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Why future nitrogen research needs the social sciences☆

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Nitrogen management is on the cusp of becoming a major global policy issue — the international community is gradually acknowledging that the feasibility of an array of environmental, health and food security goals hinges on how humanity manages nitrogen as a resource and a pollutant over the coming decades. As a result, the nitrogen research agenda should expand to consider more policy-relevant questions, such as the power dynamics of the broader food system and the many influences on farmer decision-making. Doing so demands much closer collaboration between the natural and social sciences, from problem formulation to research execution, which requires overcoming a range of ideological, institutional and knowledge barriers.

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Introduction

Nitrogen (N) fuels life while creating a multitude of environmental threats. It is both an essential input for food production and a key contributor to issues ranging from climate change, stratospheric ozone depletion and biodiversity loss, to air and water pollution [1]. Scientific research into N – its properties, dynamics and impacts – is at a watershed moment: the policy world is beginning to pay attention, evidenced by the Sustainable Nitrogen resolution adopted by the United Nations Environment Assembly in March 2019 (UNEP/EA.4/L.16) and the 2019 Colombo Declaration outlining the ambition of a 50% reduction in national-level N waste by 2030. These UN resolutions include the establishment of the Interconvention Nitrogen Coordination Mechanism to 'better facilitate communication and coherence across nitrogen policies' (UNEP/EA.4/L.16) and a commitment to 'develop national roadmaps for sustainable nitrogen management' — establishing nitrogen pollution as a major international environmental issue in its own right.

Until now, N researchers over the centuries have focused on its properties, its role in plant production and soil chemistry and, in the second half of the 20th century, its environmental impacts [2••]. Moving forward, the N research agenda needs to reflect its newfound policy relevance by examining research questions that are directly linked to policy development and implementation. This includes studying the large and complex technological, market, cultural, and government networks whose dynamics significantly shape farmer decisions, and the economic and power (im)balances between the myriad stakeholders that influence policy and practice across the broader food system — from environmental NGOs to fertilizer companies, farmer cooperatives to individual consumers. Only meaningful collaboration between natural and social scientists can effectively address these questions. The social sciences examine social processes and phenomena that link natural and human systems, and thus N pollution, including demography, technology, economic growth, political and social institutions, and culture [3].

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Table 1

Major nitrogen assessments and the main social science issues addressed in each of them

Publication	Major social science issues considered
Reactive nitrogen in the United States [4]	• Reviews impact of existing federal legislation on nitrogen pollution • Evaluates different policy instruments and management strategies for addressing nitrogen pollution • Makes policy recommendations on nitrogen pollution monitoring and control, including the need for integrated policy
European nitrogen assessment [5]	• Examines current EU policy landscape • Estimates damage costs of nitrogen pollution • Develops framework for integrated nitrogen management • Analyzes links between national and international policies • Evaluates communication and behavioral change strategies • Integrates specific policy measures into future scenarios
California nitrogen assessment [6]	• Integrates different overarching policy storylines into future scenarios • Evaluates trade-offs and synergies between different nitrogen management strategies • Examines current policy landscape in California using specific criteria • Makes recommendations on policy focal points and promising instruments, including the need for integrated policy
Indian nitrogen assessment [7]	• Reviews several policy options for reducing agricultural nitrous oxide emissions • Evaluates impact of changing diets on nitrogen flows

Since 2011, several national and regional N assessments have provided scientific and policy communities a broad sense of the nature and scale of the problem, though largely from a natural science perspective [4–7]. There are several chapters within these assessments, often drafted by natural scientists, that focus on relatively narrow social science aspects of the N problem, from preliminary estimates of damage costs to high-level reviews of policy responses (Table 1). Much more needs to be done to integrate the social sciences – including disciplines such as anthropology, psychology, law and education – into the N research agenda in order to formulate and tackle research questions that are of real use to policymakers and other stakeholders. This is the next stage of the N research agenda.

We first outline why closer interaction between the natural and social sciences is essential to answering the underlying questions that should drive the future N research agenda. We then discuss the challenges of such a *rapprochement* and how it might be achieved.

Importance of social sciences for nitrogen research

Integration of the natural and social sciences is not always crucial for addressing environmental issues, particularly where the solutions are largely technological with little need for more profound societal shifts, for example, the phase out of CFCs [8] and NO_x mitigation from industrial sources [9]. However, for several major environmental issues, including N pollution, technical approaches are only part of the solution — more fundamental social, political and economic transformations need to occur, including accurate accounting of externalities and changes in consumer and organizational behavior. Understanding what drives these transformations and the avenues for mobilizing change is the domain of the social sciences [10••].

For the purposes of this paper we consider social sciences to be a combination of both classical disciplines such as sociology, history, economics and political science and applied disciplines such as law, communication and education [11]. Together they develop theories and apply a variety of methods to understand social phenomena (e.g. markets, politics and culture), social processes (e.g. social organization, marketing and decision-making) and individual attributes (e.g. values, preferences and behaviors). From an environmental perspective, the social sciences study how people and institutions approach and respond to environmental changes, making them pivotal in the development of effective policies [12]. They can make valuable contributions in a variety of ways, from diagnosing why certain environmental practices are succeeding or failing, to challenging assumptions underlying a specific management approach or generating new ways of thinking about and justifying particular management philosophies. Furthermore, social science research can be conducted across a range of scales, some shared with the natural sciences (e.g. global and regional) others not (e.g. household and community), all relevant to understanding N pollution drivers and mitigation [11].

This unique set of attributes enables the social sciences to contribute to the next stage of the N research agenda in three important respects [10••,13]: 1) Stakeholder representation – working with social scientists can help illuminate stakeholder preferences, values and knowledge and

facilitate meaningful engagement with them – from the fertilizer industry and farmer associations, to multinational retailers and consumers. This in turn can lead to better awareness of the policy issues at play, improved sensitivity to the differences among groups, better understanding of individual and corporate decision making, and more effective communication; 2) Problem framing: the perceived solution space for a problem depends heavily on how it is characterized. For example, a predominantly technical framing of the N pollution issue may focus primarily on practical farm-level measures to increase N use efficiency and other technological solutions along the N cycle. By contrast, a social science framing might identify other obstacles to integrated N policy development, such as the lack of incentives for many policymakers to think beyond their particular focus. For example, a recent study in Ethiopia found that the performance of government extension workers was based on how much N fertilizer they could sell as opposed to the adoption of N best management practices, which resulted in poor manure management practices and significant N losses to the environment [14]; and 3) Systems analysis: Social science methods can help identify the social, political and economic factors that underpin complex sociotechnical systems, and thereby help design institutions and policy approaches uniquely suited to these systems' governance challenges [15]. As with problem framing, this could help take the current approach to N pollution mitigation beyond the evaluation of specific measures and address the deeper systemic drivers that incentivize N use beyond socially and ecologically optimal levels.

Within this broader conceptualization of the social sciences' potential contribution to N research, they can address the following specific types of research questions [16], organized by scale in Table 2:

- *Historical and contextual complexities*: Highlight the multiple stresses and processes driving N pollution, from food and economic security concerns to the international trade system, across different locations, cultures and governance structures, and the historical drivers that lead to N imbalances. Elucidate the underlying causal mechanisms that connect a group or individual's vulnerability to N pollution with vulnerability to other social processes such as power inequality based on gender, race and class among other factors.
- *Consequences*: Capture how the impacts of N pollution vary across regions and communities, and how individuals perceive these impacts. Analyze how N pollution impacts the social fabric, including welfare systems and laws, and basic social cohesion and solidarity. For example, the impacts of oceanic dead zones caused by N run-off on the health and economic viability of local fisheries. Monitor, measure and evaluate the outcomes of specific N pollution policy instruments, including their unintended environmental, economic and social consequences.
- *Conditions and visions for change*: Evaluate the most appropriate scale(s) for effective N pollution policy and how to scale up successes. Examine the way media in all its forms influences group and individual decision-making – from farmers to consumers – and how it

Table 2

Examples of nitrogen research questions that the social sciences are well-positioned to study, organized by scale, with the most relevant social sciences listed. Each scale has a unique set of stakeholders

Scale	Stakeholders	Examples of research questions	Social science disciplines
Global/societal	International institutions, international NGOs, general public	How to develop a coherent global approach to nitrogen management? At what scale is nitrogen policy most effective? How are cultural attitudes towards animal protein production and consumption evolving?	Political science; law; economics; history; psychology
National	National governments	How to design a holistic, national nitrogen policy that reduces risk of pollution swapping? How to best measure policy efficiency and effectiveness? How to develop systems that more efficiently recycle N?	Political science; law; economics; geography
Local/regional	Municipal and local governments	What are the policy levers for change in city and local governments? How to redesign cities to reduce nitrogen pollution?	Political science; law; geography
Community	Farmer cooperatives, schools, indigenous groups	Where do farming communities get their information? Who do they trust and how do their social practices and cultural norms evolve? Do existing educational programs facilitate learning around N pollution?	Sociology; anthropology; communication; education
Household/individual	Farmers, consumers	How to incentivize durable farmer adoption of nitrogen best management practices and technologies? How to stimulate lower per capita meat consumption?	Sociology; anthropology; psychology; communication
Private sector	Multinational corporations, small and medium-sized enterprises	Who are the most influential actors in the agri-food chain? How to stimulate more innovation in N management practices and technologies?	Political science; law; economics; sociology

could be used to increase awareness and drive change. Understand what 'change' means to different stakeholders and who gets to decide in different contexts. For example, a key finding from the Chesapeake Bay Program's efforts to integrate social science into its operations was the need for a better understanding of how different stakeholders define success and what qualifies as a 'restored' Bay [17•].

- *Governance and decision-making*: How to make N management decisions under uncertainty – from field to global scales. Determine the role science and other forms of knowledge – indigenous, political – play in N pollution policy development. Study why certain N management policies are more successful than others and the underlying barriers to political action. Analyze the potential for more innovative policy approaches.

A variety of social science methods exist to study these questions. They include qualitative methods such as interviews and ethnographies to gain insight into individual decision-making processes; quantitative methods such as surveys to better understand public opinion and cost-benefit analysis to economically evaluate specific policies; planning and forward thinking approaches like back-casting to develop technical and policy pathways for achieving a specific target; spatial methods like geographic information systems (GIS) to examine the distributional health and economic impacts of specific policies and pollution impacts; and meta-analytical approaches to synthesize core findings from a range of studies and experiments [11].

Consequently, the social sciences can address policy-relevant questions across all major stages of the policy cycle, from agenda setting to policy formulation, adoption, implementation, evaluation and support [18]. This is especially important now given N's increasing policy relevance at national and international scales [1]. Figure 1 shows examples of natural and social science research outputs that could be influential at different stages of the policy cycle.

Challenges to integration

Despite their importance, in many environmental research communities the social sciences have been confined to an end-of-pipe role, supporting and interpreting developments in the natural sciences rather than being an equal partner from the beginning [10••]. The barriers to mainstreaming the social sciences in the N scientific community include ideological barriers, institutional barriers and knowledge barriers [19••].

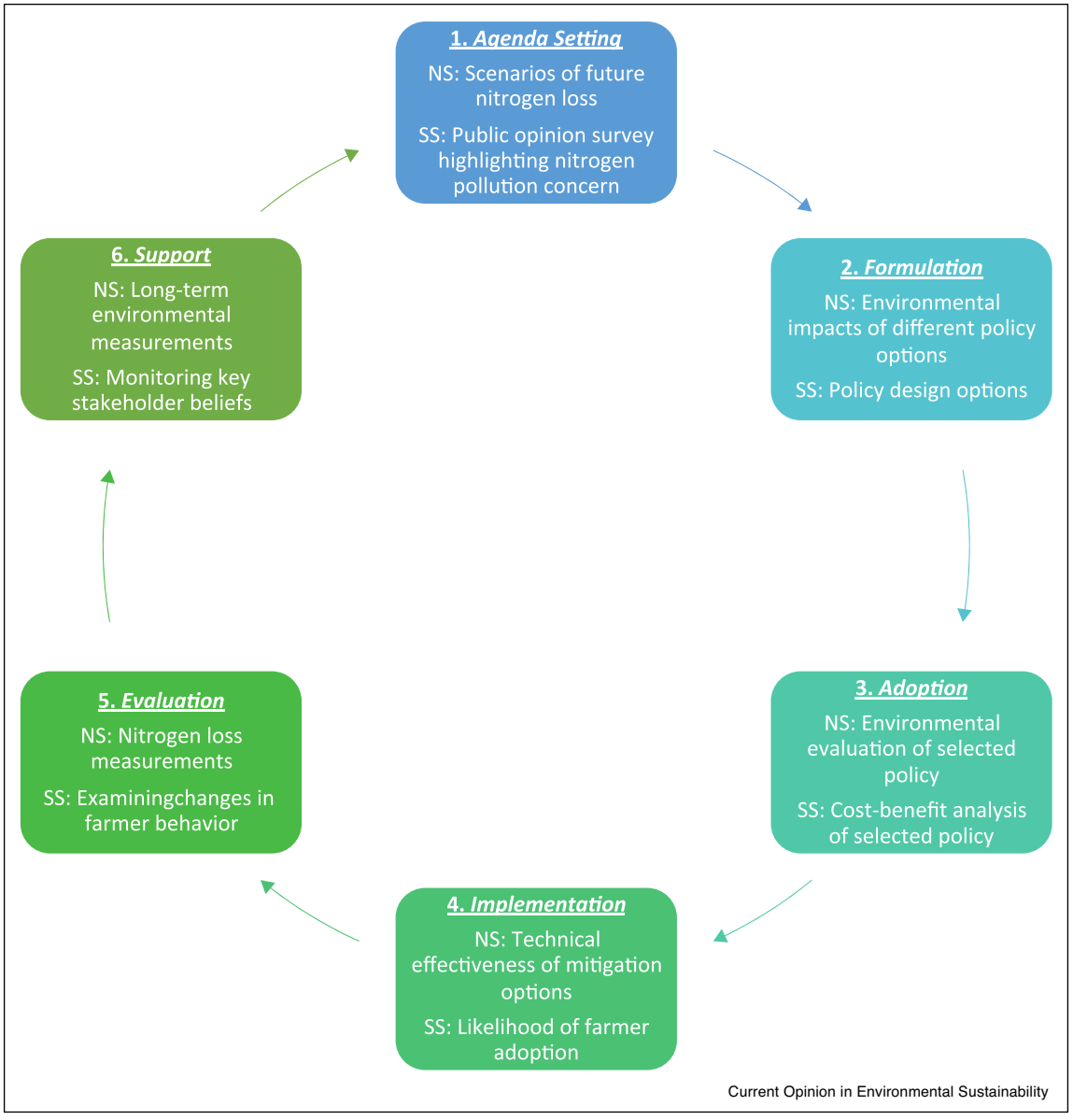
Ideological barriers include differing philosophies, world views and epistemologies that lead to incompatible ways of thinking about a problem. For example, natural and social scientists may prioritize different scales and metrics — natural scientists' primary focus may be at the watershed level, while social scientists zero on the multiple property owners and political jurisdictions. This makes it challenging to collaborate at even the initial stages of research as the problem is being framed, and gets at a fundamental difference between natural and human systems. The former function via clear relationships of cause and effect – N is lost to the environment, which leads to a cascade of ecological impacts – while human systems are more complex and cannot be treated as an organism with logical reactions to external stimuli given the often irrational nature of human behavior [3].

Institutional barriers include organizational cultures, interests, and histories, as well as decision-making structures and outputs such as government agencies and legislation. For example, research organizations like universities often have an organizational culture that prioritizes a disciplinary focus, making it hard to hire and support faculty and research programs that combine elements of the natural and social sciences [20]. Institutional barriers from a political standpoint include, for example, the inability of a top-down regulatory structure, such as the one governing the Chesapeake Bay, to effectively engage with and integrate the type of bottom-up community involvement that the social sciences can study and promote. Moreover, a lack of knowledge among policymakers and natural scientists about how to use social science tools and access experts means that social science programs are often among the first to be cut [17•]. Relatedly, a recent examination of climate mitigation research funding found that the natural sciences received 770% more funding than the social sciences over the period 1990–2018, demonstrating a large structural imbalance in what kind of research is prioritized by funding agencies [21].

Knowledge barriers include lack of training, experience and understanding of theories and methods outside of one's own discipline. Natural and social scientists alike use discipline-specific language and different theories to analyze the topic being studied, which can be inaccessible to non-specialists. This lack of a common vocabulary can make it very difficult to genuinely collaborate across all stages of research and often leads to interdisciplinary work that only includes the most quantitative and quantifiable elements of the social sciences, namely economics. For example, in the most recent assessment of the Intergovernmental Panel on Climate Change, economists constituted almost two-thirds of the 35 coordinating lead authors of Working Group III and almost half of the social science coordinating lead authors in Working Group II [12].

The question then becomes how the N scientific community can spur greater inclusion of the social sciences. At a high level, there is a need for shared conceptual frameworks that explicitly connect the natural and social sciences. Several already exist and have been analyzed

Figure 1



The six stages of the policy cycle (adapted from Ref. [18]) and examples of natural science (NS) and social science (SS) research that could inform policymaking at each stage.

extensively [22]. While it is not the goal of this paper to make a case for any one in particular, frameworks such as the Press-Pulse Dynamics (PPD) framework and the Driver, Pressure, State, Impact, Response (DPSIR) framework have shown to be effective at providing a common intellectual scaffolding for identifying the natural and human dynamics underlying a range of environmental problems and possible policy responses [22,23]. Adopting such a framework for future policy-relevant N research could facilitate collaboration between the natural and social sciences moving forward.

On a more practical level there are several things that can be done. First, it is important to reach out and create space for different social science communities at N-specific community events such as the triennial International Nitrogen Initiative conferences. This could involve specific sessions, keynote speeches and interdisciplinary working groups, as well as the inclusion of social scientists in the drafting of conference declarations. Second, funding sources should prioritize projects that make an explicit effort to integrate natural and social scientists in their proposal, such as mandating project investigators

from different disciplines, and ensuring inclusion of social scientists beyond economists. Another opportunity is within the newly established International Nitrogen Management System (INMS), a UN Environment-funded science-policy platform that is envisioned to act as a coordination mechanism between different international environmental agreements relevant to N and their national counterparts. One of the key outputs of INMS in the coming years will be the first International Nitrogen Assessment, whose policy relevance will depend significantly on how well the social sciences are involved — hopefully building on the relatively narrow conception of the role of the social sciences included in previous N assessments, as outlined in Table 1.

Finally, the social sciences could be more proactive in examining the nature of the scientific process and knowledge production, particularly in the natural sciences; namely the (often implicit) assumptions and approaches embedded as well as the formulation of problems and solutions [24]. This type of analysis could be an important initial step for natural scientists in the N scientific community to reflect on how they do research and the potential for more collaborative, interdisciplinary approaches.

Conclusion

N research has crossed a key threshold in the public consciousness over the past decade, as more institutions and policymakers have taken notice of this increasingly important issue. The onus is now on the N research community to ensure that its research agenda reflects this newfound policy relevance by formulating and answering questions that can contribute directly to the development, implementation and evaluation of effective policies. Doing so requires integrating the social sciences and the natural sciences in a much more comprehensive and concerted manner than has been done to date. Including experts from fields such as sociology, economics, anthropology and psychology in all stages of the research process, from problem formulation to execution, will significantly increase the likelihood that the N research community can make concrete contributions to policymaking at a time when better managing humanity's relationship with N is crucial for achieving a number of sustainable development objectives [25]. However, maximizing the likelihood of science being integrated into policymaking does not stop with the integration of social sciences: it demands serious and consistent engagement with a variety of stakeholders, particularly farmers, to co-produce knowledge and approaches that are more likely to be permanently adopted, as well as concerted efforts from N scientists to develop a range of policy acumen that go beyond the ivory tower. This includes more active participation in policy processes in order to build trust with policymakers to more directly drive change on N-relevant issues [26].

Conflict of interest statement

Nothing declared.

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