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Confronting the nitrogen challenge: Options for governance and target setting

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ABSTRACT

The release of excessive anthropogenic nitrogen contributes to global climate change, biodiversity loss, and the degradation of ecosystem services. Despite being an urgent global problem, the excess nitrogen is not governed globally. This paper considers possible governance options for dealing with excessive nitrogen through target setting, which is an approach commonly adopted to address global environmental problems. The articulation of the nitrogen problem and the numerous international institutions dealing with it, provide evidence of a nitrogen regime characterised by limited coordination and targets covering sources and impacts only partially. This calls for improving the nitrogen governance in the direction of more integrated approaches at the global scale. In this vein, the paper investigates two opposite governance options – here labelled as 'holistic' and 'origin-based' – and evaluates them for their capability to define solutions and targets for human-induced nitrogen. From the analysis, it emerges that origin-based solutions can be preferable to holistic solutions as they can be more specific and potentially have greater immediate results. Independent from which governance arrangement is chosen, what matters most is the speed at which an arrangement can deploy solutions to combat (fast-growing) nitrogen pollution.

1. Introduction

Nitrogen is an indispensable nutrient for the growth and function of plants, animals, and humans (Erisman et al., 2013). Above all, nitrogen is an abundant atmospheric gas (N_2), which is converted into different compounds through biochemical and physical reactions. Similarly, nitrogen is transformed by humans for various reasons such as fertiliser production or as result of combustion processes. Therefore, nitrogen is associated with essential human activities such as food production and transportation, but it can also represent a twofold problem. On the one side, the lack of nitrogen is a limiting factor for the production of food as experienced by several developing countries suffering from low soil fertility and crop yields (Eickhout et al., 2006; Wu et al., 2014). Inadequate nitrogen supply is thus connected to food access and availability, and ultimately to hunger, malnutrition, and food security. On the other hand, excess nitrogen represents a major environmental threat because a large portion of human-induced nitrogen is released into the environment and causes eutrophication, soil acidification, greenhouse gas emission, and air and water pollution at a large scale (Erisman et al., 2008; Gu et al., 2018; Gruber and Galloway, 2008). Excessive nitrogen is then connected to climate change, biodiversity loss, and the degradation of ecosystem services.

A shortage and excess of nitrogen are very different due to causes, effects, and governance aspects. For these reasons, this paper focuses exclusively on excessive anthropogenic nitrogen, which represents a global environmental problem, i.e., a problem of worldwide manifestation with (direct and indirect) impacts that transcend national borders.

The planetary boundaries diagram presents an effective visual account of the excess of nitrogen (Rockström et al., 2009; Morseletto, 2017). The figure depicts a system of bio-geophysical thresholds affected by global environmental change. Among these, the nitrogen cycle stands out as it dramatically overshoots its systemic boundary (essentially, the nitrogen cycle is in equilibrium under natural conditions) and is imbalanced by large anthropogenic additions of nitrogen (Dalton and Brand-Hardy, 2003). According to Steffen et al. (2015), the nitrogen boundary is established at 62 Tg per year (Tg/yr), while human action produces approximately 227 Tg/yr of new nitrogen (Sutton et al., 2013). A projection indicates that new nitrogen in 2050 could rise to 102–156% of the 2010 baseline value (Bodirsky et al., 2014).

Despite being an urgent global problem, the excess nitrogen problem is not governed globally. For instance, there is no framework convention on nitrogen (Oenema et al., 2011) at the level of the United Nations (UN), while no single UN treaty can handle all the threats posed by anthropogenic nitrogen (Sutton et al., 2011). A number of studies

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(e.g., Bull et al., 2011; Oenema et al., 2011; Sutton et al., 2013; Palm et al., 2004) suggest governance solutions to mitigate the consequences of the altered nitrogen cycle in the coupled human and ecological system. This paper contributes to this research agenda from the perspective of global targets, which is an approach commonly adopted to address global environmental problems such as ozone depletion, climate change, biodiversity loss, or unsustainable development. Following this perspective, the paper assesses the possibility to govern nitrogen through targets, as follows. Section 2 introduces background information on nitrogen and targets. Section 3 explains the method of assessment for the governance options, then presents these in Section 4 and confronts the options in Section 5. Section 6 summarises the argument, concluding with policy recommendations and avenues for future research.

2. The complexity of dealing with nitrogen

2.1. Origins and complexity

The main origins of anthropogenic nitrogen are synthetic nitrogen fertilisers, livestock, combustion of fuels and biomass, waste, and waste treatments (Sutton et al., 2013). These sources vary according to the economic structure of countries (de Vries et al., 2013) and are at the centre of networks of social and ecological interconnections (Niemeijer and de Groot, 2008). Accordingly, impacts on the environment are broad and diverse, and can be magnified by a "nitrogen cascade" whereby a single atom of Nr can trigger a sequence of negative environmental impacts through time and space (Galloway et al., 2003). Fig. 1 represents the main nitrogen emissions through their origins and impacts on the environment.

From these elements, it can be determined that anthropogenic nitrogen activities form a complex system of nature and human interactions. First, nitrogen has multiple sources with different intensities and uneven distributions. Second, multiple sources produce assorted environmental impacts that severely affect ecosystems and human populations at the local, regional, and global scale. Third, anthropogenic nitrogen emission/pollution is cross-sectoral. It involves a plurality of actors, from producers to consumers, and it encompasses several economic compartments dealing with basic social needs such as transport, food provision/security, and energy production/utilisation.

2.2. The nitrogen regime complex

At the international level, nitrogen is governed via a patchwork of treaties and institutions that are different in scope, norms, and subject matters. Fig. 2 represents the main international institutions dealing with nitrogen (Fig. 3).

Despite its relevance, nitrogen is not mentioned within the sustainable development goals (SDGs), which is the main UN framework for coordinating actions towards a more sustainable world. This absence might be due to an omission intrinsic to the broadness of the framework (Stafford-Smith, 2014), the scarce visibility of nitrogen in international policy circles (Kanter et al., 2016), or the fact that nitrogen is considered a specific issue to be detailed during SDG implementation. Nonetheless, nitrogen is relevant for several SDGs (Fig. 2), whether these require more nitrogen (SDG 1, 2) or less nitrogen (SDG 3, 6, 11–15) (Kanter et al., 2016; Dobermann, 2016).

Looking at the institutional architecture, it is possible to argue that the governance of nitrogen constitutes a regime, which is a system of principles, norms, rules, operating procedures, and institutions created

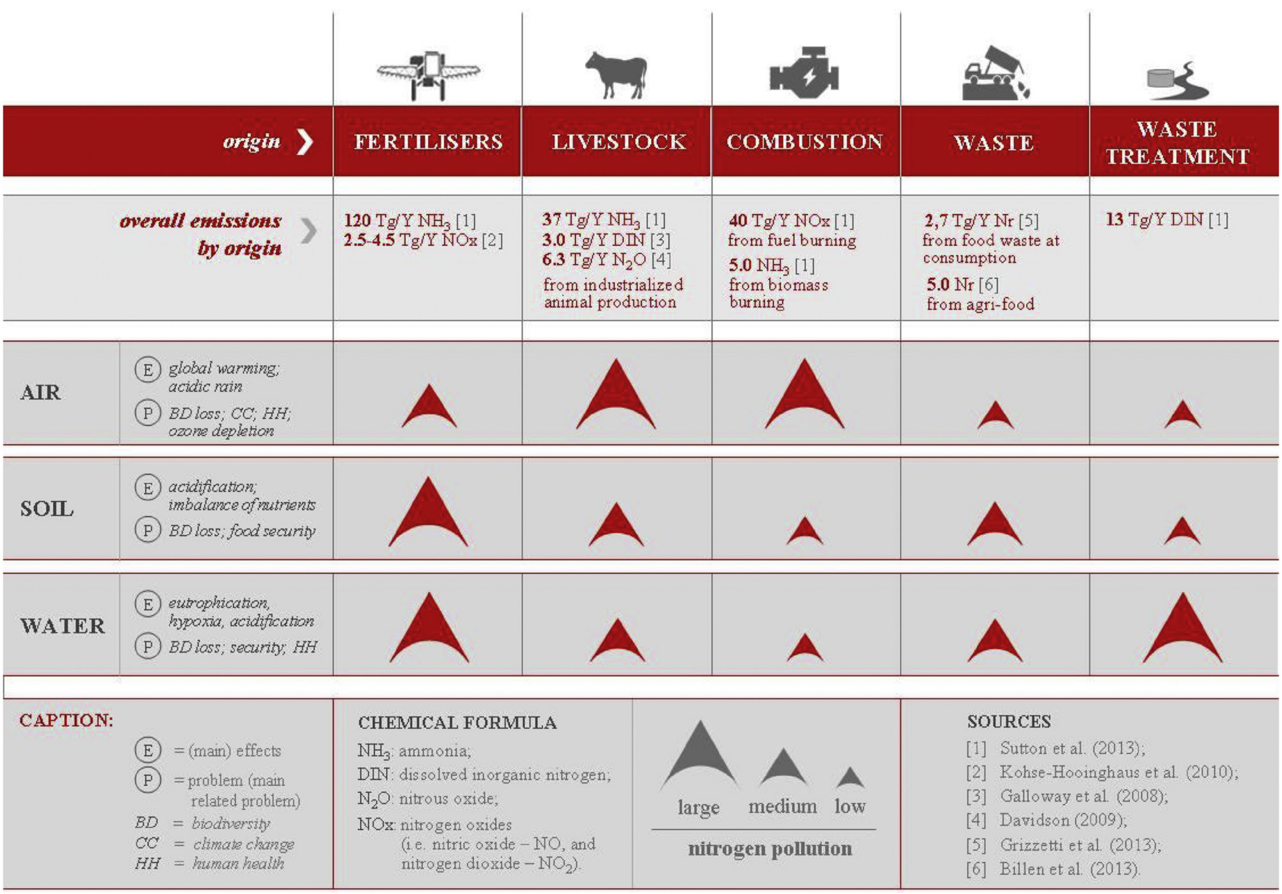

Fig. 1. Nitrogen emissions and impacts (data from: Sutton et al., 2013; Kohse-Höinghaus et al., 2010; Galloway et al., 2008; Davidson, 2009; Grizzetti et al., 2013; Billen et al., 2013).

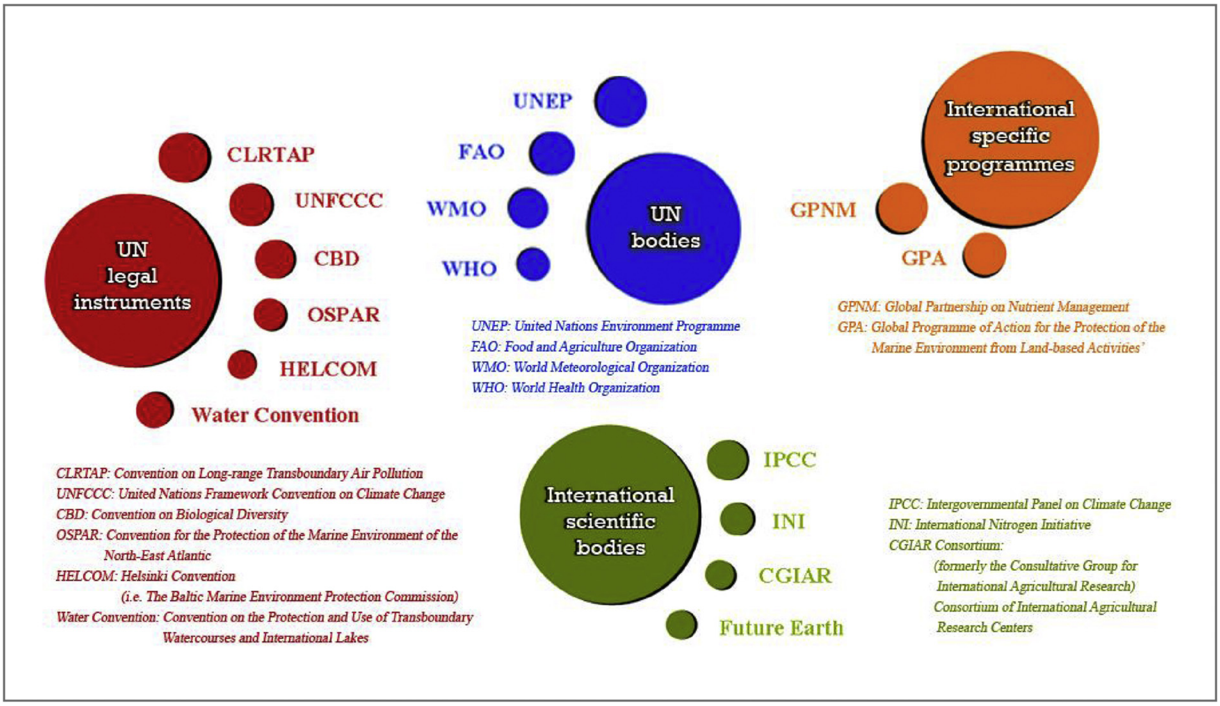

Fig. 2. Main international institutions dealing with nitrogen.

Fig. 3. Nitrogen and SDG.

to regulate and coordinate action around a topic in international relations (Chasek et al., 2016; Young, 2013). The nitrogen regime is characterised by different arrangements, limited coordination among institutions, and partial coverage of origins and impacts. In these terms, there is a regime complex for nitrogen (Keohane and Victor, 2011), which is a loosely coupled set of specific regimes operating in the absence of an integrated and unifying regime. Portions of the water, biodiversity climate change, air pollution regimes coalesce into the nitrogen regime. These regimes present several interactions due to the interplays among existing institutions and boundary-spanning activities (Gehring and Oberthür, 2008; Van Asselt, 2014; Margulis, 2017). Excessive nitrogen relates to major problems such as climate change, air pollution, biodiversity loss, food safety, and human health. These problems are interconnected and are approached by different institutions and organisations at the international level (Pisupati, 2004; Chasek et al., 2016; Ahlström and Cornell, 2018). Nonetheless, different treaties and international bodies considered nitrogen in specific areas of interest (Oenema et al., 2011), mimicking the compartmentalisation and differentiation of governmental policies.

2.3. *Targets, approaches, and global targets*

Targets are meaningful reference values conveying a desired operational policy outcome in a synthetic (often numerical) manner, while the expression “governing by targets” indicates the tendency to rely on these governance instruments for framing responses to environmental problems (Morseletto et al., 2017). Several studies recently focused on integrated approaches for nitrogen, which included targets to reduce excess nitrogen usage and mitigate its negative effects on ecosystems. For instance, Oenema et al. (2011) show the interlinkages among emissions, concentration, and exposure targets. Sutton et al. (2013) indicate an aspirational target of 20% relative improvement in nutrient use efficiency (NUE). The latter is the ratio of nutrients (nitrogen and phosphorus) in final-consumption products to new nutrient input. Erisman et al. (2015) develop the NUE concept even further in the food chain, suggesting two macro-targets, food production and food processing. Similar to NUE, Umpfenbach and Tan (2015) consider nutrient inputs, but within a wider target-set in the context of a proposal for the European Union resource-efficiency policy (EC - European Commission, 2011). These studies underline how targets can represent a pivotal element in contributing to the solutions of major social and environmental problems. However, they do not discuss the details of governance options, nor do they focus on global targets as the current study does. In this paper, the definition of global targets is relevant because the planetary scale (the one in considering the nitrogen boundary) is the one to address an issue in global terms. Moreover, the planetary scale can define a common international agenda, while promoting collaborative efforts and responses to rectify an environmental problem. In these terms, global targets can result in being a central driving force to foster international cooperation and align countries' priorities towards a desired (target) level (Clarke and Feeny, 2013). Consequently, global targets can have a mobilising role to cope with environmental problems and favour the connection of different policy domains and governance systems at the international level.

2.4. Current international targets for nitrogen

Targets for nitrogen already exist at the international level. They address specific aspects of nitrogen for air, soil, and water (e.g., Skjærseth, 2000; Keiser, 2001; Palm et al., 2004). Despite this, nitrogen regulation is fragmented and no unifying framework is in place at the international or supranational level (Oenema et al., 2011). A number of UN treaties (illustrated in Fig. 1) include targets on nitrogen, as summarised in Table 1.

These targets are different for various areas of interest and scopes and focus on emissions, concentration of pollutants, and ecological processes. However, not all of them are global, and they do not cover all causes and effects of nitrogen pollution. For these reasons, it can be argued that they do not have a fully mobilising role in current global environmental governance. Specifically, there is no strong interconnectedness among different sources of emission and resulting environmental impacts.

3. Methods

This paper considers possible governance options for contrasting excessive nitrogen through global targets. These options are presented to favour a constructive debate on governing nitrogen pollution while promoting a debate on operational solutions. To provide further elements for discussion, governance options are not only presented but are also assessed. Such an assessment presents difficulties since a) even hypothetical governance options presuppose different efforts regarding of negotiation time, international cooperation and integration, which are difficult to evaluate (not only ex-ante); b) different governance options imply different declinations and implementing mechanisms, which can be envisaged but with a large margin of errors. Beyond these difficulties, it is possible to apply evaluation techniques to preliminarily appraise governance options for nitrogen. Policy evaluation theory has been developed to assess (ex-ante/ex-post/in-itinere) policy areas according to specific criteria (Crabbè and Leroy, 2008). Although there is no standardised list of these criteria — in truth, "there is virtually an unlimited universe of possible policy evaluative criteria" (Rycroft, 1978, 88) — it is possible to apply some of the most common criteria in policy evaluation to consider the ex-ante capability of the governance options. These criteria are achievability, manageability, effectiveness, efficiency, responsiveness, coherence, and coordination, (e.g., Huitema et al., 2011; IOB Policy and Operations Evaluation Department, 2009 Baldwin et al., 2012; Nilsson et al., 2012; Jordan and Lenschow, 2010). Other frequently applied criteria such as equity, fairness, or legitimacy are not considered, as they are beyond the scope of this paper. Here, the purpose is a preliminary (and rough) evaluation of policy options that could answer the nitrogen problem in operative terms. Due to the brevity of this paper, it is not possible to delve too deeply into the selected criteria. However, a brief explanation is necessary to clarify how each criterion is intended in this text. There is no consensus in the policy and scholarly debate on the definitions/demarcations/interpretations/applications of the criteria, and their use is not always consistent.

Achievability — also indicated as attainment — refers here to the possibility that global targets are defined, accepted and implemented by the involved parties of a governance arrangement.

Manageability is the capability to control the process of targets setting and application. It depends on factors such as effective leadership, enforcement, compliance, and accountability.

Effectiveness relates to the extent to which targets contribute to the achievement of the overall reduction in nitrogen pollution. This outcome is a function of the level of ambition of targets, and depends on the way actions ensue.

Efficiency is the capacity of targets to reduce nitrogen pollution with the minimal allocation of resources. In policy, efficiency refers to the relationship between the resources invested and the effects achieved (Knoepfel et al., 2007). When adopting an economic approach of evaluation research, techniques such as cost-effectiveness analysis and cost-benefit analysis are used to assess the efficiency of a policy (Crabbè and Leroy, 2008). Here, following Knoepfel et al. (2007), efficiency is instead considered in relation to effects/objectives and the amount of resources employed.

Responsiveness indicates the ability to react in a suitable and timely way to the nitrogen problem while providing a durable contribution to its solution through targets.

Coherence — sometimes denoted as consistency (den Hertog and Stross, 2011) — is derived from the synergies and the reduction in

Table 1
Nitrogen and targets within UN treaties.
Sources: mUNFCCC http://unfccc.int/kyoto_protocol/items/3145.php; http://unfccc.int/focus/ndc_registry/items/9433.php; CBD https://www.cbd.int/sp/targets/rationale/target-8/; Water Convention http://www.unece.org/env/water/pwh_targets_set.html; CLRTAP http://www.unece.org/env/lrtap/nitr_h1.html and http://www.unece.org/environmental-policy/conventions/envlrtapwelcome/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html; OSPAR http://qsr2010.ospar.org/en/ch04.html; HELCOM http://helcom.fi/action-areas/monitoring-and-assessment/monitoring-manual/inputs/nutrient-inputs-from-atmosphere.

Treaty	Area	Scope	General Targets	Nitssrogen Targets
UNFCCC *(Kyoto Protocol and Paris Agreement)*	Climate change	Global	Atmospheric emission	N_2O and NOx emissions
CBD	Biodiversity	Global	Biodiversity	Excess nutrients reduction to non-detrimental level (Aichi Target 8)
Water Convention	Water	Transregional	Suggested targets on water safety / sanitation, wastewater	Nitrate and nitrite, concentration
CLRTAP *(Sophia Protocol, Gothenburg Protocol)*	Air pollution	Regional	Atmospheric emission	NOx and NH_3 emissions
OSPAR	Marine pollution	Regional	Eutrophication	Nitrogen oxides or their transboundary fluxes
HELCOM	Marine pollution	Regional	Sources of pollution	Reductions of nutrients and airborne pollutants

conflicts, and it is characterised by policies sticking together to hit the targets they defined.

Coordination could belong to the manageability criterion, but it deserves a separate investigation because of its relevance for targets. It is the capability to align, integrate, and synchronise different policies; as a result, policies reinforce each other in the pursuing of targets.

These seven criteria are applied to the governance options presented. A simple system of scores based on two colours (red and green) allows researchers to compare governance options according to the considered criteria.

4. Analysing governance options for nitrogen

The background information in Section 2 highlighted the complexity of the excess nitrogen problem regarding sources, consequences, and international governance. In particular, the nitrogen regime displays multiple targets, organisations, and legal arrangements. Such a complexity suggests the impossibility of defining a unique target to comprehend the multifaceted aspects of nitrogen, and the impracticability of being operationalised in heterogeneous sectors and applications. For these purposes, a set of multiple and coordinated targets could better indicate specific nitrogen issues while addressing the maintenance of essential goods and services for humanity. A global target for nitrogen can eventually emerge as a composition of interrelated sub-targets, or specific global targets that together construct a comprehensive target, as could be the reference value based and expressed on the planetary boundary concept (i.e., 62 Tg/yr, as seen in the introduction). However, setting the level of targets is ultimately a discretional policy decision. This is proportional to the level of political ambition but derives from a process involving different actors evaluating strategy, level of feasibility, and scientific knowledge (Birkland, 2014; Dietrich, 1995). Because of this, it is essential to consider governance options in which actors can tackle the nitrogen problems and possibly bring synergy and concordance in nitrogen governance.

Governance options can be numerous, and these can be considered according to different conceptions; for example, from the policy integration perspective (e.g., Jordan and Lenschow, 2010), in the relation to the modes of governance (e.g., Treib et al., 2007), or the discussion on polycentric versus monocentric governance (e.g., Skelcher, 2005). However, because of the intention to keep the analysis as plain as possible, this paper presents two opposite and ideal-typic governance responses that can make targets effective tools for curbing nitrogen pollution.

The choice of considering opposite and ideal-typic cases intends to provide the wider theoretical extent for the maximum of stimuli for reflections (also for cases not located at the extremes represented by ideal tipicity). Here, the opposite rubrics are labelled as 'holistic' and 'origin-based' (referring to sources of pollution). Conceptually, they correspond to Barrett's (2002) categories "broad-but-shallow" and "narrow-but-deep" agreements, with the first implying full participation and compliance among all actors involved, and the second among a limited number of key actors. In fact, holistic rubrics are about governance arrangements/institutional designs (broad legal regime, interagency cooperation, etc.), while origin-based concepts consider governance solutions organised around well-identified sources of pollutions.

4.1. Holistic

The term "holistic" is proposed in the book *European Nitrogen Assessment* by Sutton and colleagues, is developed in the chapter by Bull et al. (2011), and refers to all environmental compartments and economic sectors having implications for nitrogen policy.

In this paper, the holistic rubric considers nitrogen governance in an integrated way to overcome specialisation and current boundaries among international bodies; it encompasses all aspects of nitrogen with the aim to obtain a comprehensive regime configuration. Options within the holistic rubric are based on mutual interests on nitrogen, and international institutions working according to a streamlined system of norms, principles, and procedures. For Bull et al. (2011), the governance options are a) the creation of a multilateral environmental agreement (MEA) on nitrogen; b) the construction of new international body for interagency coordination; c) the establishment of formal high-level agreements between MEAs and intergovernmental organisations; and d) the enforcement of interlinkages among existing organisations and legal instruments. Accordingly, the definition of global targets for nitrogen can emerge during or after the establishment of one of these governance options.

Targets within a specific MEA, such as a framework convention on nitrogen, would ideally represent a powerful instrument for a coordinated strategy, which would "bring the different elements of the nitrogen problem together" (Bull et al., 2011, 576). Here, approved targets would potentially have a global recognition and far-reaching application. However, this option requires a long time to create a treaty with possible disagreements among parties or playing down to the lowest common denominator. Dimitrov's (2006) analysis on the failure to establish a regime centred on a single treaty can be relevant (and monitory) for nitrogen targets. The first motive of failure is the existence of global transboundary impacts, which are reciprocal cross-border consequences that are not unilaterally manageable. Simplifying, nitrogen impacts can be global, in relation to atmospheric emissions; regional for water; and local for soil. Some countries could therefore hinder a framework convention and not consider nitrogen impacts to be "global enough". A second and third cause for aborted regimes relates to the shared consequences of impacts, and shared benefits of international policy coordination at the global level. Some consequences of nitrogen can be opposed to being place specific, or the benefits of a global treaty can be interpreted as more advantageous for certain countries. These objections can make it difficult to identify and decide upon targets for global outreach.

These objections remain valid for the other governance mechanisms indicated by Bull and colleagues (above indicated with the letters, b–d). Nevertheless, these mechanisms can develop within negotiations among entities already in place and theoretically are compared more easily to a new treaty. However, the validity of these options depends on an institutional architecture being adjusted effectively to reduce nitrogen pollution.

In the case of b) 'the creation of a new body for interagency coordination', Bull and colleagues look favourably to a mechanism modelled on UN-Water, a platform to manage water governance that comprises 31 UN entities and 38 organisations. In this regard, Baumgartner and Pahl-Wostl (2013) underline that UN-Water improved the link between knowledge production and politics, but did not led to an increase in effectiveness of policy processes. UN-Water shows a weak point: the absence of an intergovernmental governing body exerting direct control and formal decision-making power. A coordinating mechanism for nitrogen therefore should consider the constitution of a governing body working as an anchoring institution on nitrogen with effective decision power over member organisations. As an alternative, Bull et al. (2011) suggest the Environmental Management Group (EMG), an interagency mechanism of the UN system, which enables the formulation of effective, coherent, and coordinated responses to specific environment challenges (UNGA United Nations General Assembly, 1999). For nitrogen, EMG would allow working within already established guidelines and procedures, but would define specific themes on nitrogen to streamline actions around objectives and targets.

In relation to c) 'establishing high-level agreements between MEAs and intergovernmental organisations'; and d) 'the enforcement of interlinkages among existing organisations and legal instruments', a holistic approach demands close involvement from international institutions. Moreover, these mechanisms should require covering all relevant aspects of nitrogen pollution. As some interlinkages are already in place, different institutions and multilateral agreements can present conflicts, overlaps, or incompatibilities (Biermann et al., 2009) that need to be mitigated. A holistic solution can be built in a step-by-step manner by upgrading the current MEA and creating further links, or boldly enforcing existing interlinkages, such as those between CLRTAP and WHO, and between the Water convention and FAO. The definition of targets on nitrogen can facilitate and strengthen this process, and favour a snowball effect for further interlinkages and targets. However, a strong coordination and integration process is necessary to obtain holistic outcomes. This is relatively easy when mandates, visions, policies, and programmes are synergetic; otherwise, some kind of hierarchical or substantive authority is required (Schubert and Gupta, 2013). A facilitating role can be played by an organisation that builds consensus on relevant issues such as targets and indicators, while providing guidance for the elaboration of response strategies. According to Bull et al. (2011) and Sutton et al. (2013), this role can be played by the Global Partnership on Nutrient Management (GPNM), which includes governments, industry, science community, NGOs, UN agencies, and international and regional organisations. GPNM can have a relevant role in studying and proposing robust targets for decision makers see (Ahlström and Cornell, 2018).

4.2. Origin-based

This rubric is different from the holistic rubric, as it goes along with specialisation and areas' boundaries. For regime strengthening, origin-based governance arrangements can have the advantage of involving strongly relevant actors and institutions. Origins of pollution have been highlighted in Section 3 and, for governance appraisal, can be divided into two groups according to the type of the actors involved: 1) livestock, waste management, and waste treatment, and 2) fertilisers and combustion devices.

The first group is characterised by a large number of dispersed organisation operating at the local and regional scale. Generally, private-owners/companies deal with livestock while public, private or public-private entities deal with waste management and waste treatment. In the case of livestock, there are few key international organisations with the recognition and representation to propose and define global targets for nitrogen. A first example is the Livestock Environmental Assessment and Performance Partnership (LEAP), a multi-stakeholder initiative aimed at improving the environmental performance of livestock supply chains. LEAP governing bodies are the Steering Committee, made up of governments, private sector, and civil society and nongovernmental organisations; a Secretariat hosted by FAO; and Technical Advisory Groups, which are composed by experts committed to developing science-based guidance and methodologies. In the same vein, category organisations such as the International Dairy Federation (IDF), which develops science-based standards for the dairy sector, or the International Meat Secretariat (IMS), which represents the global meat and livestock sector, could participate equally in the definition of targets related to livestock. The International Livestock Research Institute (ILRI) can also contribute to this process. ILRI is one of the research centres of CGIAR (formerly the Consultative Group for International Agricultural Research) working towards the sustainable use of livestock. Furthermore, if manure is assimilated to waste, there are two category associations operating at the international level: the International Solid Waste Association (ISWA), and the International Water Association (IWA). The first promotes sustainable and professional waste management worldwide and the second aims to deliver a sustainable solution for water treatment/sanitation. Both entities are organised through governing bodies, regional representatives, and international programmes and have several collaborations with governments and UN organisations. ISWA and IWA can favour the definition of global targets for nitrogen and the creation of implementing mechanisms.

It is likely that the homogeneity of issues among these institutions should facilitate a convergence to common solutions. The problem of coordination underlined in the holistic responses can exist at an issue-area level as well, but the focus on one issue should ease problem solving if combined with a strong will to tackle nitrogen pollution.

Fertilisers and combustion devices compose the second group in the origin-based rubric. These represent the main origins of nitrogen emission at the global level. They are also characterised by a limited number of producers. Research on nitrogen governance indicates that "the most successful pollution mitigation policies have been noted to be those targeted as sectors consisting of a few major actors" (Sutton et al., 2013, 77).

Fertilisers are produced almost everywhere, but the market is dominated by producers with considerable market power, as the biggest 15 corporations hold 52% of the global market (Arovuori and Karikallio, 2009). Nitrogen fertilisers make up 61% of the entire fertiliser market (Yara, 2015), with urea being the dominant product. The main fertiliser producers can play a pivotal role in identifying targets for nitrogen dispersal/reduction.

Only 30–50% of applied nitrogen fertiliser is taken up by crops and the efficiency of nitrogen fertiliser tends to decline at higher addition levels (Tilman et al., 2002). However, there are enhanced efficiency fertilisers in the product portfolio of main producers that are developed to maximise nutrient intake and minimise losses of reactive nitrogen (Trenkel, 2010). In particular, there are urea substitutes with slow/controlled release and nitrification and urease inhibitors (Timilsena et al., 2015). These products can be promoted in different ways, though forms of traditional governance, which is a hierarchical state-led model of governance, or through a new collaborative arrangement such as multi-stakeholder partnerships (Pattberg and Widerberg, 2016). For instance, leading corporations — also with the help of the International Fertilizer Industry Association (IFA) — could create a consortium to promote the diffusion of innovative products and define target for nitrogen pollution linked to selling targets. The Forest Stewardship Council is a successful model of this kind of nonstate governance (Pattberg, 2007; Beisheim and Liese, 2014). Alternatively, we can envisage an international process to phase out poorer performing products, as it occurred for chlorofluorocarbon substances or harmful pesticides (Norgaard, 1994). Kanter et al. (2015) show that phasing-out polluting fertilisers can benefit the environment, decrease farming costs, and increase industry profits. Phase-out processes can be associated with targets for dispersal-reduction or product-replacement targets within precise timelines. However, phase-out and multi-stakeholder partnerships require certain conditions to be successful. Phase out processes demand restrictive national legislations, incentives for the development of substitutes, the leadership of a relevant country/group of countries, and bringing in developing countries (Dimitrov, 2006). Multi-stakeholder partnerships require a number of conditions, including effective leadership, stringent goal-setting, and a favourable political and social context (Pattberg and Widerberg, 2016). Whether traditional nitrogen fertilisers can be voluntarily discontinued is hard to predict. For example, producers initially objected a chlorofluorocarbon phase out (i.e. the phase-out of ozone-depletion substances), but a strong agreement was reached later following national legislation and international dialogue (Dimitrov, 2006). Instead, the more recent case of the incandescent light-bulb ban indicates the leading role by governments, but with intense and constructive dialogue from and with industry (Stegmaier et al., 2014).

The case of combustion devices is more articulated than fertilisers. This sector includes engines for transportation (vehicles, aircrafts, rail-traction and marine engine) and other devices (e.g., engine generators, fuel power plants, and industrial and household heating/cooling systems). To limit the discussion, this paper considers only transportation engines for vehicles and aircrafts, being these explicative for the other typologies of engines.

Vehicle and aircraft engines are characterised by different usages, longevity, and level of emissions; however, few manufacturers control their entire production. In the case of road vehicles, 20 corporations produce approximately 90% of the almost 86 million units annually (car, buses, and trucks), while the top 10 corporations control 70% of the market (OICA, 2013). The vehicle industry has the technological solutions to reduce CO_2 and NOx emissions (Pinkse et al., 2014). Nonetheless, transformative technologies are hindered by existing (dominant) technologies that lock in the market and create path dependencies in production and consumption (Briggs et al., 2015). Therefore, carmakers have a main social and economic power coupled with the ability to influence national regulations worldwide. A sample is provided by the European Commission IP/15/5945 decision (EC - European Commission, 2015) to postpone new tests for car emissions even in the aftermath of the discovery of disguised emissions by the carmaker Volkswagen, the so-called "diesel gate" (Blackwelder et al., 2016).

The case of motor vehicles underlines the necessity of truly international technological and compliance standards because few companies manufacture vehicles that are used worldwide. Moreover, international standards should be combined with emission-reduction solutions for circulating vehicles, which amount to more than one billion units (WardsAuto, 2011). The existence of international standards would make it easier to define a global target for CO_2 and NOx emissions. The issue can also be considered the other way around; global targets can push the definition of international standards. The problem lies in which institution can promote international standards and targets. Aviation can provide a positive example in this vein. Air transport standards are harmonised worldwide through the International Civil Aviation Organisation (ICAO) a UN specialised agency operating under the Convention on International Civil Aviation. A similar organisation can be created for motor vehicles. Much of ICAO's work in the environmental field is undertaken by its Committee on Aviation Environmental Protection (CAEP). CAEP proposed the adoption of new standard for CO_2 and nonvolatile Particulate Matter (nvPM)[1] for new engines in February 2016; the proposal currently is under consideration for adoption by the European Aviation Safety Agency (EASA, 2017). This represents a significant step for the following reasons. First, emission-reduction actions are voluntary thus far; second, international aviation and marine emissions are excluded from the climate change agreements, specifically the Kyoto Protocol emission targets and the 2°C target confirmed by the Paris Agreement (ICAO, 2016). It is noteworthy considering that turbo engines — the most employed in aviation — are produced mainly by 5 corporations, which control 96% of the market (Flightglobal, 2015). It will be easy to reach an agreement on targets once these companies share a common vision on emission reduction. Moreover, engines are bought by airlines, which are particularly sensitive to fuel cost and efficiency beyond the other social, economic, and environmental implications of reducing emissions.

5. Comparing governance options

The main characteristics of holistic and origin-based governance arrangements, as outlined in the previous section, are summarised in Table 2.

A further step in the analysis is confronting holistic and origin-based solutions according to the six policy evaluation criteria (achievability, manageability, effectiveness, efficiency, responsiveness, and coordination) presented in the methodology section (Section 2).

Achievability. The holistic rubric embraces several diverse actors and institutions; therefore, it is predictable that the target-setting process requires great efforts to obtain consensual agreement, as it was for the climate change target (Morseletto et al., 2017). This process might have easier results in the origin-based case because there are different groups that are focused on a single nitrogen issue that makes them cohesive around it. From this, they can reach a consensus for each issue areas with supposedly fewer difficulties. Conversely, targets defined under the holistic response can be significantly stronger in political terms, and with far-reaching recognition compared to origin-based responses. Instead, these refer to separated issue areas with limited political extension.

Manageability. Holistic responses can be more complex to manage in relationship to the diversity of programmes embraced and number of participants and nitrogen issues; however, targets can be managed more strongly than in the origin-based case because of the supposed strong commitment by UN institutions, backed by states' steering action. States can rely on a broad policy toolbox to make targets work (e.g., laws, taxes, incentives, regulations; see Vedung, 2010). In opposition, origin-based responses can manage targets with ease since the decision process can (allegedly) focus on limited issues.

Effectiveness. The holistic responses encompass all aspects of nitrogen with an integrated cause-effect approach, and then it is thought to reach wider results and applications than origin-based responses. In addition, with the possibility of orchestrating a vast array of institutions, holistic responses can obtain comprehensive results and leverage interconnectedness among targets and on a critical mass of programmes and actions. Differently, the origin-based arrangements can reach notable results in a single-issue area, which is even more significant when compared to holistic arrangements. However, single-issue areas have limited interrelations by design; targets reflect this characteristic.

Efficiency. The holistic rubric employs larger resources than origin-based solutions as it deals with potentially all areas of intervention for nitrogen. However, efficiency looks at resources invested in relation to the effects achieved, which are wide by definition in the holistic rubric; assessing governance solutions regarding efficiency then depends on how we weigh results. Nonetheless, through applying a general principle of entropy, it could be posited that holistic solutions — requiring greater organisation than origin-based solutions — can be less agile and less efficient in pursuing targets and their outcomes. In contrast, the holistic rubric, because of the amplitude of its scope, can be more or equally efficient than the origin-based rubric when it applies an economy of scale and reaches (with the same recourses) multiple connected targets. These caveats make it difficult to compare the two governance solutions from an efficiency perspective, as potentially both of them can reach the same level of efficiency under the best possible conditions.

Responsiveness. The holistic arrangements can imply prolonged negotiations involved in selecting multiple interests for the targets definition. However, consistent and enduring actions can result once targets (and related fine-tuned measures) are decided. Vice versa, origin-based solutions can arrange targets more promptly from its (supposed) simpler structure and more agile decision-making process. Targets can be adjusted along the way to improve the quality of outputs.

Coherence. The holistic solution relates to a vast array of arrangements and it is likely that these can have a lesser level of coherence than origin-based solutions. These arrangements can devise synergistic targets with higher-level coherence, as they are focused on single issues. On the presumption of the large the number of actors, the wider the possibility of conflicts among policies and targets, it is plausible to expect more coherence in the origin-based solutions compared to the holistic solutions.

Coordination. Assuming that coordination efforts increase with the articulation of a system, the holistic case results are more difficult to coordinate than the origin-based results. Coordination is supposed to be simpler, as it refers to homogenous groups characterised by relatively limited number of actors. However, coordination among issue areas

[1] http://www.icao.int/Newsroom/Pages/New-ICAO-Aircraft-CO2-Standard-One-Step-Closer-To-Final-Adoption.aspx; see also http://www.greenaironline.com/news.php?viewStory=2195; http://ttgnordic.com/important-progress-on-aircraft-co2-standard-aviation-mbm-expected-as-icao-environment-committee-sits-for-landmark-10th-meeting/.

Table 2
Holistic versus origin-based governance arrangements.

Characteristic	Holistic	Origin-based
Focus	Integrated cause-effect relationship	Individual cause-effect perspective
Participation and compliance	Requires a large number of actors and institutions	Limited to groups that cohere around a single-issue area
Feasibility	Depends on the agreement among multiple actors and institutions	Depends on the agreement within cohesive groups
Overall advantage	Involves main actors and institutions at the international levels	Buy-in by main actors and stakeholders in the issue area
Overall disadvantage	Difficulties in bringing together multiple and diverse actors	Issue areas can remain isolated as interlinkages among them are difficult to establish

Table 3
Policy evaluation criteria — holistic versus origin-based.

CRITERIA	HOLISTIC	ORIGIN-BASED
achievability	● more difficult because of the high number of actors involved	● easier because of cohesive groups that can reach consensus
manageability	● more complex to manage because of diversity of programmes and the number of participants	● simpler to manage because the decision process can be more lean and focused
effectiveness	● higher because of wider application and expected comprehensive results	● lower, but high on single-issue area because of lesser broad results, however effective on specific issues
efficiency	● equal under best possible conditions	● equal under best possible conditions
responsiveness	● lower because of diversity of programmes and the number of participants	● higher because of its simple structure and agile decision-making process
coherence	● lesser because of the number of actors and multi-focus policies	● higher because of the synergies among targets and policies
coordination	● more difficult because of the articulation of actors and organisations	● easier because of the higher homogeneity of groups and relatively low number of actors

might be problematic. As in the holistic responses, it seems necessary to have a governing body that helps coordinate crosscutting themes and actions among issue areas to hit targets at the global level.

Table 3 synthesises the two governance arrangements according to the considered criteria. Red and green dots are added to facilitate a rapid comparison in the table. Green is used when a solution tends to prevail on the other (in red) for each criterion. Colours have a visual purpose and they do not imply a value judgement.

In relation to the coordination criterion (but also to all other criteria), it is relevant to underline the necessity of an institution that promotes, synthesises, and coordinates scientific research on nitrogen. This institution can facilitate both the holistic and the origin-based paths. Such a role can be played by the International Nitrogen Initiative (INI) or by the International Nitrogen Management System (INMS). INI fosters the understanding of the nitrogen cycle and interacts with decision makers and stakeholders to identify management strategies. INMS is under construction, and provides coordinated scientific support for international nitrogen policy making (see Brownlie et al., 2015). INI and INMS can support institutions such as GPNM in assessing the scientific validity of possible targets for both holistic and origin-based solutions. For scientific purposes, these institutions could use NUE as a common scientific metric (since it is relative and employable at all scales), and a nitrogen cascade as common principle to assess nitrogen causes and effects. The same elements could be used by the same governance institutions, whether they follow holistic or origin-based views. For the definition of targets, both the holistic and origin-based rubrics can adopt different approaches, such as the so-called source-based or receptor-based approaches (Hicks et al., 2011). The first looks at the sources of a contaminant and can be relevant in defining emission or efficiency targets. The second looks at its endpoint contaminations and can be relevant for defining critical load targets (Bull, 1995). In particular, the receptor-based approach is significant due to the mobility and transformative characteristics of nitrogen (which is in air, soil, and water, and interacts with every living species) and because it addresses pollutants simultaneously.

To summarise, the holistic response is challenging for approval and management because of the many actors and institutions involved and because of the difficulties in having different interests converge. However, the holistic response can obtain comprehensive results for pollution reduction. Conversely, the origin-based solutions can be realised in a relatively easy way with more specific (and potentially greater) results; however, actions risk being focused on issue areas while their integration can be limited. In addition to divergent directions, there is no incompatibility among the two approaches since an origin-based solution can be absorbed eventually — at a later stage — within a holistic solution. Origin-based governance can be an intermediary step towards holistic governance.

Conclusions

The nitrogen problem calls for bold responses at the global level. Despite this, the diversity and multiplicity of actors and the way they consider the urgency of action can obstruct or slow down the implementation of effective solutions. Global targets are instruments that can favour actors working in the same direction while aligning actions towards desired achievements. In these terms, global targets are suitable to address environmental concerns at the planetary scale, in particular those caused by excessive anthropogenic nitrogen. Nitrogen is a peculiar governance issue; it gathers essential human and natural activities in a complex tangle, which are combined in assorted negative consequences to the human and natural systems. Such complexity suggests employing a target approach based on multiple global targets, which can help frame focused responses while favouring collaborative efforts to curb nitrogen pollution. The nitrogen regime is currently characterised by different arrangements and targets with partial coverage of sources and impacts. Such a state might be considered suboptimal and calls for improving governance in the direction of more coherent and integrated approaches. This study analyses two options for organising nitrogen governance at the global scale. The responses are investigated and evaluated according to their capability to define and develop targets that fit the multifaceted nitrogen problem. The two cases show that there is no easy and ready-made solution for anthropogenic nitrogen pollution. Both governance arrangements show strong and weak points, and different performances according to the selected evaluation criteria. From the analysis, it emerges that origin-based solutions can be preferable to holistic solutions as they can be more specific and potentially have greater immediate results. Independent from which governance arrangement is chosen, what matters most is the speed at which an arrangement can deploy solutions to combat (fast-growing) nitrogen pollution.

Future research should provide viable answers to nitrogen pollution from a governance point of view. I see three ways forward. One avenue can be an in-depth examination of the nitrogen regime, and consider mapping the entirety of organisations dealing with nitrogen to understand their scope, mandates, activity, and pattern of relationships. A valid analytical instrument is represented by network analysis and its applications; see Kahler (2009). A second avenue for future studies can be considering alternative ways to develop integrated approaches to nitrogen, through targets, or other instruments in the policy toolbox. Samples can be applied to the Integrated Assessment Models (IAMs) or frameworks such as the Driver-Pressure-State-Impact-Response (DPSIR); see Häyhä et al. (2016). A promising area of research seems to be related to solutions for nitrogen based on circular economy principles. A third avenue can be deepening the investigation of the governance options here proposed, and explore new ones while considering assessing criteria and side effects. These avenues should be not for academic fulfilment, but for contributing — with a can-do spirit — viable solutions to the problems caused by nitrogen in excess.

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