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Concepts for Considerations in the Design of an Indian Integrated Nitrogen Assessment

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CHAPTER OUTLINE

Introduction

Fritz Haber, in his Nobel Prize lecture in 1918, explained that it was the growing demand for food which motivated him to explore the "synthesis of ammonia from the elements" (Erisman et al., 2008.) In collaboration with Carl Bosch, an industrial scale process (known as the Haber-Bosch process) was developed to manufacture large amounts of nitrogen (N) fertilizer. This breakthrough has not only radically changed agriculture but has also more than doubled the release of the reactive nitrogen (Nr) into the environment. Reactive nitrogen, defined as "all biologically, chemically and radiatively active nitrogen compounds in the atmosphere and biosphere" (UNEP and WHRC, 2007), readily transfers between chemical species and environmental media (soil, atmosphere, and water) causing numerous negative consequences to both human health and ecosystem (Aneja et al., 2008, 2009). This active cycling of Nr is known as the Nitrogen Cascade (Galloway et al., 2003).

In addition, about 20% of anthropogenic Nr is released through fossil fuel combustion. Large cities are concentrated sources of Nr due to increased use of fossil fuels for transport and energy as well as incineration of solid waste (Svirejeva-Hopkins et al., 2011).

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Reactive nitrogen released from these sources has no productive use and so is a “no regrets” target for decreasing environmental Nr pollution loading.

The use of Haber-Bosch Nr has greatly increased agricultural productivity over the last half century with an estimated 40–60% of the global population dependent on it (Erisman et al., 2008). Unfortunately, agricultural uptake of nitrogen is not very efficient and a large fraction of nitrogen fertilizer, often greater than half, is not used by the crops. The excess nitrogen fertilizer is lost to air, groundwater, or surface runoff, resulting in the loading of Nr downstream and downwind (Davidson et al., 2012). Furthermore, Nr removed from farms in food products ends up being processed in whatever human waste facility is being used. Advanced treatment might denitrify 40–50% of the Nr in the human waste stream with the remainder about equally divided between discharge to rivers or land application (Van Breemen et al., 2002; Svirejeva-Hopkins et al., 2011). Less advanced sewage treatment systems likely discharge most of the Nr into river systems. Svirejeva-Hopkins et al. (2011) recommended that in the future sewage processing systems should focus on including treatment that allow for Nr reuse as a fertilizer rather than denitrifying or discharging Nr to rivers. Galloway et al. (2014) reviewed several N-footprint calculators which provide information to consumers, institutions, and governments on their contribution to Nr loss to the environment as a result of dietary, housing, goods and services, and energy use choices.

Unlike other developed countries of the world and China, India lacks a unified study on Nr. Globally, India ranks second in agricultural output, first in cattle population, and second in emissions of ammonia and nitrous oxide from the agricultural sector (Aneja et al., 2012) as a result of a dependence on high levels of fertilizer application. Consumption of fertilizer N increased from 0.6 MT in 1965–1966 to 17.4 MT in 2016 (Tewatia and Chandra, 2016) and the country has emerged as the second largest consumer of fertilizer N in the world. By 2050, input of fertilizer N is expected to increase twofold further enhancing Nr loss into adjacent environments, affecting the health of receiving ecosystems and their inhabitants (Bijai-Singh et al., 2008). In addition, with India developing in leaps and bounds, demand for energy is increasing at a rapid pace leading to a forecast of NO_x emissions increasing to 22,800 Gg in 2020, from 350 Gg in 1990 (Garg et al., 2006). Given the present and future predictions of Nr use and emissions, it is imperative that the flow of Nr in India is critically assessed. Without proper management, Nr losses will cause an ever-increasing cascade of environmental and human health problems in India. With India’s burgeoning population and need to improve quality of life for a large percentage of the population, managing Nr in India involves a delicate balance of energy and fertilizer use efficiency so that power and crop yields supply the needs of the populace with minimum Nr loss to air, water, and soil. The Zhang et al. (2015) examination of historical trends in N fertilizer use in India, and its comparison to several other countries, helps highlight the need for reversing current trends of fertilizer N use efficiency in India. The need for sustainable integrated Nr management poses a challenge for the Indian scientific community to provide policy makers with reliable estimates of Nr transfers among ecosystems and to offer feasible strategies to decrease the undesirable loss of Nr to the environment (Aneja et al., 2012).

One of the first steps in developing an Nr management strategy is conducting an assessment of the Nr inputs, and fate and transport within the region under consideration. Such an assessment requires quantification of Nr fluxes at regional and national scales. This chapter provides a suggested outline for an Nr assessment based upon previous Nr assessments and general outlines for scientific assessments.

Following up an Nr assessment with the development of effective management policies is complicated because of the ease with which Nr moves across the air, soil, and water media. A policy to address an issue in one media may inadvertently cause an increased pollutant load in another media (UNEP and WHRC, 2007). UNEP and WHRC (2007) explored case studies of some of the more successful policy efforts in Europe, North America, Latin America, and the Caribbean where the range of concerns necessary for integrated Nr management are considered. Another policy difficulty is setting the targets for agricultural N use given current and future food needs. Zhang et al. (2015) estimated the nitrogen use efficiency that agriculture must achieve to remain sustainable while supplying food and fiber to the growing world population.

Overview of the Development of an Integrated Science Assessment

The US Environmental Protection Agency (USEPA) published a description of the stepwise process of developing a generic integrated science assessment which can provide a useful framework for designing an Nr assessment for India (US EPA, 2015) (Fig. 3.1). This stepwise process includes literature searches, evaluation of individual study quality, synthesis and integration of the evidence, and development of the scientific conclusions and casual determinations.

The agencies and advisory committees included in the USEPA framework are particular to formulation of air quality standards in the USA, and therefore some of the evaluations would not be needed for an N_r assessment in India. Naturally, the agencies and advisory committees would need to be replaced with the appropriate Indian agencies and advisory committees.

An important initial step in the integrated science assessment process is to identify the key relevant policy and scientific questions to be evaluated by the assessment. The USEPA recommends holding public science and policy issue workshops to seek input on the current state of the science, and to engage stakeholders and experts in discussion of the policy-relevant questions which can develop the key assessment questions. A call for information by the lead agency or organization that invites the public to provide information, especially peer-reviewed articles, on the range of issues associated with Nr in India will also be helpful in the implementation of the first step of the framework; the literature search.

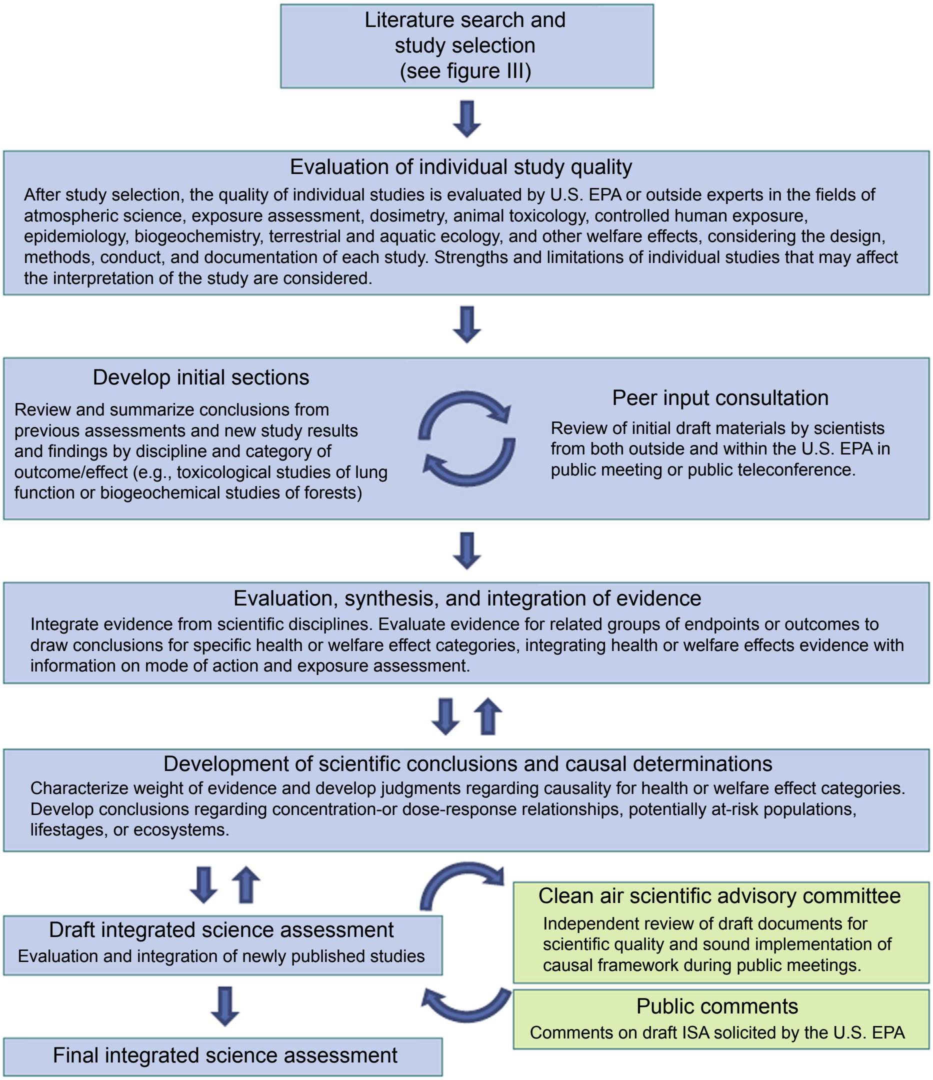

FIGURE 3.1 Characterization of the general process for Integrated Science Assessment development. (US EPA, 2015).

The USEPA framework presumes that government agency staff will be conducting the reviews and summarization of the literature and studies, and producing the first draft which is then reviewed by subject matter experts. An alternate approach is to assemble subject matter experts into panels to conduct the reviews and summarization, and to have each subject matter panel write the draft report for that subject. The drafts are then made available for public review and comment. The latter approach was used in the USA and European nitrogen assessments (USEPA, 2011; and Sutton et al., 2011b) which are discussed below.

The USEPA recommends that only studies which have undergone peer review and have been published or accepted for publication should be considered for inclusion in the literature review. Selected references should undergo full-text review and be evaluated by considering design, methods, and documentation of each study, but not the study results. The USEPA (2015) includes the following relevant characteristics to evaluate the scientific quality of the literature:

- Were study design, methods, data, and results clearly presented in relation to the study objectives? Were limitations and underlying assumptions of the design and other aspects of the study stated?
- Are the health, ecological, or other welfare effect measurements meaningful, valid, and reliable?
- Were likely covariates or modifying factors adequately controlled or taken into account in the study design and statistical analysis?
- Do the analytic methods provide adequate sensitivity and precision to support the conclusions?
- Were the statistical analyses appropriate, properly performed, and properly interpreted?

After literature review and summarization, the available research needs to be evaluated and synthesized. During the synthesis, there is value in integrating evidence across various approaches or disciplines where coherence can add support to cause—effect associations. Uncertainty should also be considered during evaluation of literature.

Different types of studies are likely to have different types of strengths, limitations, and uncertainties. In laboratory studies, conditions can be better controlled, often leading to less variability in the results, and allowing smaller effects to be detected. However, control conditions may limit the range of responses and large scale processes are difficult to reproduce, so results may not reflect the responses that would occur in the natural environment.

On the other hand, field studies measure biological changes in uncontrolled situation with high natural variability and can provide important information across multiple factors. However, these factors can often be site-specific. Field studies are especially useful for considering pollutant effects at larger geographic scales and higher levels of biological organization. Though because conditions are not controlled, variability is expected to be higher and may mask the effects. The presence of confounding factors can make it difficult to attribute observations to specific causes.

In developing scientific conclusions, the USEPA (2015) discusses aids in judging causality. Effects on ecosystems are often a result of a mix of influences both synergistic and antagonistic. The causality judgment framework provides for a systematic evaluation of the body of evidence which should be informed by peer and public comment and advice. This framework should not be used as a checklist but rather as a means to help weigh the existing evidence inferring causality. In particular, not meeting one or more of the principles does not automatically rule out the causality. Consistency of findings across studies is informed by the repeated observations or associations under different circumstances. However, it should be kept in mind that discordant results could be due to difference in methods, random errors, confounding factors, or study power, and hence should be automatically ruled out.

The USEPA (2015) also offers a framework for evaluating the weight of scientific evidence in determining causal relationships. Ecological effects should be viewed in terms of level of organization, such as cellular, organism, population, community, and ecosystem. While impact to individual organisms may not be of significance, if enough organisms are effected, communities and ecosystems may be disrupted, resulting in detrimental changes in ecosystem function or services.

Evaluation of Reactive Nitrogen Assessments in the USA and Europe

The Nr assessments conducted both for the USA and Europe in 2011 are compared and contrasted to provide examples of how an Indian assessment might be designed. While we did not include it in our comparison, Gu et al. (2015) represented an additional example of a national Nr assessment for China.

The USEPA assembled a Science Advisory Board (SAB) Integrated Nitrogen Committee to conduct the Nr assessment for the USA (USEPA, 2011). The objectives of the SAB report were to:

- "Identify and analyze from a scientific perspective the problems Nr presents in the environment and links among them;
- Evaluate the contribution an integrated N management strategy could make to environmental protection;
- Identify additional risk management options for USEPA's consideration; and
- Make recommendations to USEPA concerning improvements in nitrogen research to support risk reduction."

The European Nitrogen Assessment (ENA; Sutton et al., 2011b) was organized by the European Science Foundation Research Networking Programme "Nitrogen in Europe" or NinE, to achieve the following objectives:

- To develop the underpinning science that links different forms of N. Hence detailed studies in a single N pollutant are not the first priority. Instead, the priority is for studies examining the interchange and relationships between different N pollutants as N cascades through the environment.
- To develop the science linking N interactions between environmental compartments. Coupled to the above is the need for studies that link N emissions, transformations and impact between soils, plants, air and water and between differ contexts, urban—rural, aquatic—marine, biosphere—troposphere—stratosphere, etc.
- To establish approaches at ranges of scales, from physiological scale, patch scale, landscapes (e.g., 25 km^2), regional watersheds (e.g., 10,000 km^2) to regions of

Europe and the whole continent. Each of the scales is relevant, but the larger scales that allow explicit assessment of the N cascade are particularly relevant (landscapes to continental).

- To refine methodologies for relating information between different spatial and temporal scales. It is a major scientific challenge to carry information developed at finer scales to larger scale models, while also posing challenges for the different science communities to interact successfully.
- To apply the analyses of NinE in selected case studies across Europe. These may include contrasting case-study landscapes, major watersheds and larger contrasting regions of Europe, including the comparison between source and sink areas for N.
- To establish a meta-database of N research activities and assessment that integrate different N forms, interactions and scales. Such a meta-database would take the widest possible scope, including process analyses and case studies, providing access to both datasets and reports.
- To prepare a major assessment report covering the interlinked problems of N in Europe. The assessment report would be informed by the results of scientific activity of NinE and draw extensively on the NinE meta-database.

In both SAB and ENA processes, chapters were written by a group of experts assembled for the purpose and peer-reviewed externally. The overall structure of the two reports was generally similar with chapters focused on specific aspects of Nr as well as interactions between the different Nr chemical species and media (atmosphere, water, and soil). However, while the SAB report featured a single document with an executive summary contained in the body of the document, the ENA report presented the chapters as separate documents and included technical and policy summary documents. The ENA report also had a more extensive economic analysis compared to the SAB report. The summary and economic chapter documents are likely to be helpful for more easily disseminating information tailored to key audiences during policy-making deliberations.

Both reports started with an overview of the benefits and problems associated with current Nr use (for example, Table 3.1) followed by chapters detailing the sources, transfers, and transformations of Nr in the environment (for example, Fig. 3.2). The N cascade was described and diagrammed (for example, Figs. 3.3 and 3.4), leading to a discussion of the need for an integrated Nr management approach.

The ENA document includes a graphic that creatively summarizes the five key societal threats of excessive Nr; water quality, air quality, greenhouse gas balance, ecosystems and biodiversity, and soil quality. This useful communication tool lists these five threats to make an acronym called the “WAGES” of excess nitrogen. The ENA report also summarizes the cost of economic impacts of excessive Nr in Europe (Tables 3.2 and 3.3) showing that the economic and social impacts are substantial. These estimates are also useful in communicating the importance of Nr management to the public and policy makers.

Table 3.1 Examples of Impact of Excess Reactive Nitrogen on Human Health and Environment (US EPA, 2011)

Impact	Cause	Location	Metric	Source
Air				
Visibility decrease	Fine particulate matter	National parks and wilderness areas	Visibility impairment	NO_y and NH_x from fossil fuels and agriculture
Land Ecosystem				
Biodiversity loss	Nitrogen deposition	Grasslands and forests in the USA receiving N deposition in excess of critical load	Decrease in species richness of grasslands and forests	Utilities, traffic, and animal agriculture
Forest decline	Ozone and acid deposition	Eastern and western USA	Decreased timber growth; increased susceptibility to disease and pests	Utilities, traffic, and animal agriculture
Land Agriculture				
Crop yield loss	Ozone	Eastern and western USA	\$2–5 billion/year	Utilities and traffic
Water				
Acidification of surface waters; loss of biodiversity	Acidification of soils, streams, and lakes is caused by atmospheric deposition of sulfur. HNO_3, NH_3, and ammonium compounds	Primarily mountainous regions of the USA	Out of 1000 lakes and thousands of miles of streams in the eastern USA surveyed. 75% of the lakes and 50% of the streams were acidified by acid deposition	Fossil fuel combustion and agriculture
Hypoxia of coastal waters	Excess nutrient loading, eutrophication, variable freshwater runoff	Gulf of Mexico, other estuarine and coastal waters	Benthic finfish/shell fish habitat loss, fish kills, sulfide toxicity, costs >\$50 million annually	N, P from energy and food production
Harmful algal blooms	Excessive nutrient loading, climatic variability	Inland and coastal waters	Fish kills, losses of drinking and recreational waters costs >\$100 million annually	Excess nutrient (N & P) loading
Human and Environmental Health Damages				
Human mortality	$PM_{2.5}$, O_3 and related toxins	US urban and nearby areas	Pollution-related deaths estimated at 28,000–55,000 per year (a range of cardiovascular and respiratory system effects are associated with this pollution)	NO_y and NH_x from fossil fuels and agriculture

Table 3.1 Examples of Impact of Excess Reactive Nitrogen on Human Health and Environment (US EPA, 2011)—cont'd

Impact	Cause	Location	Metric	Source
Total damage to public health and environment	NO_x into air	Chesapeake Bay watershed	\$3.4 billion; 200,000 MT	Mobile sources
Total damage to public health and environment	NH_x and nitrate into air and water	Chesapeake Bay watershed	\$1.5 billion; 400,000 MT	Agriculture

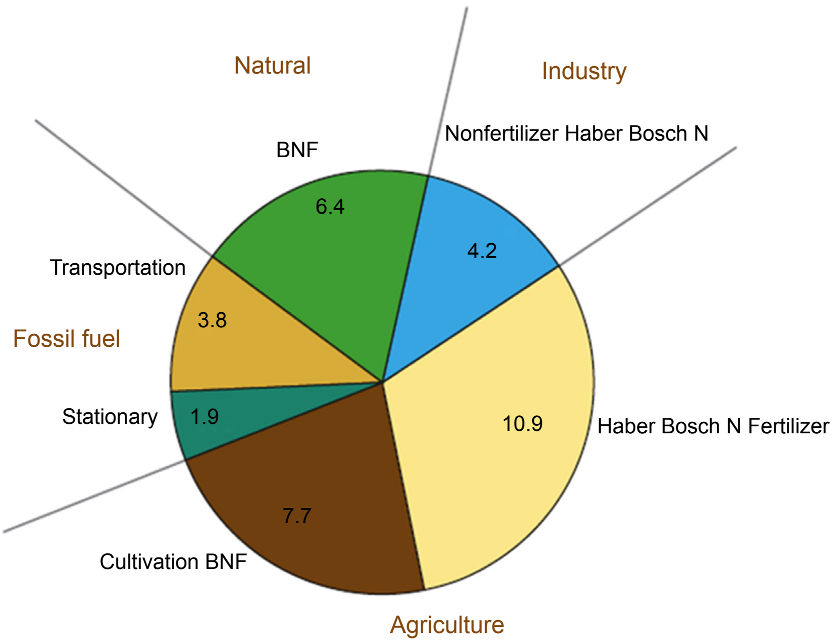

FIGURE 3.2 . Sources of reactive nitrogen introduced into the United States in 2002 (Tg N $year^{-1}$). BNF, biological nitrogen fixation. (EPA 2011)

In addition to Nr source and transformation discussions, both documents outline existing law and regulations covering various aspects of Nr use. The potential interaction of Nr effects with climate change is also discussed. The ENA report includes a comprehensive summary of the change in radiative forcing due to European Nr emissions to the atmosphere showing the complex interactions of Nr. Interestingly, the overall effects of European Nr emissions are estimated to have a net cooling with uncertainty bounds ranging from substantial cooling to small net warming (Sutton et al., 2011a).

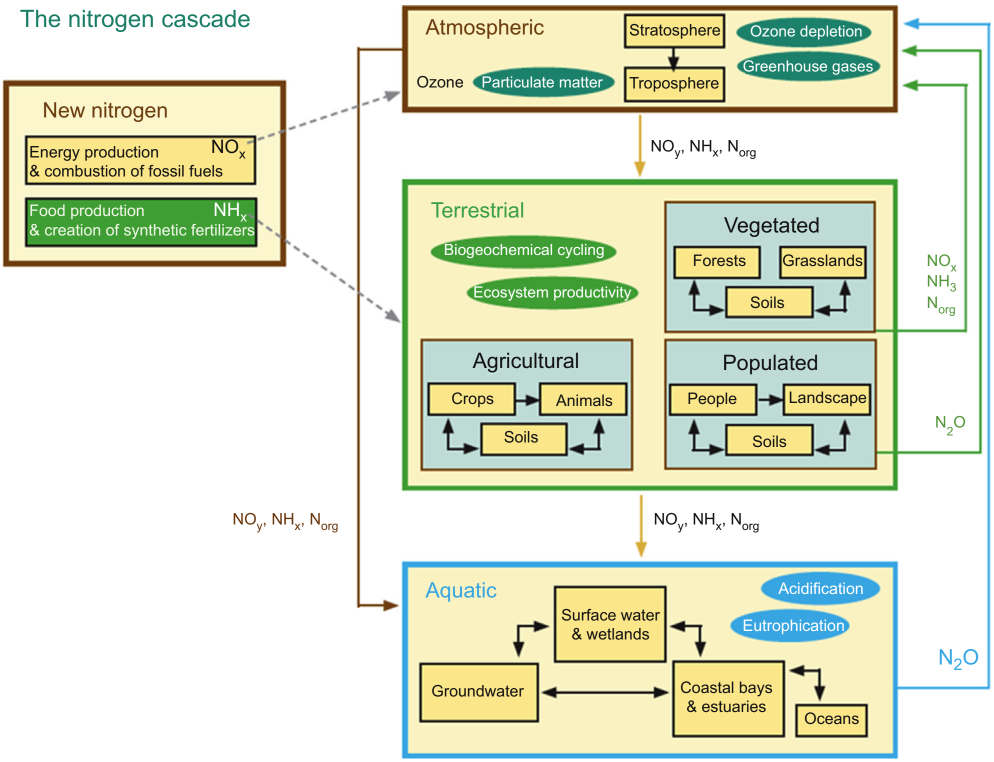

FIGURE 3.3 The nitrogen cascade (EPA 2011).

Following the subject topic chapters, each document states its major findings and recommended management actions. The SAB report management recommendations are as follows:

1. The Committee estimates that if EPA were to expand its NO_x control efforts for emissions of mobile sources and power plants, a 2.0 Tg N year^{-1} decrease in the generation of Nr could be achieved.
2. The Committee estimates that excess flows of Nr into streams, rivers, and coastal systems can be decreased by approximately 20% (approximately one Tg N year^{-1}) through improved landscape management and without undue disruption to agricultural production.
3. The Committee estimates that livestock-derived NH_3 emissions can be decreased by 30% (a decrease of 0.5 Tg N year^{-1}) by a combination of BMPs (best management practices) and engineered solutions.
4. The Committee recommends that a high priority be assigned to increasing funding for nutrient management. We estimate that adequate financial support for sewage treatment infrastructure upgrades to remove nutrients could decrease Nr emissions by between 0.5 and 0.8 Tg N year^{-1}. Additional Nr management from eligible

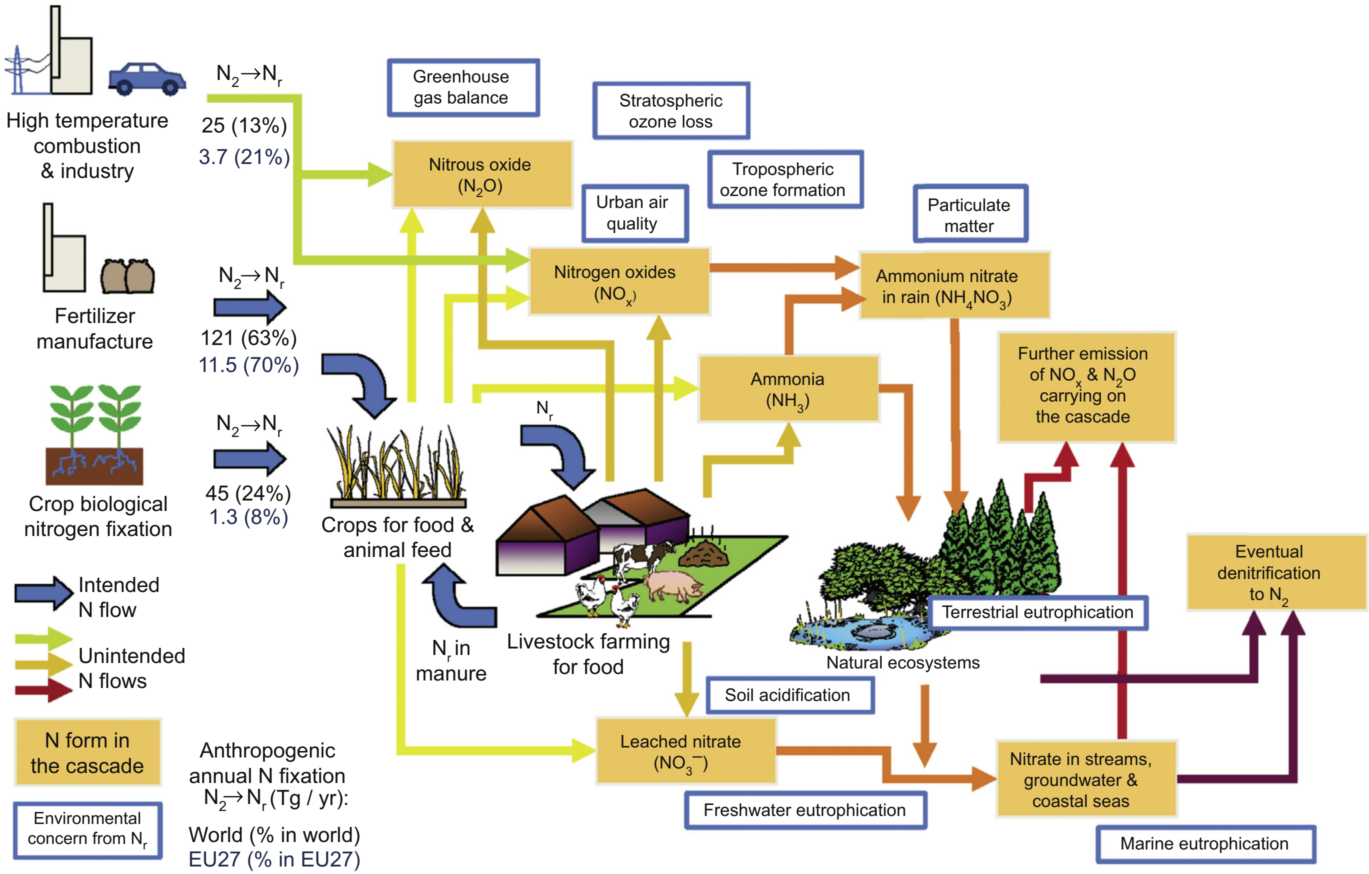

FIGURE 3.4 Simplified view of the nitrogen (N) cascade, highlighting the major anthropogenic sources of reactive nitrogen (Nr) from atmospheric di-nitrogen (N_2), the main pollutant forms of Nr (*filled boxes*) and nine main environmental concerns (*unfilled boxes*). Estimates of anthropogenic N fixation for the world (Tg year for 2005, in straight text) are compared with estimates for Europe (Tg year for 2000, in italic). *Thick arrows* represent intended anthropogenic Nr flows; all other *arrows* are unintended flows. (Sutton et al., 2011a).

Table 3.2 Estimates of Overall Social Damage Costs in the European Union (EU-27) as a Result of Environmental Nr Emissions (Billions Euros per Year at 2000). Values are Shown Here Rounded to the Nearest 5 billion Euro to Avoid Precision Issues, Explaining Differences With the Sums. The Calculated Value for N_2O Effects on Human Health is 1–2 billion Euros per year (Sutton and van Grinsven, 2011)

	NO_x Emission to Air	NH_3 Emission to Air	N_r Loss to Water	N_2O Emission to Air	Total
Human health	35–100	5–70	0–20[a]	<5	40–190
Ecosystems	5–35	5–35	15–50[a]	—	25–115
Climate	—	—	—	5–10	5–10
Total	40–135	10–105	15–70	5–15	70–320

[a]The value for health effects is proportionately smaller than the value for ecosystems as not all leaching is associated with health effects (e.g., denitrified during the path from soil to sea).

Table 3.3 Estimated Cost of Different Nr Threats in Europe per Unit Nr Emitted (Sutton et al., 2011c)

Effect	Emitted nitrogen form	Emission/ loss to	Estimated cost € per kg N_r emitted
Human health (particulate matter, NO_2 and O_3)	NO_x	Air	10–30
Ecosystems (eutrophication, biodiversity)	N_r (inc. Nitrate)	Water	5–20
Human health (particulate matter)	NH_3	Air	2–20
Climate (greenhouse gas)	N_2O	Air	5–15
Ecosystems (eutrophication, biodiversity)	NH_3 and NO_x	Air	2–10
Human health (drinking water)	N_r (inc. Nitrate)	Water	0–4
Human health (increased ultraviolet radiation from ozone depletion)	N_2O	Air	1–3

stormwater and nonpoint sources could be accomplished through increased support.

The ENA key recommended actions are summarized as a package of seven key actions in four sectors as follows (Sutton et al., 2011c):

Agriculture:

1. Improving N use efficiency in crop production.

This includes improving field management practices, genetic potential and yields per Nr input, with the potential to reduce losses per unit of produce, thereby minimizing the risk of pollution swapping.

2. Improving N use efficiency in animal production.

As with crops, this includes management practices and genetic potential, with an emphasis on improving feed conversion efficiency and decreasing maintenance costs, so reducing losses per unit of produce and the extent of pollution swapping.

3. Increasing the fertilizer N equivalence value of animal manure.

Increasing fertilizer equivalence values requires conserving the Nr in manure during storage and land application (especially reducing NH_3 emissions where much Nr is lost), while optimizing the rate and time of application to crop demand.

Transport and industry:

4. Low-emission combustion and energy-efficient systems.

These include improved technologies for both stationary combustion sources and vehicles, increasing energy efficiency and use of alternative energy sources with less emission, building on current approaches.

Waste water treatment:

5. Recycling N (and phosphorus) from waste water systems.

Current efforts at water treatment for Nr in Europe focus on denitrification back to N_2. While policies have been relatively successful, this approach represents a waste of the energy used to produce Nr. An ambitious long-term goal should be to recycle Nr from waste waters, utilizing new sewage management technologies.

Societal consumption patterns:

6. Energy and transport saving.

Against the success of technical measures to reduce NO_x emissions per unit consumption, both vehicle miles and energy use have increased substantially over past decades. Dissuasion of polluting cars and far-distance holidays, and stimulation of energy-saving houses and consumption patterns can greatly contribute to decreasing NO_x emissions.

7. Lowering the human consumption of animal protein.

European consumption of animal protein is above the recommended per capita consumption in many parts of Europe. Lowering the fraction of animal products in diets to the recommended level (and shifting consumption to more N-efficient animal products) will decrease Nr emissions with human health co-benefits, where current consumption is over the optimum.

The SAB report followed its management recommendations with a discussion of risk reduction strategies. Four types of management strategies were discussed: command and control, government-based programs for effecting policy, market-based instruments, and voluntary programs.

In the ENA report, the cost effectiveness of various management strategies are discussed in the context of communicating with the public and policy makers. A marginal abatement cost curve case study from the UK is discussed as an example of an important analysis to inform policy makers of the cost and benefit of achieving significant levels of change in Nr losses (Reay et al., 2011). Such an analysis can help identify the most cost-effective management measures. The report also models future scenarios of N using a storyline, similar to that used in the IPCC Special Report in Emission Scenarios, to predict the effect of various management scenarios which provide interesting insights that are a valuable basis for further work (Winiwarter et al., 2011).

Conclusion

The comparison of the SAB (USA) and ENA (Europe) reports provided a good set of examples from previous Nr assessments to develop the outline for a process to evaluate Nr sources, fate and transport, and management options for India. The ENA report framework, with separately published chapters and chapters devoted to technical and policy summary might prove more beneficial in using the report to influence policy making. The inclusion of an in-depth economic assessment is also a valuable attribute of the ENA report.

The USEPA framework for integrated science assessments provides a good review of the concepts and approaches critical to the implementation of a robust scientific evaluation of the state of a science, a process which is fundamentally different from the proper implementation of an individual experiment, or study with which most researchers are familiar.

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