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

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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
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\textsubscript{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\textsubscript{r} pollution (Abrol et al 2017, Raghuram et al 2021). The rising global scientific and policy awareness on N\textsubscript{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)\textsuperscript{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\textsubscript{r} policies currently in force around the world’ (Kanter et al 2020a). Policies to improve N\textsubscript{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\textsubscript{r}.

The accumulation of N\textsubscript{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\textsubscript{x}), ammonia (NH\textsubscript{3}), ammonium (NH\textsubscript{4}\textsuperscript{+}) and nitrous oxide (N\textsubscript{2}O) in air, and nitrates (NO\textsubscript{3}\textsuperscript{-}) in water (Sutton et al 2019a).

A global study (Kanter et al 2020a) compiled and classified 2726 national and regional N\textsubscript{r} policies (hereafter the ‘global database’), including those of SA. It noted that global N\textsubscript{r} policies lacked coherence and integration regarding environmental sinks and warned of negative consequences for N\textsubscript{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\textsubscript{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, Gunntingham and Sinclair 2017).

Here we present the results of a rigorous process of assembling and analysing policies related to N\textsubscript{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\textsubscript{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\textsubscript{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\textsuperscript{14}.

2. Global and regional overview of N\textsubscript{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\textsubscript{r} hotspots showing high absolute quantities and growth rates relative to global means (figure 1). N\textsubscript{r} emissions as NH\textsubscript{3} and N\textsubscript{2}O have roughly doubled since the 1980s. For NH\textsubscript{3} and N\textsubscript{2}O the agriculture sector (including animal husbandry) is the main emission source; nitrogenous fertiliser applications contribute over 50% to NH\textsubscript{3} emission for all countries, except Maldives.

Emissions have tripled since the 1980s in the case of NO\textsubscript{x}, for which per capita emissions have also increased (figure 2). Major contributors to NO\textsubscript{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\textsubscript{2.5}), which includes N\textsubscript{r} components in the form of ammonium (NH\textsubscript{4}\textsuperscript{+}) and nitrate (NO\textsubscript{3}\textsuperscript{-}) (Kumar et al 2018, Aslam et al 2020). PM\textsubscript{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

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\textsuperscript{13} Section A in additional information illustrates the selected SDGs and their pertinence for South Asia and nitrogen management.

\textsuperscript{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                             | All                      |                                                     |
| (13) Climate action        | Less nitrous oxide (N$_2$O) 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, soil                                   |

(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$_2$), ammonia (NH$_3$) and nitrous oxide (N$_2$O) 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\textsubscript{x}), ammonia (NH\textsubscript{3}) and nitrous oxide (N\textsubscript{2}O) 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\textsubscript{x} and for NH\textsubscript{3} are common; and the axis for N\textsubscript{2}O 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 alternative 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\textsubscript{2}O and NH\textsubscript{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\textsubscript{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\textsubscript{2}O emission grew in SA by 35\%, NO\textsubscript{x} emissions nearly doubled \((Crippa et al \, 2019b)\).

Similarly, while chemical fertilizers have always been the single largest source of N\textsubscript{2}O in SA, the growth rate of N\textsubscript{2}O 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\footnote{Details in section B additional information.}:

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

\[ \text{Details in section B additional information.} \]
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 upon the 61 policies to create a more comprehensive, more inclusive nitrogen-related 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\textsubscript{2}O 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\textsubscript{2}O. 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. 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 keywords. 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\textsubscript{2}O management we adapted the global study’s filtering criteria. We developed an additional 50 keywords or terms. 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\textsubscript{2}O 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\textsubscript{2}O 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\textsubscript{2}O 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

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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.                                     | – Uneven representation of nitrogen relevant sectors e.g. lacking policies on transport and energy |
|                                       | – 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. | – Not all original policy texts were available in English (*such policies were interpreted and coded by our research team)*. |
|                                       | – Policy abstracts are useful for initial checks and where the original policies are unavailable in English. |                                                                              |
|                                       | – Inbuilt search tool enable the filtering of policies.                     |                                                                              |
| ECOLEX [www.ecolex.org/](www.ecolex.org/) | – The global nitrogen policy database (Kanter *et al.* 2020a) was established using ECOLEX policies. | – Fewer policies are available for certain sectors. For example, agriculture and rural development policies for SA totalled 224 in ECOLEX and 489 in FAOLEX. |
|                                       | – 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). | – 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/](www.fao.org/faolex/en/) | – For SA FAOLEX had more policies (2699 as at Feb 2021) than ECOLEX (1918 policies). | – Although FAOLEX is more extensive than ECOLEX, it does not contain all nitrogen related policies therefore it was necessary to search for alternative sources. |
|                                       | – 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). |                                                                              |
| Additional policy sources (e.g. government/ministry websites, other web sources) | – Enabled a more comprehensive collection of policies from a wider range of N\textsubscript{r} relevant sectors. | – Relevant policies are more challenging to locate and identify as websites ranged in quality, and due to the absence of inbuilt website search tools. |
|                                       | – Availability of policies varied according to the country.                 | – Websites are occasionally unstable with broken web links, and/or have an unsafe web location. |
|                                       | – Where policies identified by local experts were unavailable from government websites we searched for other online sources. | – 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*) |

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                                                                 | Descriptions                                                                                                                                                                                                 |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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.                                                            |
| 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<sub>r</sub> production, consumption and loss. Including those with quantifiable targets that could have impacts on N<sub>r</sub> management.               |
|                   |                                                                                                                                             | Economic                                                                         | Use financial incentives and signals to spur quantifiable improvements in nitrogen management and mitigation.                                                                                                 |
|                   |                                                                                                                                             | Framework                                                                        | Broad objectives related to N<sub>r</sub> 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<sub>r</sub> 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<sub>r</sub> pollution and/or into new technologies that could improve N<sub>r</sub> management whether directly or indirectly. |
|                   |                                                                                                                                             | Commerce                                                                         | Regulate an aspect of the business environment surrounding N<sub>r</sub> production and consumption.                                                                                                         |
|                   |                                                                                                                                             | Pro-nitrogen                                                                    | Lower the price of N<sub>r</sub> production and consumption via government aid or other means, usually incentivizing higher farmer-level N<sub>r</sub> 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<sub>r</sub> 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 | Positive | If the policy promoted a reduction in N<sub>r</sub> 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 | Large | Includes nation-wide policies such as an agricultural policy with potentially wide implications for N<sub>r</sub> management.
| Medium | Includes policies that may encompass a large area (national) but have potentially indirect implications for N<sub>r</sub> 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 | High (direct) | As in the global study, the policy text must have one or more of the 29 key words<sup>18</sup>, 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<sub>r</sub>, 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<sub>r</sub> 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<sub>r</sub> pollution.

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<sup>18</sup> Section B in additional information.
made slight adjustments to policy type definitions to allow flexibility for policies with indirect N\textsubscript{\alpha} 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\textsubscript{\alpha} management.

To highlight policies with the greatest potential to influence N\textsubscript{\alpha} 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\textsubscript{\alpha} 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\textsubscript{\alpha} 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.

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\textsubscript{\alpha} 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\textsubscript{\alpha} pollution. In the SANH database, 6% of the policies had no environmental considerations, therefore risking unsustainable N\textsubscript{\alpha} outcomes. Of the remainder, 62% were considered positive and could reduce N\textsubscript{\alpha} 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

\footnote{Policies could be classified with multiple policy types—some policies include both regulatory and economic features.}
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\textsubscript{2} 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 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.
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 countervailing 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
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, Meginnis 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 $N_r$. 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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