ready known to be present in an individual's genome could reveal information distinctive to that individual. GA4GH members have been developing solutions to this potential security breach since the project's inception, including aggregating data among multiple beacons, tracking usage to restrict systematic searches and introducing tiers of secured access that require users to be authorized for data access—but these necessarily limit the scope of information that can be shared widely. Innovative policy and regulatory measures, as well as technological solutions, are needed to securely handle individual genomic and clinical data.

A second challenge is scalability. For every problem there will be domain-specific challenges that may require uniquely applicable tools. For instance, the field of dementia research may demand new solutions that integrate data from brain MRI technology. Furthermore, it is expected that individual fields will have previously developed standards, which may demand that GA4GH adapt its existing solutions in order to be compliant. Applying existing GA4GH approaches in new contexts will require solutions that are easily portable, customizable, and interoperable. GA4GH must also focus on solutions that can benefit many different patient groups, jurisdictions, health systems, and environmental and socioeconomic realities, such as interoperability with mobile devices, which are now broadly available even in developing nations. Open technology, built-in interoperability, and ease of use of data-sharing tools are essential.

Data sharing has inherent costs related to data curation, hosting, and computation. Hoopen *et al*. described substantial costs of post-data curation, leading to a proposal for lower-cost submitter-driven annotation as a more sustainable curation solution (*12*). Many databases currently recover costs through user fees (*13*), creating either a need to charge and share revenue or a two-tiered system that may limit some downstream users from accessing the full complement of information. Member projects, such as ICGC's PanCancer Analysis of Whole Genomes (PCAWG), have implemented federated cloud-based solutions that bring the cost of analyzing a single sample from U.S. $200 by using traditional academic high-performance computing models to under U.S. $20 per sample. Cloud-based approaches also have the benefit of being compatible with some country-specific legal frameworks (*14*). Several business models to support genomics big data research have been proposed, including a subscription model, which may inherently limit access, and a "freemium" model, which charges not for data access but for associated services, such as curation and interpretation (*15*).

Notwithstanding emergence of new business models for private and public sector partnerships to support some data-sharing costs, government agencies may need to support some features of the ecosystem (e.g., curation) so that clinicians and patients have access to as much free, curated data as possible. In addition to economic incentives, more can be done to establish greater academic recognition for data sets through citations and microattribution, in which quantitative credit is attached to every data-use accession (*16*, *17*).

Finally, ensuring engagement among the entire global community is necessary from a social justice and medical perspective, although this will likely require distinct legal, cultural, and business models. In some countries, health care and research organizations are interested in GA4GH as a means to link nascent national efforts in precision medicine with other international groups, such as the Brazilian Initiative on Precision Medicine (www.fcm.unicamp.br/gtc/evento/1/trabalho/8). Training and infrastructure needs related to data storage, management, security, and policies are common to many jurisdictions. Technology and economic incentives can make it possible for an international, federated network of genomic and clinical data to become a network for learning that will illuminate causes of disease and potential interventions for prevention and treatment. ■

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SUPPLEMENTARY MATERIALS

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CLIMATE CHANGE

Global adaptation after Paris

Climate mitigation and adaptation cannot be uncoupled

By **Alexandre K. Magnan** *and* **Teresa Ribera**

Besides achieving major decisions on greenhouse gas (GHG) emissions mitigation, the 2015 Paris climate change Agreement (*1*) also initiated a process to "establish a global goal on adaptation" (Article 7.1), a crucial step that encourages parties to the agreement to go beyond the restrictive and historic funding-focused lens that structured United Nations Framework Convention on Climate Change (UNFCCC) talks on adaptation until now (*2*–*4*). Suggesting that global adaptation is as important as global mitigation is an important shift in international climate negotiations that highlights the importance of not uncoupling 21st-century

POLICY

PHOTO: AP PHOTO/PETER DEJONG

Dutch coast line reinforced in anticipation of rising water. Sand supplementation uses natural currents to push sand onto coastal dunes and dikes—in Petten, Netherlands, 7 million cubic meters (247 million cubic feet) of sand were dumped in 2008 in front of a sea-dike.

mitigation and adaptation storylines. After all, one cannot define the "well below +2°C" long-term temperature goal as sustainable without providing evidence on societies' ability to adapt to the unavoidable impacts of such warming (*5*). Although this represents great progress, we discuss three key challenges around the development of a global adaptation framework within the UNFCCC: defining a global goal, identifying tracking criteria, and anticipating political barriers. A major underlying condition is that the framework must make sense from both a negotiation and a scientific perspective.

For the first time, parties are encouraged to build a collective understanding of what adaptation means, notably through definition of references and tools to capture, track, and aggregate national adaptation efforts (Art. 7.14 and Decision 1/CP.21 paragraph 43b). A more comprehensive framework for global adaptation can help answer a crucial question that parallels the one on global mitigation: Are we as humankind on track to adapt to climate change?

UNDERLYING RATIONALE. Before Paris, many international scientific efforts, such as the Intergovernmental Panel on Climate Change (IPCC) syntheses, highlighted the importance of adaptation due to the irreversibility of some climate change impacts. Almost exclusively focusing on local-to-national approaches, they raise three main conclusions. First, although some territories are at the frontline of climate change impacts and will be affected first (e.g., small islands, arctic and desert margins), no country is in a safe position over the century (*6*). Second, there is a growing number of adaptation responses emerging in both developed and developing countries (*7*), which make adaptation a challenge not only for the Global South. Third, the general understanding seems to be that the shaping and implementation of adaptation only come under national to local purview (*4*, *8*). This is too restrictive, as it does not account for risks from non- or maladaptation beyond national boundaries—on regional to global scales (*9*). Adaptation initiatives in one place may have adverse effects in neighboring places or interconnected ones, so that reducing vulnerability here can lead to increasing vulnerability there (*4*, *10*). One must also consider the risk that countries will not be able to adapt, which will have negative effects at regional to global scales (e.g., human migration, or slowdown in crop production).

Together, these arguments advocate for better consideration of trans-boundary effects of national adaptation strategies, and for strengthening bilateral to multilateral cooperation. Although the UNFCCC Cancún Adaptation Framework already stresses this point, it limits cooperation to countries that have common direct and revealed interests. Yet, the cascading effects of climate change impacts suggest that there will also be partly unpredictable ramified consequences. This emphasizes the need for the international community to anticipate impacts before they occur (i.e., address the unrevealed impacts) and consider possible indirect impacts (i.e., cascading effects).

Beyond simply providing funds for national-level adaptation, there is a need for enhancing a global sense of responsibility on the shaping of adaptation. This supposes the international community to improve the comprehensiveness of the existing Cancún Adaptation Framework. It could be inspired by the way the framework for mitigation has been progressively developed, i.e., definition of a common goal (the +2°C target established in Copenhagen in 2009) and references and tools [e.g., atmospheric pollution equivalent to one metric ton of CO_2 and Intended Nationally Determined Contributions (INDCs)] to track progress and efficiency.

EXPECTATIONS AND CHALLENGES. At least four major benefits are to be expected from a global adaptation framework. First, it would be a way to put nations of the world on the same road, as happened for mitigation. Second, it would provide incentives and guidance at the national level (*11*), which will stimulate design and implementation of adaptation strategies. Here again, the case of global mitigation is inspiring. Third, it would help address the under-debated question "Are we on track to adaptation?", which is complementary to "Are we on track to mitigation?", to decide whether the well below +2°C, if not +1.5°C, mitigation target established in Paris describes a sustainable future. Last, the better we track adaptation at the national level, the better we will be able to anticipate and avoid negative effects of non- or maladaptation on the regional to global scales.

Three major challenges arise and lay foundations for a post-2015 road map for climate negotiations on adaptation. First, we must define what a global adaptation goal should be, as this is the first building block of any tracking mechanisms. Both the Cancún Adaptation Framework and the Paris Agreement (*1*) remain imprecise on this, the latter referring to "enhancing adaptive capacity, strengthening resilience and

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reducing vulnerability to climate change, with a view to contributing to sustainable development." Such a multitarget perspective (i.e., adaptive capacity + resilience + vulnerability + sustainable development) is too broad and gives way to very intuitive and subjective interpretations. Something more specific is needed.

As food for thought, we draw on our previous work (*9*) in proposing the following definition of the global adaptation goal, which addresses a more precise issue (i.e., human security): the commitment of the international community to ensure human security in a "well below +2°C" world by the end of the century, meaning first, enhancing adaptation efforts when possible, and second, providing adequate answers for those whose security could not be covered in a well below +2°C world. We link the global adaptation goal to human security in response to widespread and crosscutting threats that can spread rapidly within and across nations and generate crises that challenge both governments and people. In addition, in line with the United Nations Office for the Coordination of Humanitarian Affairs, human security underscores the universality and interdependence of a set of freedoms that are fundamental to human life, as well as to societies' adaptive capacity to climate change (e.g., equity, access to safe environmental resources).

A second challenge calls on the scientific community to help move toward a more structured approach to adaptation and more explicit targets by defining criteria to capture adaptation national efforts. There is a long-standing and sensitive debate on indicators (*4*, *12*). On one hand, defining qualitative and/or quantitative metrics at the national level raises problems such as representativeness ("Do indicators capture what is really happening in the field?") and comparability (an indicator can be relevant for one country but not another). On "representativeness," for example, a national adaptation plan may not necessarily entail nationwide efficiency in the adaptation decision-making process. On "comparability," for example, an indicator reflecting the percentage change of the economic cost of extreme events in 2050 compared with that change in 1990 encounters the problem of discrepancies from one country to another in the extent of national databases and current levels of exposure. These limitations are inherent in the context-specific nature of adaptation.

On the other hand, as shown for mitigation within the UNFCCC context, a universal agreement requires negotiations to be based on a few clear criteria. Given that impacts are and will be worldwide, and non- or maladaptation has and will have transboundary effects, it is crucial to overcome the "intuitive and subjective" understanding of adaptation currently spread through negotiations. Even imperfect references to capture adaptation are needed to guide and delimit international discussions.

A way to reconcile the pros and cons of indicators could be for scientists to provide parties to the UNFCCC with an updated synthesis of benefits and limitations of existing methods to assess adaptation efforts qualitatively and quantitatively (*13*, *14*)—in line with the IPCC principle of being policy-relevant without being policy-prescriptive. Parties could discuss the relevance of those references from a policy point of view and identify indicators to apply at the country level, in accordance with national circumstances and country-driven principles enhanced in the Paris Agreement (Art. 2.2 and 7.5).

"Even imperfect references to capture adaptation are needed to guide and delimit international discussions."

One example comes from Mexico's INDC (*15*): reduce by 50% the number of municipalities considered "most vulnerable" to climate change. The key is to support knowledge coproduction (*16*) to define equilibrium between what is scientifically robust and what is politically acceptable, and eventually assess the feasibility of an indicator-based framework. This supposes that the scientific and the negotiation communities will make compromises. Scientists must accept an imperfect and rough estimate of adaptation efforts to be a foundation for international action. Parties must accept being challenged by scientists on the robustness of their criteria in order to avoid misinterpretations. For example, it would be crucial in the case of Mexico to clearly define what describes the "most vulnerable" municipalities.

Last, tracking adaptation efforts and transboundary negative consequences will raise political barriers. For example, some developing countries could be reluctant to report their adaptation efforts, depending on the way the international community will take them (e.g., encourage further efforts with more funding or prioritize countries showing less progress). Some developed countries may fear that their own authorities, populations, and stakeholders can blame them for insufficient nationwide efforts. Although it is difficult to envisage all political barriers now—particularly as they may be correlated to barriers inherent in the negotiation process on mitigation—it is important to pay attention to their emergence. Science has a vital role to play, notably, by demonstrating the usefulness of a global adaptation framework and by regularly bringing new empirical evidence on indirect and collateral effects of non- or maladaptation beyond national boundaries.

Three conditions will eventually determine whether Paris really laid foundations for a new era for climate change adaptation. The first is ratification of the Paris Agreement by April 2017 (*1*). The second is the ability of the international climate negotiation community to build a more comprehensive global adaptation framework and not uncouple mitigation and adaptation storylines over the 21st century. This will partly depend on the third condition: the effectiveness of the science-policy interface and the ability of the scientific community to help define practical criteria (i.e., specific adaptation goals reflecting national circumstances), design tracking protocols (i.e., how to aggregate national contributions and provide a global stocktaking), and develop research to assess adverse effects of non- and/or maladaptation (e.g., transdisciplinary analyses of concrete case studies). ■

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