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A preliminary framework for understanding the governance of novel environmental technologies: Ambiguity, indeterminateness and drift

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ABSTRACT

We propose a conceptual framework to explain why some technologies are more difficult to govern than others in global environmental governance. We start from the observation that some technologies pose transboundary environmental risks, some provide capacities for managing such risks, and some do both. For "ambiguous" technologies, potential risks and risk management capacities are uncertain, unknown or even unknowable. Governance systems are indeterminate towards ambiguous technologies, as existing norms, rules, scripts and routines do not imply default solutions under institutional focal points. Indeterminateness can lead to institutional drift, with risks accordingly remaining unmitigated and risk management capacities remaining unexploited. We use the cases of solar geoengineering, gene drive systems and bioinformatics for illustrating this framework. As technological ambiguity may often be irresolvable, we conclude that it might force us to confront the limits to anticipatory global decision-making on matters of long-term environmental sustainability.

1. Introduction

Technology is central to Global Environmental Governance (GEG). Some technologies are sources of transboundary environmental or socio-ecological risks, for instance cross-border pollution from chemical manufacturing. Other technologies provide capacities for managing such risks, for instance solar power or Carbon Capture and Storage mitigating harmful impacts from climate change. Starting from this distinction, we ask why some novel technologies appear inherently more difficult to govern than others? Why are some technologies contested, disputed and subject to years of deliberations, consultations, and international negotiations that may yield little more than least-common-denominator outcomes, whereas others appear to unproblematically fit into existing governance frameworks?

We develop a theoretical framework that is broadly situated in cooperation theory (whereby states cooperate on novel technologies to realize gains or to avoid losses) and utilize a problem-structural lens (whereby the attributes of a given technology shape the associated collective action problems and interact with other relevant factors such as interests or norms; Jinnah et al., 2021). Novel technologies vary on a spectrum of *ambiguity* from ambiguous to unambiguous (Rotolo et al., 2015). Unambiguous technologies tend either to pose transboundary risks or provide capacities for managing such risks. This facilitates governance responses: for the former type, the default solution is risk assessment and management in order to reduce or avoid transboundary harm. For the latter, it is to facilitate technological development, deployment or diffusion as a global public good. Conversely, ambiguous technologies pose *some* risks and provide *some* management capacity, although the extent to which they do so is unclear. Accordingly, they cannot easily be classified as either a problem or a solution. Ambiguity can result from scientific uncertainty as well as divergent stakeholder norms and perceptions. Ambiguous technologies do not have an obvious institutional solution but instead lead to governance *indeterminateness*, with existing norms, rules, scripts and routines failing to provide clear

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answers to the regulatory challenge. Failing to resolve this indeterminateness results in *institutional drift*: the "[n]eglect of institutional maintenance in spite of external change," which results in "slippage in institutional practice on the ground" (Streeck and Thelen 2005: 31). In other words: the indeterminateness of governance systems towards ambiguous technologies drives political inaction and negligence. We propose that this framework is sufficiently flexible and open-ended to be compatible with a variety of larger theoretical perspectives in International Relations. We first develop its different conceptual elements and subsequently highlight its explanatory power for three major instances of ambiguous technologies in GEG. We conclude with some considerations on the implications of ambiguity for GEG as well as for cooperation theory more broadly.

2. Novel technologies and governance responses

Novel technologies can present sources of transboundary risks and/or provide capacities for the management of such risks. Transboundary risks entail environmental harm as well as adverse socio-ecological impacts that result from novel technologies either creating novel types of inequity or reinforcing existing ones. We choose the term "risks" to denote that such negative effects are probabilistic rather than deterministic. Risk management capacities are technology-based or technology-supported ways for assessing, managing or eliminating risks. Such capacities can serve to reduce the environmental footprint of human societies or assist them in adapting to harmful environmental changes, regardless of whether these have anthropogenic or natural origins. The purpose of relevant international institutions varies depending on whether a given technology is a source of transboundary risk or whether it offers risk management capacity. For the former category, this purpose is to avoid or reduce adverse transboundary effects, with institutional design typically having to account for negative externalities and upstream-downstream problems (Mitchell and Keilbach 2001). For the latter category, the purpose of international institutions is to supply risk management capacities as a global public good, which can entail either the technology itself or its effects (such as the global benefits from domestic renewable energy sources). The supply of global public goods faces various specific governance challenges that notably differ from those associated with the avoidance or reduction of adverse transboundary effects (Barrett 2007, National Academic of ScienceEngineering and Medicine, 2021). Novel technologies that constitute sources of risk require different governance approaches than novel technologies that offer risk management capacities; these approaches are not substitutable. In other words, institutional design must be fit for purpose. We note that international institutions can provide various other functions in regards to novel technologies, for instance regarding monitoring, enforcement or financial and technical assistance. However, we consider such functions as secondary, in the sense that they support the primary institutional functions of realizing gains or averting losses.

3. Ambiguity, indeterminateness and drift

Governance systems thus generally address technological risks from the perspective of reducing or avoiding transboundary harm and technological risk management capacities from the perspective of global public goods. The boundary between the two categories is often fuzzy, meaning that some technologies will predominantly fall into one category yet partially also into the other. Wind power, for instance, provides risk management capacities in terms of avoiding climate change, yet also poses some limited risks for some migratory species of birds. Solar power similarly has strong public goods characteristics in combination with some limited risks in its supply chain. Conversely, coal power technology and associated carbon dioxide emissions have some very limited beneficial effects (e.g. possibly on plant growth) although their harmful impacts are obviously incomparably greater.

Some technologies, in other words, *predominantly* constitute sources of risk or *predominantly* provide risk management capacities. These technologies are unambiguous in the sense that they have obvious governance implications. This greatly simplifies political responses. Once certain ozone-depleting substances were found to cause significant transboundary harm that far outweighed their limited economic utility, the international institutional response amounted to a comprehensive global phase-out of production and consumption (differences across substances and in country-specific obligations notwithstanding; Parson 2003). This is not to trivialize the challenge of effective international cooperation on such and other matters of transnational harm. In cases like this, institutional responses might still be hampered by problems of collective action and the distributional implications of regulation. The same applies to international cooperation for ensuring that the benefits associated with a technology which primarily provides risk management capacities will be supplied as a public good. Yet in these cases, the overall objectives of existing governance frameworks are relatively straightforward: while governments and other stakeholders might disagree on operational details, international institutions reflect the fundamental normative consensus that, in principle, transboundary harm should be reduced or avoided and public goods should be promoted for the benefit of the global community.

Yet there are other technologies that present uncertain, unknown or even unknowable mixtures of these two factors: they may have *some* public good characteristics and may cause *some* harm, yet the balance between the two cannot readily be discerned. Such technologies are ambiguous in the sense that it is unclear whether they should be considered as a problem or as a solution. This ambiguity results from two interlinked factors. First, novel technologies can come with significant scientific uncertainties regarding their costs, benefits, risks, feasibility, scalability and so forth. Such uncertainty is in part an unavoidable fact of life (Jasanoff 2007) yet can increase to the point where the relative benefits of different international regulatory choices become difficult to ascertain (Dimitrov 2003). Second, ambiguity may also result from differences in norms and perceptions. Differences in risk tolerance, social discount rates or social values can lead to differences in how states evaluate the relative benefits and drawbacks of a given technology. Some states might perceive a novel technology as a game changer whereas others hold a more cautious attitude. Perceptions will also differ when technological impacts are likely to be asymmetrical, for instance when some states are prone to face relatively large risk or expect relatively large benefits from technological risk management capacities.

The lack of an obvious and default way of responding to these ambiguous technologies implies *governance indeterminateness*: existing norms do not clearly define relevant standards of appropriate behavior; transaction costs impede identifying ways of applying or adjusting existing operational rules to enable cooperative gains; or decision-makers lack behavioral scripts and cognitive routines for rapidly processing the technological challenge and devising an adequate course of action. Differences in the larger ontological and epistemological outlook imply differences in how we understand the specific causes of indeterminateness. However, its mere existence as a relational property of governance systems, in regards to an ambiguous technology, appears consistent with a wide range of theoretical approaches in International Relations. Regardless of how we conceive of its causes, the consequence of indeterminateness is to complicate governance responses as a result of divergent technology assessments, a lack of agreed default solutions as well as the risk of regulatory mismatch from unknowingly choosing a governance approach that later turns out to be inconsistent with the technology in question. Indeterminateness can thus lead to a situation of institutional drift, that is, the failure of institutions to adapt to important changes in their respective functional domains (Streeck and Thelen 2005; Rabitz 2019a). As above, the link connecting indeterminateness to drift can be approached from different theoretical vantage points. A rationalist perspective, for instance, might emphasize how governments with vested interests in the status quo may use indeterminateness as a pretext for inaction until improved scientific knowledge will supposedly enable meaningful regulatory choices at an undefined point in the (distant) future (Helm 1998). Sociological accounts might emphasize how indeterminateness obscures the normative implications of international rules and thus prevents consensus on desirable behavioral responses from emerging. We suggest that the explanatory power of our framework is independent from such larger questions and, in the following three sections, briefly show how it sheds light on the governance challenges of three major instances of ambiguous technology in GEG.

4. Solar geoengineering

Solar geoengineering (sometimes called solar radiation modification), principally through the injection of aerosols into the stratosphere, is a proposed method for reducing climate change and the associated risks through the partial reflection of incoming solar energy (Reynolds 2019). A global solar geoengineering program via stratospheric aerosol injection seems to require a fraction of the costs associated with climate impacts (Barrett 2008), and its beneficial temperature effects would also manifest quickly. While there is close to zero commercial interest in the technology, a variety of modelling exercises highlight its apparent technical feasibility and efficacy for partially limiting the global rise in temperatures and thereby contributing to sustainable development. These potential benefits co-exist with significant potential risks, including the chance of environmental harm (by damaging the ozone layer or by disrupting regional precipitation patterns) and socio-environmental challenges that are being discussed under labels such as "moral hazard", "slippery slopes" or the "termination problem", among others. While a detailed discussion is well beyond the scope of this paper, the magnitude, or in some cases even the very existence, of all these risks and opportunities is a matter of substantial dispute (Reynolds 2021). Solar geoengineering is thus an ambiguous technology.

This ambiguity translates into governance indeterminateness. Again, cutting short a voluminous literature, there is no obvious focal point providing default rules, procedures, scripts and heuristics for resolving the issue in its entirety. For instance, it remains unclear whether solar geoengineering would, or should, constitute an essential tool for achieving the temperature targets of the 2015 Paris Agreement on climate change; whether it would have negative impacts on global biodiversity goals or whether it might rather serve to protect biodiversity from climate impacts (McDonald et al., 2019); or the extent to which research and deployment would, or should, be subject to the precautionary principle, considering both the risks of the technology itself and the risks which the technology is intended to manage (Reynolds 2019). Despite a plethora of proposals for how governance could be constructed for this issue (e.g. Chhetri et al., 2018; National Academic of ScienceEngineering and Medicine, 2021), governance responses have been minimal so far, primarily amounting to three non-binding governing body decisions under the Convention on Biological Diversity (CBD). With existing governance frameworks thus being largely indeterminate, governance questions pertaining to research into and potential deployment of solar geoengineering technology remain unaddressed. This has resulted in institutional drift with potential risks remaining unmitigated and risk management capacities unexploited.

5. Gene drive systems

Gene drive systems are a proposed technique for biasing patterns of biological reproduction (NASEM 2016). They would allow for genetic modifications to be "driven" through entire target populations. For species with short reproductive cycles, they would thus enable rapid population replacement (i.e. switching wild types to transgenic species) or even eradication (Esvelt et al., 2014). In principle, gene drives allow for unprecedented biological control at the ecosystem scale. In addition to combatting vector diseases such as malaria, they might be highly effective for protecting vulnerable ecosystems from biological invasions and for proofing agricultural systems against pests. As gene drives are likely to diffuse widely and potentially uncontrollably, including in a transboundary context, they present biosafety risks that are likely significantly greater than those associated with conventional Genetically Modified Organisms (GMOs). The magnitude, nature and manageability of these risks is a matter of ongoing dispute. No clearly appropriate risk assessment methodologies presently exist for gene drives (see Dolezel et al., 2020). Various technological solutions to the biosafety problem are currently being explored, such as methods for reversing the effects of gene drive releases or for limiting geographic spread, although these might also end up introducing new problems, including from unpredicted interactions among system components.

Gene drives being an ambiguous technology that might either endanger biodiversity or provide an effective tool for its conservation, global biodiversity governance is so far indeterminate (Rabitz 2019). Do gene drives pose a threat to the CBD's conservation objective or a potential tool for its implementation? How do gene drives fit into the obligation on CBD parties to "control or eradicate" invasive alien species (Article 8. h), considering that drives might either be a tool for control or eradication, or might constitute invasive alien species themselves? How would the provisions of the CBD's Cartagena Protocol on Biosafety (notably regarding risk assessment and Advance Informed Agreement) apply to gene drives? So far and as with solar geoengineering, the CBD has merely passed a series of nonbinding governing body decisions on the wider categories of "synthetic biology" that emphasize and reiterate the need for case-by-case risk assessment and precautionary decision-making. As the negotiations for the CBD's post-2020 Global Biodiversity Framework unfold, it looks increasingly unlikely that parties will adopt more detailed and stringent regulation at the 15th Conference of the Parties, to be held in 2022. While a robust international regulatory framework is absent, pilot projects are moving rapidly towards initial open field experiments, constituting a textbook definition of institutional drift.

6. Bioinformatics

The fusion between biotechnology and information technology leads to an increasing use of digitalized genetic sequences for research and development across the life sciences, notably including agriculture and pharmaceuticals. The increasing efficiency of DNA sequencing and digital storage solutions is giving birth to vast digital genomic libraries, the content of which can be analyzed at a hitherto unprecedented scale via new applications in machine learning and big data analytics. Bioinformatics holds significant potential for improving human well-being, as well as for environmental sustainability, conservation and food security (Gaffney et al., 2020). At the same time, the gradual displacement of physical samples with digitalized electronic sequences in the contemporary life sciences is raising questions regarding the fair and equitable sharing of benefits resulting from the utilization of genetic resources, a core objective of the CBD, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRA) and other instruments (Lawson et al., 2019). This objective is based on the ethical principle that the countries, communities or other organizations that have cultivated and conserved genetic resources should participate in commercial and other benefits that are derived from their utilization.

Bioinformatics is an ambiguous technology because, on one hand, the unfettered access to genetic sequence data could facilitate research and development with pay-offs for environmental sustainability: by stimulating innovation in green technologies and by contributing to biodiversity conservation (Halewood et al., 2018). On the other, the technology potentially undercuts fair and equitable benefit-sharing: the utilization and transfer of genetic sequence data is notoriously difficult to monitor, which aggravates the compliance problem in ABS, commonly and broadly referred to as "biopiracy" (Rabitz 2015). This would raise questions of social justice and prevent benefits from being channeled into projects for nature conservation. Yet the financial volume which could be leveraged through benefit-sharing from genetic sequence data is uncertain, as is the extent of spin-off benefits from innovation on the basis of such data. We neither know which monetary (and other) resources benefit-sharing could mobilize for nature conservation; nor do we know the degree to which benefit-sharing and its associated compliance procedures would hamper innovation in the life sciences.

The CBD and the ITPGRFA generally require the sharing of benefits from the utilization of physical genetic resources. The extent to which they do (and should) apply to genetic sequence data is an explosive political issue which has already wrecked a multi-year reform process under the ITPGRFA and has become a major sticking point in the negotiations on the CBD's post-2020 Global Biodiversity Framework (Rohden and Scholz 2021). The indeterminateness of governance frameworks has contributed to institutional drift: while biotechnological research and development increasingly shifts towards genetic sequence data, questions of access and benefit-sharing remain unresolved. In practice, this means that the biotechnology industry (in predominantly developed countries) continues utilizing genetic sequence data without appropriate international and national regulations that would ensure the fair and equitable sharing of benefits with the stakeholders (predominantly from developing countries) that have cultivated and conserved the corresponding physical specimens. This highlights the distributional implications of indeterminateness and drift.

7. Conclusions

The growing relevance of technology for GEG requires an appropriate conceptualization of their relationship. We have here provided a preliminary conceptual approach that centers on technological ambiguity as a key factor influencing governance responses. Our framework is sufficiently flexible and open-ended to be compatible with a variety of theoretical traditions, such as rationalist or sociological approaches to international cooperation and institutions. In other words, we do not aim to provide a competing account but rather propose a middle-range conceptualization which can be integrated into different ontological and epistemological frameworks in order to (hopefully) enable a more fine-grained analysis of novel technologies in GEG.

As we propose, and as the cases of solar geoengineering, gene drives and bioinformatics highlight, ambiguous technologies pose substantial governance challenges and tend to be met with political inaction, negligence or indecisiveness. This appears to be the case outside of the environmental sphere as well. Contemporary developments in Artificial Intelligence, machine learning and big data, for instance, may offer vast improvements to human well-being while simultaneously raising major questions on issues such as algorithmic discrimination, civil rights implications of facial recognition software or the status of lethal autonomous weapon systems under international humanitarian law. There and elsewhere, the indeterminateness of governance systems towards ambiguous technology implies a threat of systematic under-regulation.

As ambiguity can result not just from scientific uncertainty but also from divergent norms and perceptions, expert advice is no silver bullet and might even be detrimental if the existence of genuine differences in values or in technology assessment criteria is treated as a mere lack of scientific information (Jasanoff 2007). Somewhat schematically, governance choices for ambiguous technologies boil down to restrictive regulation (thus reducing or avoiding harm but possibly missing out on critical capacities for the management of environmental risks) or enabling regulation (thus seeking to unlock management capacities but possibly incurring harm in the process). Neither sound science nor precaution offers an easy way out of this dilemma: as both can lead to enabling regulation for technologies that turn out to predominantly constitute sources of risk, or inappropriately restrictive regulation for technologies that might otherwise have provided important capacities for reducing anthropogenic impacts on nature or for making human societies more resilient to environmental changes. Crucially, there is no solid basis for preferring either approach *ex ante*. A powerful illustration of this problem is the debate on solar geoengineering: given the systemic political failure in the global efforts for climate change mitigation, foregoing a potential future use of solar geoengineering might be folly – yet developing or deploying such measures might just as well turn out to be dangerous. All of this raises the uncomfortable question whether technological ambiguity presents a hard limit to what GEG can accomplish? This might seem to suggest there are situations that demand a regulatory leap of faith – that is, locking-in a regulatory choice on the prohibition-facilitation spectrum without the possibility to resolve ambiguities, and without the option of deferring to overarching principles such as sound science or precaution as general heuristics. However, the key lies in accepting ambiguity and embarking on a deliberative governance pathway that 'keeps an eye' on the evolving risk landscape, builds up diverse decision-making capacities in appropriate governance institutions, and maintains the requisite governance adaptability that does not preclude future regulatory choices – once such decisions emerge as appropriate responses to the evolving risk landscape.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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