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Policies to combat nitrogen pollution in South Asia: gaps and opportunities

Anastasia L Yang[1,*], Nandula Raghuram[2,10], Tapan Kumar Adhya[3], Stephen D Porter[1], Ananta Narayan Panda[3], Himadri Kaushik[3], Anuradha Jayaweera[6], Sarath Premalal Nissanka[6], Asif Reza Anik[4], Sharmin Shifa[4], Shaima Chowdhury Sharna[4], Rajendra Joshi[5], Muhammad Arif Watto[7], Anju Pokharel[8], Aminath Shazly[9], Rifaath Hassan[9], Sangeeta Bansal[10], David Kanter[11], Smriti Das[12] and Roger Jeffery[1]

[1] School of Social and Political Science, University of Edinburgh, 15a George Square, Edinburgh EH8 9LD, United Kingdom
[2] School of Biotechnology, Guru Gobind Singh Indraprastha University, Sector 16C, Dwarka, New Delhi 110078, India
[3] School of Biotechnology, Kalinga Institute of Industrial Technology (KIIT), Campus XI, Patia, Bhubaneswar 751024 Odisha, Inida
[4] Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur 1706, Bangladesh
[5] Department of Chemical Science and Engineering, Kathmandu University, Dhulikhel, Nepal
[6] Faculty of Agriculture, University of Peradeniya, Peradeniya, 20400, Sri Lanka
[7] University of Agriculture Faisalabad, University Rd, Police Lines, Faisalabad, Punjab 38000, Pakistan
[8] YAE Youth Alliance for Environment, Balwatar, Kathmandu, Shakuna Marg Gairidhara, Kathmandu 44600, Nepal
[9] The Maldives National University, Rahdhebai Hingun, Malé, Maldives
[10] Sustainable India Trust, F4, A Block, NASC Complex, National Rainfed Area Authority building, PUSA, Dev Prakash Shastri Marg, New Delhi 110012, India
[11] College of Arts and Science, New York University, 285 Mercer Street, 8th floor, New York, NY 10003, United States of America
[12] TERI School of Advanced Studies, Plot No. 10 Institutional Area, Vasant Kunj, New Delhi 110070, India
[*] Author to whom any correspondence should be addressed.

E-mail: anastasia.yang@ed.ac.uk

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Abstract

Assessing and managing nitrogen sustainably is imperative for achieving the 17 UN Sustainable Development Goals (SDGs) targeted for 2030. South Asian countries, aware of the environmental and health impacts of nitrogen pollution, regionally as well as globally, piloted the 2019 UN resolution on sustainable nitrogen management, calling for urgent policy action. This paper assists South Asia policy development by providing new insights into nitrogen-related policies in the region; it makes a step-change advance on an existing global analysis and database. We built on available methods to better identify, classify and analyse 966 nitrogen-related policies for the region. We compared the global and regional nitrogen policy landscapes to explain the benefits of a deeper policy assessment. The policies we classified as having 'higher' relevance—those with direct reference to nitrogen and/or its potential impacts—represent the current nitrogen policy landscape for South Asia. We show that a small proportion of policies (9%) consider multiple pollution sources, sectors, nitrogen threats and impacts, with integrative policy instruments. A 5% of policies also consider both non-point and point sources of pollution, representing standout policies. More such policies with an integrated approach are vital in addressing the complexities of nitrogen pollution. Adapting existing and drafting new policies are both required to deal with other current and emerging nitrogen issues. Our analysis provides evidence for a roadmap for sustainable nitrogen policy in South Asia and beyond and supports efforts to reduce the threats posed by nitrogen pollution to achieve the SDGs.

1. Introduction

Although the environmental threats from excessive carbon dioxide emissions are widely understood, threats from nitrogen emissions are not. Because of human activities, nitrogen has exceeded planetary boundaries, affecting ecosystem functioning (Steffen *et al* 2015, Sutton *et al* 2019a). Since air and water

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pollution cross national boundaries, regional and international collaborations are essential for effective control of nitrogen pollution (UNEP 2019b, 2019c, Kanter *et al* 2020a). The UN resolution on sustainable nitrogen management (UNEP 2019b) marked a major milestone in intergovernmental recognition of the importance of minimising harmful reactive nitrogen (N_r) for sustainable development. Countries in South Asia (SA) have played an important role in this process. India eventually led the resolution, reflecting the growing realisation that SA was among the global hotspots for N_r pollution (Abrol *et al* 2017, Raghuram *et al* 2021). The rising global scientific and policy awareness on N_r had already led to the creation of the International Nitrogen Initiative (INI) (Galloway *et al* 2003). In 2021 the INI held its 8th conference, highlighting the imperative for addressing nitrogen for achieving the 17 UN Sustainable Development Goals (SDGs) targeted for 2030 (INI 2021) (table 1)[13].

The policy agenda to implement the UN resolution, calling for a roadmap for action, is still under development. An important step is 'to establish a baseline understanding of the national and regional N_r policies currently in force around the world' (Kanter *et al* 2020a). Policies to improve N_r balance include but are not restricted to legislation, regulations, standards, taxes and subsidies. Such policies cover a range of sectors and environmental areas that are under threat from N_r.

The accumulation of N_r compounds adversely affects the environment by contributing to poor quality of air, soil, freshwater and marine environments, climate change, eutrophication and biodiversity loss (Galloway *et al* 2003, 2008, Sutton *et al* 2011a, Erisman *et al* 2013, Abrol *et al* 2017). The nitrogen compounds of most environmental concern are nitrogen oxides (NO_x), ammonia (NH_3), ammonium (NH_4^+) and nitrous oxide (N_2O) in air, and nitrates (NO_3^-) in water (Sutton *et al* 2019a).

A global study (Kanter *et al* 2020a) compiled and classified 2726 national and regional N_r policies (hereafter the 'global database'), including those of SA. It noted that global N_r policies lacked coherence and integration regarding environmental sinks and warned of negative consequences for N_r pollution due to the risk of pollution swapping. Policy integration is desirable because nitrogen is part of complex systems, where anthropogenic alteration of the nitrogen cycle results in diverse impacts. However, separate government ministries typically oversee separate sectors, leading to uncoordinated or fragmented policy responses. In environmental policy analysis, measuring policy integration is important to assess to what extent policies have considered the dynamics and interactions within a system to avoid exacerbating environmental problems (Mickwitz 2003, Mickwitz and Kivimaa 2007, Mcginnis and Ostrom 2014, Gain *et al* 2020). Effective control of N_r needs policy integration and inter-ministerial co-ordination. A multi-level approach, striking a balance between different contexts can help to avoid policy gaps and enhance policy effectiveness (Corfee-morlot *et al* 2009, Gunningham and Sinclair 2017).

Here we present the results of a rigorous process of assembling and analysing policies related to N_r across SA, going beyond the global study by collecting a broader range of policies and innovating analytical approach. Firstly, we provide an overview of N_r pollution in SA as part of the global problem. We then explain our research design and summarise the number and kinds of nitrogen-related policies in the region, comparing our results to those of the global study. In the discussion we show in more detail the gaps in, and opportunities for, N_r policies in SA, concluding with recommendations. Three case studies (additional information available online at stacks.iop.org/ERL/17/025007/mmedia) provide further insights[14].

2. Global and regional overview of N_r pollution trends

South Asia—Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka—has less than 5% of the world's land mass and 14% of global arable land, but supports c.2 billion people, over 25% of the world's population (UN 2020).

The region contains many N_r hotspots showing high absolute quantities and growth rates relative to global means (figure 1). N_r emissions as NH_3 and N_2O have roughly doubled since the 1980s. For NH_3 and N_2O the agriculture sector (including animal husbandry) is the main emission source; nitrogenous fertiliser applications contribute over 50% to NH_3 emission for all countries, except Maldives.

Emissions have tripled since the 1980s in the case of NO_x, for which per capita emissions have also increased (figure 2). Major contributors to NO_x emissions are fossil-fuel burning sectors such as road transport, industry, and energy, as well as waste burning and residential use of low-grade fuels. SA is also a hotspot for particulate matter pollution ($PM_{2.5}$), which includes N_r components in the form of ammonium (NH_4^+) and nitrate (NO_3^-) (Kumar *et al* 2018, Aslam *et al* 2020). $PM_{2.5}$ poses a severe regional health risk, with air pollution being a major cause of death (WHO 2016, Krishna *et al* 2017).

Nitrogen losses follow different trajectories over time in different sectors. Policy interventions should therefore address not only the predominant sector for

[13] Section A in additional information illustrates the selected SDGs and their pertinence for South Asia and nitrogen management.

[14] D1: Policies for combating air pollution in Delhi, India; D2: Policies impacting fertilizer use in India; D3: Environmental legislations in Sri Lanka.

Table 1. UN SDGs linked with nitrogen management and key economic sectors and environmental sinks/impacts, Source: partly adapted from INMS (2021).

SDG		Link of SDG with N management	Economic sector	Environmental sink/impacts
(1) No poverty		Supporting livelihoods by reducing nitrogen resource loss	Cross-cutting	
(2) Zero hunger		Nitrogen fertiliser efficiency and biological nitrogen fixation to sustain food demand	Food, agriculture	Soil, water, climate change
(3) Good health & well-being		Improved health through better nitrogen air and water quality	Waste, food	All
(4) Quality education		Education and training in sustainable nitrogen management	Cross-cutting	
(5) Gender equality		Valuing nutrients in manure helps to address gender inequalities	Cross-cutting	
(6) Clean water & sanitation		Decreased nitrate (NO_3-) contamination of drinking water and rivers	Waste	Water
(7) Affordable & clean energy		Bioenergy and biogas with reduced nitrogen footprint	Energy	Air, climate change
(8) Decent work and economic growth		Nitro-finance to mobilize growth in the circular	Cross-cutting	
(9) Industry, innovation & infrastructure		Nitro-innovation for resource recovery in air and water	Industry, waste, transport	Water, air, climate change
(10) Reducing inequality		Widening access to cost-effective nitrogen resources	Cross-cutting	
(11) Sustainable cities & communities		Decreased nitrogen oxides (NO_x) & $PM_{2.5}$ improves urban air quality	Urban development. & tourism, waste, land use change	Water, air
(12) Responsible consumption & production		Nitrogen & health food: demitarian, vegetarian & vegan lifestyles	Food, waste, urban development & tourism	All
(13) Climate action		Less nitrous oxide (N_2O) as a long-lived greenhouse gas	All	Climate, air
(14) Life below water		Less nitrogen water pollution helps protect reefs and avoid coastal dead zones.	Agriculture, transport, waste	Water, ecosystem
(15) Life on land		Decreased ammonia (NH_3) & NO_x emissions help protect terrestrial biodiversity.	Land use change, agriculture	Water, ecosystem, soil

(Continued.)

Table 1. (Continued.)

SDG		Link of SDG with N management	Economic sector	Environmental sink/impacts
(16) Peace, justice, & strong institutions		Nitrogen cooperation as a contribution to environmental diplomacy	Cross-cutting	
(17) Partnerships for the goals		Strengthened partnerships through the nitrogen coordination mechanism	Cross-cutting	

Note: section C additional information (table A1) describes the relevance of these SDGs for SA and nitrogen management.

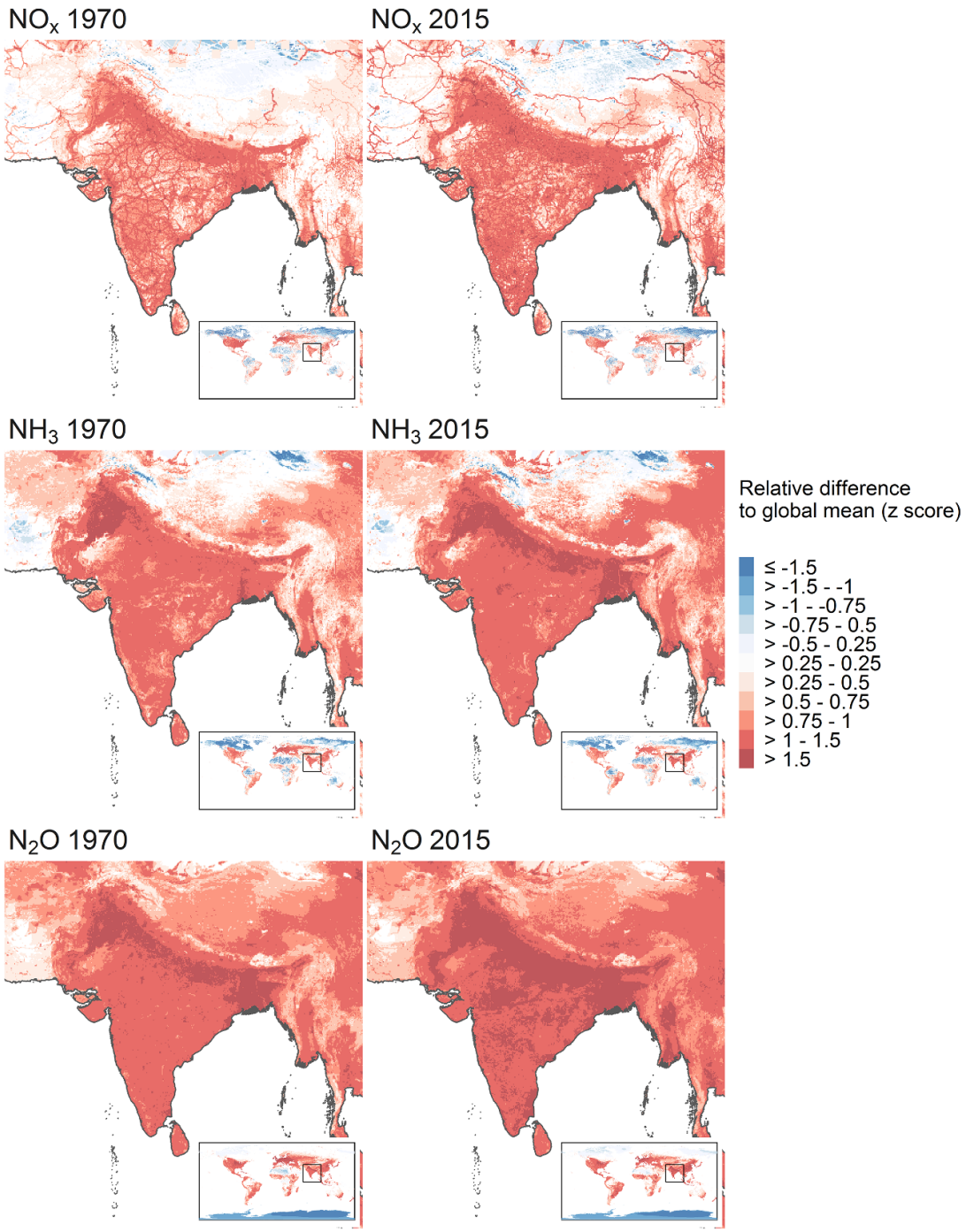

Figure 1. Relative differences from global means (Z-scores) for SA emissions of nitrogen oxides (NO_x), ammonia (NH_3) and nitrous oxide (N_2O) for 1970 and 2015.
Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa *et al* (2019a) and EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa *et al* (2019b). These maps have been calculated using Z-scores (standard deviations away from the global mean) for emissions over terrestrial cells only.

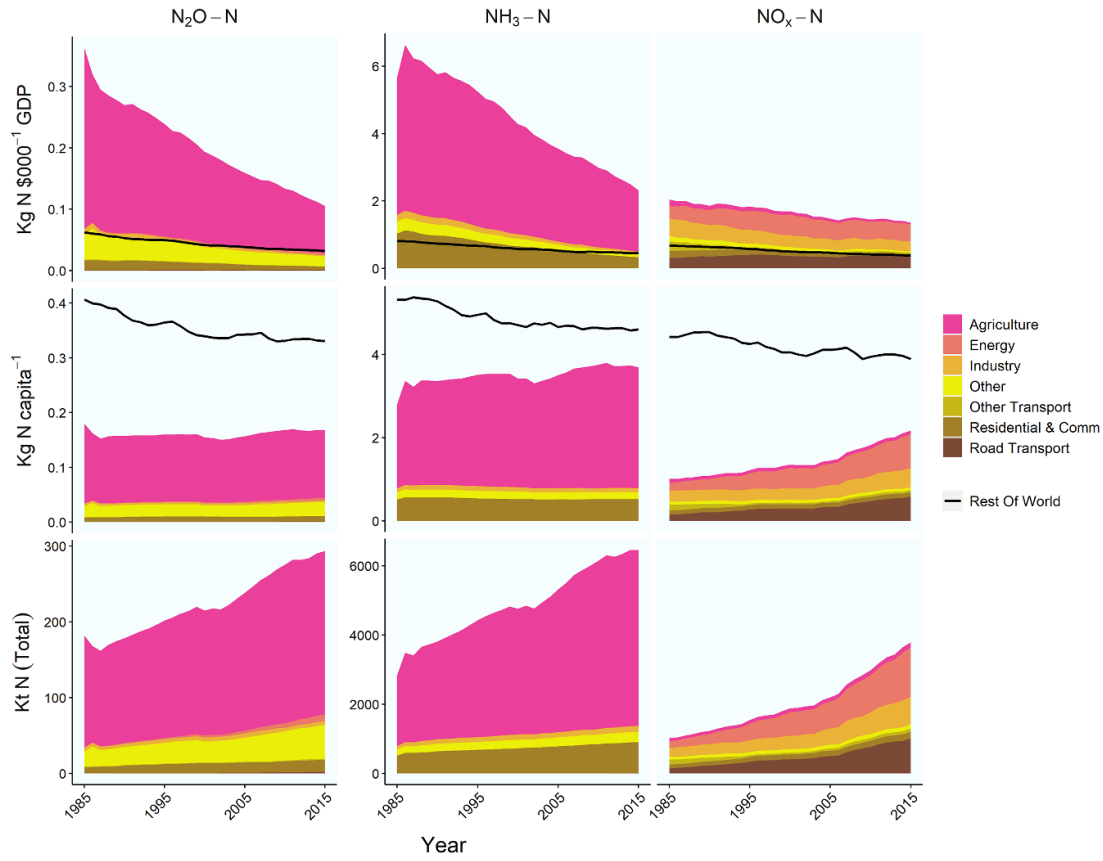

Figure 2. Nitrogen oxides (NO_x), ammonia (NH_3) and nitrous oxide (N_2O) emission trends from 1985 to 2015, by sector for SA standardised by gross domestic product (GDP) in constant prices, by population, and as regional totals in Kt N.
Note: EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa *et al* (2019a) and EDGAR v5.0 Greenhouse Gas Emissions data sourced from Crippa *et al* (2019b). *Y*-axes for NO_x and for NH_3 are common; and the axis for N_2O is different. The emission source sectors are defined by EDGAR which uses the IPCC category classification (additional information: table C8) and utilizes emission factors from IPCC methodologies. The regional emissions are shown to increase over time for all the nitrogen compounds for the total estimated nitrogen loads (Kt N). GDP and per capita figures were introduced to illustrate alterative options for standardising emission numbers. In contrast to the overall totals in Kt N, the nitrogen emissions for constant price GDP appear to decrease over time, reflecting steep increases in GDP for the region. It may also indicate that emissions are not always close-coupled to the economy alone. For per capita emissions, the trends are somewhat more stable for N_2O and NH_3; this may be a result of decreasing regional population growth rates since the 1980's while total emissions have increased. The GDP and per capita emission trends correspond with the 'rest of the world' trends, as indicated by the black line. However, in contrast to the rest of the world trends, NO_x emissions per capita in SA are increasing.

each nitrogen compound emitted currently, but also sectors expected to grow fastest in the absence of mitigating or controlling actions. For example, during 2000–2015, while N_2O emission grew in SA by 35%, NO_x emissions nearly doubled (Crippa *et al* 2019b). Similarly, while chemical fertilizers have always been the single largest source of N_2O in SA, the growth rate of N_2O pollution from agriculture has been low, whereas domestic wastewater, navigation and aviation growth was several-fold faster (Bhattacharya *et al* 2017).

In SA, opportunities for collective responses to these emissions are enhanced by the existence of regional intergovernmental mechanisms, such as the South Asia Co-operative Environment Programme (SACEP) and the South Asian Seas Programme. SA countries are aligned with the major international initiatives on nutrient pollution such as the Colombo Declaration (UNEP 2019a), and most recently the Berlin Declaration (INI 2021). A common regional framework is possible for a coordinated approach to support the global implementation of the UN resolution on sustainable nitrogen management and progress towards the SDGs. Yet to understand policy needs we first have to assess the current policy landscape.

3. Methods

National policy regimes within each SA country form the core focus of our three-stage approach[15]:

For the first stage we used the global ECOLEX policy database to classify and analyse policies consistent with the approach of the initial global study (Kanter *et al* 2020a) to provide an updated regional picture of the nitrogen policy landscape for SA for end-2019. Five additional policies were found and

[15] Details in section B additional information.

Table 2. Number of nitrogen-related policy interventions in SA. The values in parentheses are a percent of SA total (966 policies).

	Total no. of policies		SANH database 2019 Sources		
Country	ECOLEX database 2019	SANH database 2019	Policies sourced from FAOLEX	Policies sourced from national websites	SANH subset policies: high-medium relevance & large-medium scope
Afghanistan	2 (3%)	89 (9%)	79 (8%)	10 (1%)	58 (6%)
Bangladesh	7 (11%)	187 (19%)	67 (7%)	120 (12%)	119 (12%)
Bhutan	4 (7%)	60 (6%)	31 (3%)	29 (3%)	38 (4%)
India	17 (28%)	192 (20%)	69 (7%)	123 (13%)	136 (14%)
Maldives	3 (5%)	40 (4%)	20 (2%)	20 (2%)	29 (3%)
Nepal	5 (8%)	108 (11%)	63 (7%)	45 (5%)	65 (7%)
Pakistan	11 (18%)	175 (18%)	136 (14%)	39 (4%)	98 (10%)
Sri Lanka	12 (20%)	115 (12%)	61 (6%)	54 (6%)	106 (11%)
South Asia	61	**966**	**526**	**440**	**649**
Percentages	100%	100%	55%	46%	67%

Note: Policies were sourced from FAOLEX (www.fao.org/faolex/en/) and other web sources. The global study sourced SA policies from ECOLEX (www.ecolex.org/) (Kanter *et al* 2020a). More details can be found in the SANH policy database (Data Availability).

classified, producing 61 policies for SA. A limitation of the global database was revealed at this point. Using a single database source and strict filtering process identified a limited number of nitrogen-relevant policies for SA.

In the second stage, we built on the 61 policies to create a comprehensive, more inclusive nitrogen-related policy database for SA. We collected policies, valid on 31 December 2019, considered directly and indirectly relevant to nitrogen management. By doing so we collected an additional 905 SA policies (table 2), allowing us to assess whether previous conclusions in the global study on N_r policies hold true for SA.

We conducted our search by first clarifying the definition of policy to include the following kinds of documents: legislation, acts, laws, ordinances, plans, strategies, regulations, statutes, standards, rules, orders, codes, frameworks, and guidelines. We then explored other available policy sources including FAOLEX, an international environmental policy database, and other web sources such as national government ministry and law websites. We found advantages and disadvantages between the policy sources for this study (table 3), which justified using a combination of sources. Overall, 55% of the collected policies came from the FAOLEX database and 45% came from other national sources.

During and after collecting policies we filtered to ensure their relevance to N_r. The global study applied a strict filtering approach. To keep policies directly relevant to nitrogen management the policy text had to contain one or more of 29 keywords[16]. They further reviewed those policies to filter again for direct relevance. Having such a focused approach is justifiable when the scope is global. However, for a regional study we could broaden the search criteria, and use multiple policy sources. As a result, a larger number of policies was identified, even when filtered for 29 key words. In Afghanistan, for example, the global study identified seven policies with direct relevance to nitrogen, whereas our search generated another 43 policies, including the 'Afghanistan Regulation of Importing Chemical Fertilizer 2007'.

To ensure that we included policies with indirect influence on N_r management we adapted the global study's filtering criteria. We developed an additional 50 keywords or terms[17]. Expanding the number of keywords is time-consuming as it increases the search possibilities and could leave room for interpretation. To safeguard against this and ensure our approach was standardised, search and classification protocols were established and followed (further described in step 3). The main advantage of this approach however was that it enabled us to capture N_r relevant policies that could have otherwise been overlooked. For example, food security policies, which may not refer to directly to nitrogenous fertiliser use, could still influence N_r management by promoting agricultural production and encouraging more chemical inputs (Fouilleux *et al* 2017). Likewise, we captured policies that contained synonyms of the original keywords, such as 'global warming' as a synonym of 'climate change'. Overall, we identified an additional 460 SA policies considered indirectly N_r relevant, including the Sri Lankan 'Soil Conservation Act 1951', and the Maldives 'National Waste Management Policy 2015'.

Finally, our filtering process included clustering. The global study clustered 'networks of policies organized around the same goal within a country' and entered them only once; linked policies were considered part of a co-ordinated policy action. We followed a more relaxed approach. Even with shared goals, policies may specify further actions beyond the

[16] Section B in additional information.

[17] Section B in additional information.

Table 3. Advantages and disadvantages of using different nitrogen-related policy sources used for this study: ECOLEX, FAOLEX and other web sources.

Policy sources	Advantages	Disadvantages
Shared characteristics of the FAOLEX and ECOLEX databases	– Provision of an open access database. – Policy details are provided on country, year, subject, key words, policy abstract, web links to the original policy text and linkages with other related policies e.g. amendments or repeals. – Policy abstracts are useful for initial checks and where the original policies are unavailable in English. – Inbuilt search tool enable the filtering of policies.	– Uneven representation of nitrogen relevant sectors e.g. lacking policies on transport and energy – Not all original policy texts were available in English (*such policies were interpreted and coded by our research team).
ECOLEX www.ecolex.org/	– The global nitrogen policy database (Kanter *et al* 2020a) was established using ECOLEX policies. – Joint initiative of United Nations Environment Programme (UNEP) and International Union for Conservation of Nature (IUCN) and Food and Agriculture Organisation of the United Nations (FAO).	– Fewer policies are available for certain sectors. For example, agriculture and rural development policies for SA totalled 224 in ECOLEX and 489 in FAOLEX. – ECOLEX is not regularly updated (policies available between 2017 and 2020 totalled 28 in ECOLEX and 234 in FAOLEX).
FAOLEX www.fao.org/faolex/en/	– For SA FAOLEX had more policies (2699 as at Feb 2021) than ECOLEX (1918 policies). – All policies identified as nitrogen relevant in SA from the ECOLEX database were originally sourced from FAOLEX. – FAOLEX has been collecting policies systematically since 2014 and collects information directly and proactively. The database is regularly updated (FAO, 2021).	– Although FAOLEX is more extensive than ECOLEX, it does not contain all nitrogen related policies therefore it was necessary to search for alternative sources.
Additional policy sources (e.g. government/ministry websites, other web sources)	– Enabled a more comprehensive collection of policies from a wider range of N_r relevant sectors. – Availability of policies varied according to the country. – Where policies identified by local experts were unavailable from government websites we searched for other online sources.	– Relevant policies are more challenging to locate and identify as websites ranged in quality, and due to the absence of inbuilt website search tools. – Websites are occasionally unstable with broken web links, and/or have an unsafe web location. – Often policy abstracts are not provided. – Some policies are only available as hardcopies which were difficult, or not possible to access. – Not all policies, or policy descriptions are available in English (see previous comment*)

more general goals or assertions. Therefore, the whole policy text was checked to determine if it should be clustered with others or not.

For the third stage we applied an adjusted classification approach to the SANH database to assess those policies that potentially impact on nitrogen management. In addition to assessing sinks, (which reflect environmental areas threatened by N_r), sectors (as potential sources), and policy type as in the global study (Kanter *et al* 2020a), we developed further classifications: pollution type, impact direction, scope and relevance. In most cases, classifications required checks of the whole policy document. For classification definitions see table 4.

For sinks, we followed the global study definitions. For sectors we made minor adjustments, adding sectors to accommodate our broader collection approach. For policy type we altered two aspects of the global study definitions. Firstly, we recognise that a policy may include multiple policy instruments. We added the option of coding each policy as multiple if, for example, it is a framework policy that includes research and development (R&D) plans and advocates monitoring and evaluation (the 'Water Act of Bhutan 2011,' for example). This approach allows us to better assess the extent of policy integration, assuming that more instruments in a single policy indicates greater comprehensiveness. We also

Table 4. Nitrogen-related policy classification descriptions.

Categories	Overview	Classifications
Environmental sink	The objective or content 'mentioned' one or more sinks; Policies could be either sink or sector focused, or focused on both.	Water, air, climate, soil, ecosystem, and multiple. Option for 'sink not included' if the policy was only sector focused.
Economic sector	Policies were coded to sectors following the original codes provided by Kanter *et al* (2020a). Additional sectors were also added. We adjusted 'industry' to include only industrial emissions.	Agriculture, energy, transport, waste, and multiple. *Additional sectors:* food, land use change, urban development & tourism, and other. Option for 'sector not included' if the policy was only sink focused.

Categories	Overview	Classification	Descriptions
Policy type	Refers to the type of policy instruments referred to (or proposed) in a policy. We adjusted this classification to account for policies that could include multiple policy instruments. Therefore policies could be coded under one or more of these types, as appropriate.	Regulatory	Policies that set quantifiable limits or restrictions on N_r production, consumption and loss. Including those with quantifiable targets that could have impacts on N_r management.
		Economic	Use financial incentives and signals to spur quantifiable improvements in nitrogen management and mitigation.
		Framework	Broad objectives related to N_r pollution and/or delegation of authority for nitrogen policymaking to another governing body'. A number of indirectly relevant policies fell under this definition.
		Data and methods	Establish or propose data collection and reporting protocols for various aspects of N_r pollution. Also including standards (also considered regulatory). Further including policies that refer to monitoring and evaluation (M&E).
		Research & Development (R&D)	Refer to and/or allocate funding for R&D both into the effects of N_r pollution and/or into new technologies that could improve N_r management whether directly or indirectly.
		Commerce	Regulate an aspect of the business environment surrounding N_r production and consumption.
		Pro-nitrogen	Lower the price of N_r production and consumption via government aid or other means, usually incentivizing higher farmer-level N_r use.
Pollution type sources	This new classification identified whether the policy recognised or targeted certain nitrogen pollution sources and distinguished between 'point' and 'non-point' sources, or both. This difference is important in policy analysis, since point pollution sources are easier to identify and target with incentives or disincentives, and monitoring is relatively easy	Point source	Refers to nitrogen pollution that is discharged directly into water or into the atmosphere at a 'discrete point', making it easier to control and monitor.
		Non-point source	Refers to pollution that comes from many land, air or water sources and can be transported overland, underground, or in the atmosphere, making them difficult to measure and control.
		Both	Refers to policies that are targeting and/or refers to both point and non-point source pollution.
		Unspecified	They do not reference or recognise the different types of N_r pollution sources.
		Non-applicable	The default classification for policies classified with a negative impact direction, and/or as having an indirect relevance (see below).

(Continued.)

Table 4. (Continued.)

Impact direction	This new classification aims to indicate the 'potential' impact the policy could have on N_r management. Depending on whether it was environmental focused or purely economically focused or both.	Positive	If the policy promoted a reduction in N_r pollution and/or improved nitrogen management whether directly or indirectly e.g. environmental standards, and water quality control policies. Generally policies associated with a sink or environmental risk were classified as either positive or mixed/neutral in impact direction e.g. Bangladesh's 'National Water Policy 1999'.
		Mixed/neutral	Policies that could have both positive and negative implications, e.g. enhance food production and considers environmental impacts, or if the policy is potentially neutral in its impacts.
		Negative	A policy that could potentially cause excess nitrogen, such as those that promote synthetic fertiliser use or fossil fuels e.g. promotes fossil fuels.
Impact scope	This new classification aims to distinguish the scale of 'possible' impact a policy could have on N_r use. Impact scope and relevance were both used to filter policies for the main analysis.	Large	Includes nation-wide policies such as an agricultural policy with potentially wide implications for N_r management.
		Medium	Includes policies that may encompass a large area (national) but have potentially indirect implications for N_r management, or a sub-national level policy which may have direct effects but these are more localised.
		Small	Includes those with smaller spatial areas than provincial, and may be area/zone specific, and/or with minor indirect implications for nitrogen management, e.g. plant quarantine rules or eco-zoning policy.
Relevance	This new classification aims to distinguish the level of relevance, whether direct or indirect, towards nitrogen.	High (direct)	As in the global study, the policy text must have one or more of the 29 key words[18], such as ammonia, or water pollution etc. These policies give the existing nitrogen policy landscape.
		Medium (indirect)	Policies that still have clear relevance to N_r, but do not contain any of the 29 key words but perhaps synonyms of these. Another 50 words were identified to help guide classifications.
		Low (indirect)	Includes those policies more distantly related to N_r management such as 'seed' policies or road expansion policies. These policies do not contain any key words or related synonyms but due to their sector or environment relevance could have indirect knock-on implications for N_r pollution.

[18] Section B in additional information.

made slight adjustments to policy type definitions to allow flexibility for policies with indirect N_r relevance.

These classifications provide a foundational overview of the number of policies and their distribution. Our next step was to analyse their 'potential' quality. Most discussions of environmental policy quality include an analysis of both policy intent and the effectiveness of outcomes (Bennear and Coglianese 2005, Castellanos and Boersma 2012). We deal here solely with intent, analysing the goals, objectives, and purpose expressed in policy texts, as indicators of their potential quality. We define 'stand out' policies as those that address a variety of sinks and sectors, pollution sources, and have multiple interventions, therefore considered best placed to confront the multidimensional challenges of N_r management.

To highlight policies with the greatest potential to influence N_r management, we further classified policies by relevance and scope. Here we analyse 649 policies, those classified with high to medium relevance and scope, accounting for 67% of the SANH database.

4. Results

4.1. Global and regional patterns

In this study by adjusting the classification approach, our results are only partly comparable to the global results. This section compares and contrasts for sink, sector and policy type between the studies.

In the global database for sinks, water- and air-focused policies were most common (figure 3). For the SANH database water-focused policies were the most common (13%) as a single specific sink, followed by those with an ecosystem focus (8%). However, the SANH database revealed a much higher proportion of policies that mention 'multiple' sinks than the global database (28% vs 2%). This suggests a greater degree of integration across environmental sinks in SA policies than globally.

For sectors in both databases, agriculture was the largest single category, with 21% of all SANH policies (35% in the global database). The second largest category in the SANH database was multiple sectors (31%, compared to 1% of the global database). A 10% of the policies did not include sectors (referring only to sinks) versus 48% in the global analysis.

The two databases differed again in regard to policy type (figure 4). Framework policies, with broad N_r related objectives, were the most common category (45%) in the SANH database. In the global database regulatory policies were the most common (32%). The policies considered as 'core' (those with economic and regulatory features) have a high potential to directly reduce N_r pollution. In the global database, these two categories totalled 41% (32% regulatory, with 9% economic). Fewer core policies were found in the SANH database, with 12% regulatory and 9% economic[19].

Comparing sector and policy type between the two databases (figure 4) shows that within the agriculture sector, commerce (50%) and pro-nitrogen (19%), dominated in the global database but were more limited (both at 8%) in the SANH database. Pro-nitrogen policies are those expected to increase N_r pollution, for example, through incentivising fertiliser without mitigation measures. In the agricultural policies R&D, which could inform pollution mitigation options, was rarely incentivised (1%) in the global dataset, although more common in SANH database (15%).

4.2. Assessing policy quality

Here we describe the main patterns that emerge from the SANH database for SA in regard to the additional classifications on pollution source type and impact direction (figure 5). We then discuss policy integration.

31% of policies did not specify pollution source type for regulation or management; 12% mentioned point sources, 5% mentioned non-point sources, while 23% mentioned both kinds of pollution sources.

Classifying impact direction highlighted whether a policy, by its text alone, is likely to mitigate (positive), or exacerbate (negative), N_r pollution. In the SANH database, 6% of the policies had no environmental considerations, therefore risking unsustainable N_r outcomes. Of the remainder, 62% were considered positive and could reduce N_r pollution, while 32% were identified as having a mixed or neutral impact.

For identifying policy integration, we assessed whether multiple sinks, sector and policy types were addressed: 15% of policies demonstrated integrated objectives (figure 3). Multiple policy types, as another measure of integration, were featured in 53% of policies. Policies that had both features of integration—multiple sinks, sectors and policy instruments—were found in 9% of the SA policies. Lastly, 35 policies (5%) not only had integration features but also referred to both pollution type sources. These are considered standout policies in terms of integration, comprehensiveness and potential impact.

5. Discussion

This is the first comprehensive compilation and analysis of regional nitrogen-related policies for SA. There is evident value of using an adjusted approach, using alternative policy data sources and a broader

[19] Policies could be classified with multiple policy types—some policies include both regulatory and economic features.

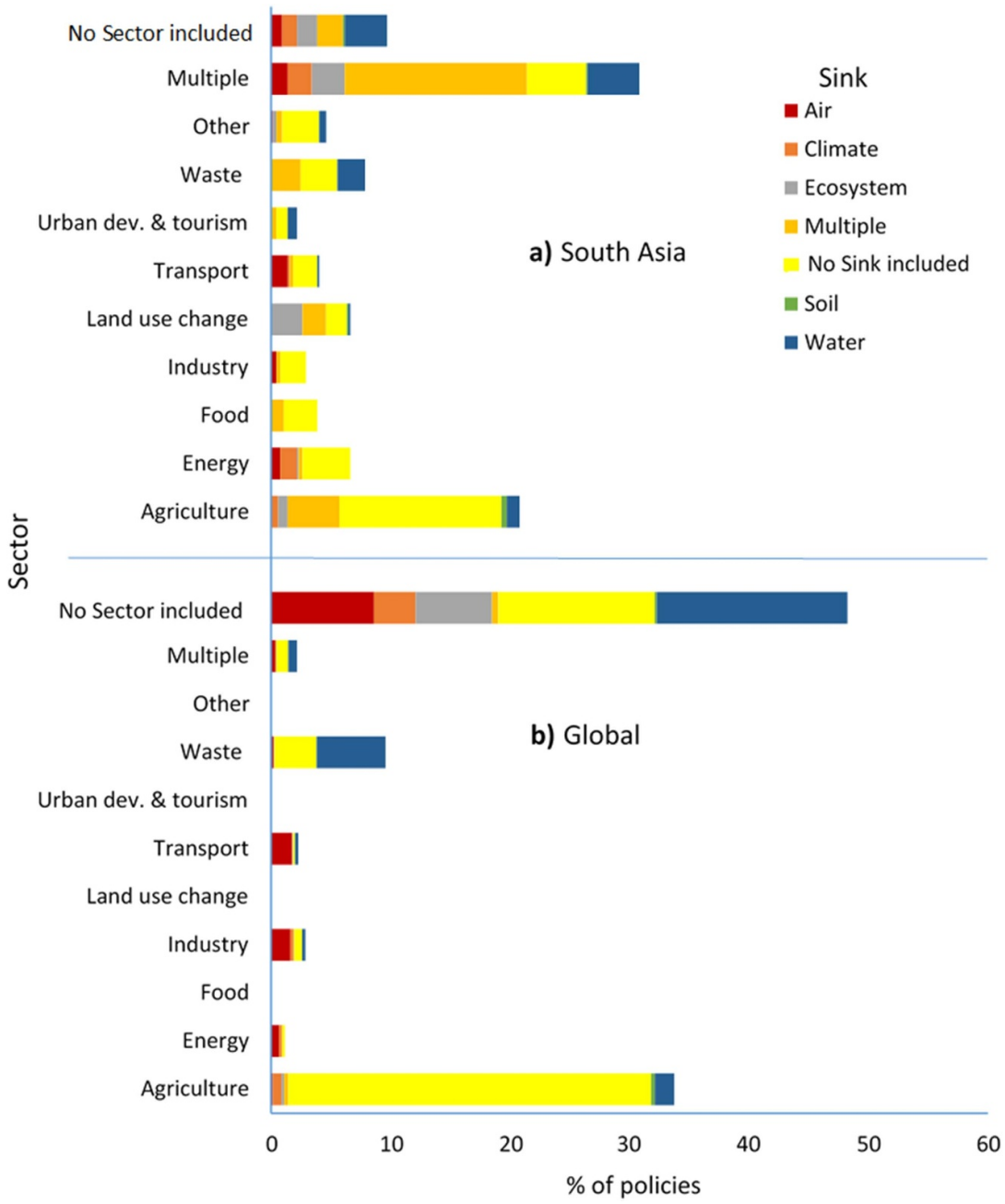

Figure 3. Classification of nitrogen-related policies by sink and sector as percentages. (a) Regional; South Asia, total 649 policies; (b) Global, total policies 2726.
Note: data sources: (a) for South Asia, SANH database (b) Global, global database (Kanter *et al* 2020a). Details at section C in additional information (tables C1 and C2). For sectors, the classification 'no sector included' forms a large proportion of the global datasets sector classifications (49%); this means that these policies were only sink focused. For the global database and for SA, the agriculture focused policies rarely refer to a sink.

search protocol for analysing regional nitrogen-related policies. We collected nearly 1000 policies, of which only 6% came from the global database. Our classifications helped enhance the policy assessment and assisted in filtering for relevancy, enabling regional and global comparisons and to make a first-level assessment of potential impacts.

5.1. Regional patterns

Despite some differences in the number, relevance, and scope of nitrogen-related policies between the countries of SA, many similarities enable some significant generalisations for the region, especially pertaining to agriculture. Numerous sector-based nitrogen-related policies in SA target agriculture (21%), reflecting the global picture of agriculture as a key source for generating N_r waste. Yet the number was lower than expected, given that agriculture is a substantial part of SA economies and land use (except in Maldives). Most agricultural policies were classified as mixed/neutral indicating some consideration of the environment. Further analyses of other regions will reveal whether this observation is a reflection of the more comprehensive compilation

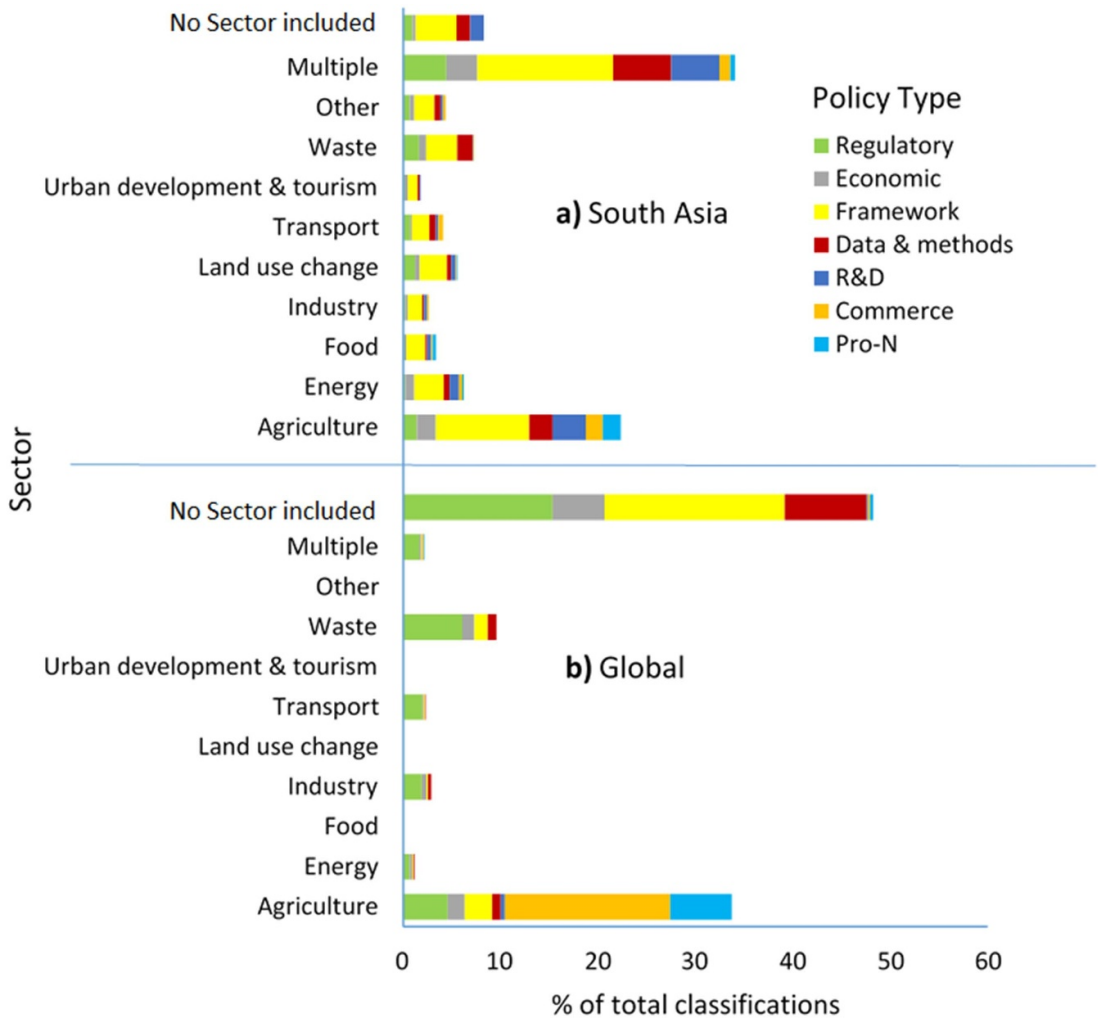

Figure 4. Classification of nitrogen-related policies by sector and policy type as percentage of total classifications. (a) Regional; South Asia, total 649 policies, total classifications 1221; (b) Global, total policies 2726, total classifications 2726.
Note: data sources: (a) for South Asia, SANH database (b) Global, global database (Kanter *et al* 2020a). Details at section C in additional information (tables C3, C4 and C7). For SA every policy could be classified as more than one policy type, therefore the *x*-axis is based on the number of classifications, not on the number of policies. We generated 1221 classifications from our 649 policies. In the global database, framework was the most common classification (19%) for policies that are sink focused only (that is, where no sector was included). In contrast framework featured as the most common characteristic across all the sector types including multiple and 'no sector included' for SA.

of policies undertaken in this paper or is unique to SA.

In line with the global study, non-agricultural sectors in SA attracted a small proportion of nitrogen-related policies (2%–8%). However, each of these sectors, such as transport and energy and waste, is increasing in importance within each country because of changing patterns of economic activity, leading to increasing N_r emissions. Therefore, these sectors require further attention for sustainable N_r management policy interventions, within and between countries of the region. Attention to these sectors might also bring the focus on NO_x, (the fastest increasing form of N_r regional emissions to air, figure 2) and aid in counterbalancing any policy implications towards agriculture, which is politically most sensitive to policy interventions (Birner and Resnick 2010, Pingali *et al* 2017).

Our results indicate that a wide range of sectors are relevant for considering N_r in policy, further justifying the need for cross-sector collaboration. Classification of sub-sectors would reveal further specificity in policy intentions, for example, under 'energy', to reveal whether policy interventions are targeted towards promoting renewables or fossil fuels.

SA policies were more sink-oriented than in the global analysis. Policies that consider at least one sink indicate a better understanding of source-sink relationships with potentially positive implications for sustainable nitrogen management. Most SA policies were identified as having a positive potential impact direction, whereas a third of the policies were identified as mixed/neutral, i.e. consider the environmental implications, but to varying degrees. Policies in both classes still require scrutiny. Although they have environmentally oriented objectives and/or

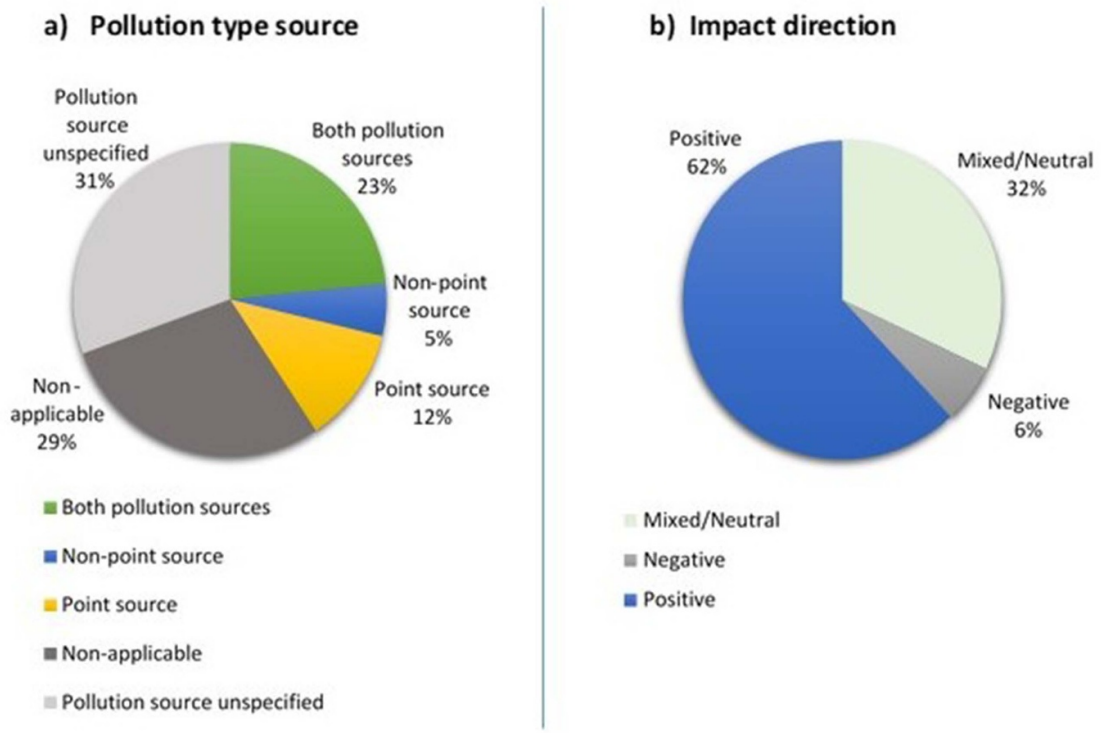

Figure 5. Breakdown of policy classifications as percentage for the Region; South Asia, total 649 policies. (a) Pollution type; (b) impact direction.
Note: data source: South Asia (SANH database). Details at section C in additional information (tables C5 and C6). For *Pollution type* (a) the classifications include point source, non-point source, both pollution types recognised, pollution source unspecified, and non-applicable. The results for *impact direction* (b) reflect whether the policy, by content alone, has the potential to lead to improvements in Nitrogen management (positive); if it potentially could cause excess N_r (negative); or if it had the potential to do both and/or if the policy is potentially neutral in its impacts (mixed/neutral).

considerations, they may still lack the necessary targets and instruments to manage sources of N_r sustainably. Therefore such policies could benefit from amendments to strengthen environmental safeguards especially in relation to N_r.

Only a small percentage of policies were classified as having the potential for increasing N_r. These included, for example, policies that subsidise the prices of synthetic fertilisers. While not all pro-nitrogen and commerce policies are inappropriate (Zhang *et al* 2015), such policies can support unsustainable fertiliser use if environmental considerations are overlooked (Kanter *et al* 2020b). Our results can thus guide prioritisation of policies for checking and modification, and also offer opportunities for adjustment to better mitigate detrimental impacts of N_r.

5.2. Policy integration

In assessing policy integration, our analysis and results differed from the global study by considering multiple policy types and pollution sources, in addition to sinks and sectors. Policies that consider multiple sectors or sinks indicate integrated objectives, which are necessary to promote synergies and limit the risk of pollution swapping (Kanter *et al* 2020a). These policies rarely featured in the global database, but multiple sinks or sectors featured in almost a third of the SA policies[20]. Covering various sectors or sinks in a policy's intent is preferable to addressing single sinks or sectors; it is further preferable to cover both. Of the SA policies, 15% address both multiple sinks and multiple sectors. The result indicates that some policies are looking beyond silos. Similarly, over half of the analysed policies involved multiple policy types. Overall, only a small proportion of policies have both integrated objectives and approaches, that is, addressing multiple sinks, sectors and policy types. In the SANH dataset, 57 policies (9%) hit this mark. An example is Bangladesh's 'National 3 R (reduce, reuse, recycle) Strategy for Waste Management 2010', which recognises waste impacts on water, air, and the climate, and outlines multiple interventions.

The 35 policies in the SANH dataset we consider as 'stand out' represent those with 'the potential' to deal most effectively with N_r pollution[21]. They consider both non-point and point source pollution with integrated objectives and approaches. Encouragingly, some policies could meet this criterion. These include Bangladesh's 'National Environmental Policy 2018', Sri Lanka's 'National Environmental (Amendment)

[20] 31% of the SA policies are targeted towards multiple sectors and 29% to multiple sinks.
[21] Section E in additional information.

Act, No. 56 of 1988' and the Maldives 'National Action Plan on Air Pollutants 2019' amongst others. A next step in our work is to analyse the extent to which these policies actually deliver on their potential.

Addressing the gap of integrated policies requires adding comprehensive, multi-sink and sector policies with interventions that deal with the multifaceted nature of N_r (Sutton *et al* 2019b). The formulation and implementation of such policies requires inter- and intra-ministry and multi-actor co-operation at multiple scales to reduce nitrogen pollution and align with, and progress towards the 17 SDGs (Mickwitz 2003, Mickwitz and Kivimaa 2007, Mcginnis and Ostrom 2014, Gain *et al* 2020).

However, integrated policies also need to be complemented by more specific actions, via 'core' targeted policies, such as vehicle emission standards, to incentivise sustainable nitrogen management. An example is India's 'New Urea Policy 2015–2019', which incentivises nitrogen use efficiency in agriculture by subsidies on neem-coated urea as a fertiliser, while prohibiting use of urea fertilizer without neem coating[22]. Such policies may be single sink and/or sector focused but still help by providing tangible legislation to guide behaviours around N_r use.

6. Conclusion

Compiling the SANH database for nitrogen-related policies and their analysis is an important first step to understanding the SA regional nitrogen policy landscape. The database is useful for assessing nitrogen policy landscapes in each country. The number of nitrogen-related policies per country does not necessarily reflect performance in tackling N_r[23]. Nonetheless, the coverage of sectors, sinks, and policy types does provide insights that can assist in supporting future efforts for developing the N_r road maps mentioned in the Colombo Declaration (UNEP 2019a). Although these numbers provide indicators of a country's policy approach to tackling N_r, additional research is needed to understand drivers of policy formulation, and actual policy impact on N_r. Our focus has been at the national scale, but additional attention at provincial or local scale would also be beneficial, especially when multilevel policy actions can enhance performance when tailored to be context-specific (Corfee-morlot *et al* 2009, Gunningham and Sinclair 2017)[24].

As for policy gaps and opportunities, those policies classified as 'high' relevance indicate the current nitrogen policy landscape for SA. Where there are gaps, new policies are required to deal with N_r issues. Existing policies can also be adapted to deal with N_r more directly and effectively. For instance, food and seed policies, classified in our database as having medium to low relevance, often do not refer to nitrogen directly, but can still have implications for its management. Within these policies, minor amendments could be applied in order to address N_r, such as legislation to consider the N_r footprint along the food supply chain.

Our findings suggest that only a small proportion of policies have attempted to integrate across sectors and sinks, with a range of policy instruments, and even fewer policies that also consider pollution sources. For all policies, however, integration is an essential characteristic for managing N_r pollution and its complexity and to support core principles of the SDG's (UN 2015). The environmental consequences if SA were to miss any of its SDGs, through failures to reduce nitrogen waste across all sectors, would be global.

This paper leads the way to understanding nitrogen policy for SA and demonstrates the benefits visible by building on the global approach to cover the complete range of policies that impact how N_r pollution is managed. By assessing current policies, we can better understand the gaps and opportunities, and support progress towards the SDGs through reductions in nitrogen waste. In the wake of COVID-19 policy action is crucial to ensure that existing and new nitrogen-related policies serve as guidance towards a 'green recovery' where regional co-operation will be imperative.

Data availability statement

The data that support the findings of this study are openly available.

The data that support the findings of this study are openly available at the following URL/DOI: https://catalogue.ceh.ac.uk/documents/e2f248d5-79a1-4af9-bdd4-f739fb12ce9a.

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[22] Section D2 in additional information.
[23] Maldives had 40 policies compared to 192 for India (table 1).
[24] Section D1 in additional information.

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ORCID iDs

Anastasia L Yang https://orcid.org/0000-0002-8947-2383
Nandula Raghuram https://orcid.org/0000-0002-9486-754X
Tapan Kumar Adhya https://orcid.org/0000-0002-8267-1793
Stephen D Porter https://orcid.org/0000-0002-1013-8754
Asif Reza Anik https://orcid.org/0000-0002-0461-6094
Shaima Chowdhury Sharna https://orcid.org/0000-0002-2137-0030
Muhammad Arif Watto https://orcid.org/0000-0003-0807-9262
Sangeeta Bansal https://orcid.org/0000-0003-2211-7720
David Kanter https://orcid.org/0000-0003-4332-4833
Roger Jeffery https://orcid.org/0000-0003-1702-7253

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