**0.23**	**0.02**
Total	**14**	**67**	**0.66**	**674**	**0.083**	**18**	**143**	**6**	**923.37**	**100**
Population (millions) 2014	34.4	156.3	0.7	1310.2	0.5	27.0	199.4	20.9	1827.8	
Total N_2O emissions per million inhabitants	0.40	0.43	0.90	0.51	0.18	0.68	0.72	0.30	0.51	

Source: Crippa et al. 2019b. Population figures from World Bank

Appendix Table 4: Percent change in Nitrous oxide (N_2O) emissions in South Asia from different sectors between 2000 and 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Electricity and Heat Production	1188	348	113	212	101		15	294
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		-10		-25			20	-92
Manufacturing Industries and Construction	295	332	100	80	-17	64	77	44
Civil Aviation	452		-33	178	-29		12	
Road Transportation	2905	379	301	214	357	231	163	115
Railways		168		88			-8	
Water-borne Navigation	2591	172	226	43	245			265
Other Transportation	1804		131	25	144			
Other Sectors	228	33	26	23	462	24	13	-8
Non-Specified	156		-17	98	-14			-53
Solid Fuels	68	23	466	18	47	57	37	-37
Oil and Natural Gas	1179	209	55	12	64		88	
Chemical Industry				-81			-99	
Other Product Manufacture and Use	68	23	37	24	49	21	37	10
Manure Management	83	29	-21	6		33	74	1
Emissions from biomass burning	133	22	22	14	-46	13	26	64
Direct N_2O Emissions from managed soils	38	29	-12	28	-27	36	47	30
Indirect N_2O Emissions from managed soils	36	47	-13	21	-48	35	63	8
Indirect N_2O Emissions from manure management	37	31	-15	11		28	73	12
Wastewater Treatment and Discharge	66	38		46	57	67	54	23
Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3	655	134	41	83	166	43	50	30
Other								
Overall percentage change	**44**	**35**	**7**	**35**	**135**	**36**	**45**	**26**

Source: Crippa et al. 2019

Appendix Table 5: Application rate of nitrogen as fertilizer in various global regions during 2002 and 2017 in kg/ha.

Region	**2002 (kg/ha)**	**2017 (kg/ha)**	**Growth (%)**
Southern Asia	62.9	94.3	50
Africa	11.9	15.1	27
Northern America	58.2	71.0	22
OECD	65.8	75.6	15
Eastern Asia	194.9	213.7	10
European Union	86.9	94.0	8
World	*56.2*	*69.8*	*24*

Source: FAO 2020

Appendix Table 6: Ammonia (NH_3) emissions (Gg $year^{-1}$) in South Asia from different sectors for 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka	South Asia total	South Asia (%)
Electricity and Heat Production	0.148	0.239	0.004	12.561	0.013		1.439	0.106	**14.51**	**0**
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		0.004		0.067			0.033	0.000	**0.10**	**0**
Manufacturing Industries and Construction	0.101	0.065	0.358	144.613	0.003	0.481	16.822	7.442	**169.89**	**2**
Civil Aviation	0.013		0.000	0.310	0.001		0.019	0.000	**0.34**	**0**
Road Transportation no resuspension	0.036	0.919	0.001	6.365	0.007	0.040	2.459	0.099	**9.93**	**0**
Railways		0.002		0.019			0.002	0.000	**0.02**	**0**
Water-borne Navigation	0.001	0.003	0.000	0.005	0.000			0.000	**0.01**	**0**
Other Transportation	0.000		0.000	0.015	0.000				**0.02**	**0**
Other Sectors	1.579	67.465	6.352	800.424	0.019	52.649	155.790	16.356	**1100.64**	**14**
Non-Specified	0.004		0.006	0.194	0.000		0.002	0.007	**0.21**	**0**
Solid Fuels	1.598	2.403	0.426	62.036	0.011	0.204	5.930	0.596	**73.20**	**1**
Other Process Uses of Carbonates				2.160			0.360		**2.52**	**0**
Chemical Industry	0.058	2.436		25.535			6.365		**34.39**	**0**
Non-Energy Products from Fuels and Solvent Use		0.003		0.026			0.004	0.000	**0.03**	**0**
Manure Management	6.867	56.632	0.319	357.659		16.757	134.304	3.112	**575.65**	**7**
Emissions from biomass burning	3.104	16.265	0.084	217.522	0.001	4.046	25.905	0.136	**267.06**	**3**
Urea application	3.159	54.340		684.871		4.617	101.914	10.833	**859.73**	**11**
Direct soil emissions from managed soils	61.751	300.616	1.374	3472.974	0.000	70.960	779.288	36.593	**4723.56**	**60**
Incineration and Open Burning of Waste	0.067	0.019	0.003	1.873	0.005	0.050	0.269	0.010	**2.30**	**0**
Wastewater Treatment and Discharge	0.163	0.801	0.004	6.140	0.002	0.129	0.849	0.104	**8.19**	**0**
Total	**79**	**502**	**8.93**	**5795**	**0.064**	**150**	**1232**	**75.40**	**7842.31**	**100**
Population (millions) 2014	34.4	156.3	0.7	1310.2	0.5	27.0	199.4	20.9	**1827.8**	
Total NH_3 emissions per million inhabitants	2.29	3.21	12.27	4.42	0.14	5.55	6.18	3.61	**4.29**	

Source: Crippa et al. 2019a. Population totals from World Bank.

Appendix Table 7: Percent change in Ammonia (NH_3) emissions in South Asia from different sectors, 2000 to 2015

Main Activity	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Electricity and Heat Production	1452	299	88	508	100		46	-31
Petroleum Refining – Manufacture of Solid Fuels and Other Energy Industries		4		24			42	-99
Manufacturing Industries and Construction	206	3	139	24	-3	36	41	41
Civil Aviation	452		-33	178	-29		12	-98
Road Transportation no resuspension	2473	5107	186	690	634	690	1236	292
Railways		168		88			-9	81
Water-borne Navigation	2445	172	208	43	227			265
Other Transportation	1854		137	2342	151			
Other Sectors	16	23	25	23	19	30	34	-6
Non-Specified	-18		-16	88	-20			-53
Solid Fuels	69	23	362	19	48	57	37	-34
Other Process Uses of Carbonates				60			74	
Chemical Industry	-5	-47		-26			-5	
Non-Energy Products from Fuels and Solvent Use				146				-86
Manure Management	79	55	-4	21			104	29
Emissions from biomass burning	134	23	22	14	-44	12	26	118
Urea application	1200	15		60			13	60
Direct soil emissions from managed soils	48	33	-17	38	-49	44	42	40
Incineration and Open Burning of Waste	72	9	36	8	115	30	45	2
Wastewater Treatment and Discharge	69	27	39	27	49	19	36	10
Overall percentage change	**58**	**30**	**21**	**35**	**50**	**40**	**42**	**27**

Source: Crippa et al. 2019a