Smoke from a forest fire in the Sierra Nevada Mountains, California (16 June 2008).

CLIMATE POLICY

Making climate science more relevant

Better indicators for risk management are needed after Paris

By **Charles F. Kennel,[1,2] Stephen Briggs,[3,4] David G. Victor[5,6,7]**

For nearly three decades, the central goal in international climate policy had been to set the political agenda—to engage all countries on the need for action. So long as that was the goal, it was sufficient for policy-makers to focus on simple indicators of climate change, such as global average surface temperature. With the 2015 Paris Agreement, governments launched a process that can move beyond setting agendas to coordinating national policies to manage the climate. Next month in Marrakesh, diplomats will convene to flesh out the Agreement. They need to focus on the infrastructure of data and analysis that will be needed as the Agreement becomes operational. The scientific community can help by identifying better lagging indicators to describe what has changed as policy efforts progress, and leading indicators to focus policy on the right risks as the planet warms.

Instead of setting climate commitments centrally through a "top down" process, the genius of the Paris approach is to decentralize. Countries set, then extend, their own pledges. If the system works as planned, it will lead to deeper global cooperation that is flexible enough to accommodate the diversity in national interests and capabilities (*1*). Yet the flexibility of this approach is also its greatest risk in implementation. Managing this complex, highly decentralized process must engage all levels of government and the private sector. The scientific community should judge its relevance by whether it helps these decentralized actors and its processes craft and implement more effective policies.

PLANETARY VITAL SIGNS

The Paris Agreement continued the practice of setting goals according to global average surface temperature (*2*). Yet global temperature is not the most fundamental indicator of climate system change (*3*). A larger suite of indicators—what we called "planetary vital signs" (*4*)—could convey a more balanced picture (*5*). Earlier this year, policy-makers recognized the need for such information (*6*). Now, a concrete plan is needed to provide better vital signs. The first deadline is 2018 when the Paris Agreement will finish its first "stocktaking" of its progress.

The first steps to meeting that deadline are being taken. The Global Climate Observing System (GCOS), hosted by the World Meteorological Organization, defined 50 "essential climate variables" (ECVs) (*7*) that can organize acquisition of the observations needed to understand and model climate. This list is too long and complex, but GCOS is well suited to convening discussions about assembling ECVs into a few vital signs that can inform policy-makers and the public about climate change. Other groups are working on similar fronts, which is auspicious, but the scientific community needs to focus more on coordinating the many groups working in this area.

Making these vital signs useful for policy will require that scientists codevelop the indicators with policy-makers to align what we can measure technically (now and in the future) with what policy-makers actually need (*4*). If the scientific community is well organized by 2018, it will be poised to take advantage of a big political opportunity. The first Paris stocktaking will surely find that national pledges are far off track to meet the 2°C goal, which is likely to trigger a search for more realistic lagging indicators of progress.

BETTER RISK MANAGEMENT

Whereas better lagging indicators are essential, the real transformative potential lies with helping policy-makers address climate change as a risk-management problem.

King *et al.* (*8*) draw a useful distinction between two kinds of climate risk indicators. Direct risk refers to the probability of an ecological or societal impact of incremental change in climate, whereas systemic risk is the likelihood of major system compromise, natural or human. Direct risk is the easier of the two for scientists to estimate, in the realm of partial derivatives calculated against stable, orderly systems. It is calculated forward, starting from an ensemble of climate change forecasts, and is evaluated independently of the broader social system. Countries are doing these assessments (*9*), as are coastal zone managers, the insurance industry, and many others. Direct risk is familiar to anyone who has purchased fire insurance for their home or a policy-planner who has contemplated how to respond to a discrete, uncertain event.

Assessing systemic risk is more difficult yet more essential. It starts in a similar way—with an actuarial perspective that assesses the likelihood of impacts on valued assets—but aims to uncover how whole systems will respond. For example, there is growing interest in how climate changes will affect crop yields. In turn, yields affect incomes in

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farming communities and food supplies in local and global markets. But the questions of greatest import for policy-makers concern the whole system—in the face of rare extreme events—such as whether famine or economic recession will follow. Climate and remote-sensing experts can provide partial answers for some of the forces that drive famine; social scientists, less precisely, can generate indicators that synthesize those driving forces with the social conditions that are often the root cause of famine. Such analyses establish the plausibility of the risks decision-makers are prepared to act on. The more trustworthy the leading indicators are about impact, the better motivators of action they could be.

The Bayesian methodology for producing reliable systemic risk indicators has been understood for a long time. This approach relies on making best estimates—often through elicitation of the views of experts who may have insight into system behavior—and then adjusting estimates based on experience and other sources of new information. What's new—in contrast with existing integrated assessment models that dominate much of the climate science debate—is that useful Bayesian analysis for climate risks should start by asking decision-makers what matters to them along with their insights about social system response. Also new is the ability to inform this process with large data sets—including large numbers of climate model projections—that can inform climate risk analysis. The weaker link lies in the social sciences—in developing systematic ways to characterize how different types of societies respond to stresses of different types and magnitudes. When looking at flood or drought risks, for example, the natural science community is well geared to interrogate climate projections and complex watershed models that connect mountain snows, rainfall, and soil moisture to river and underground aquifer flows. Such methods arrive, with reproducible methods, at probabilistic estimates of the likelihood of floods and droughts of given magnitudes. But assessing the full systemic impacts requires knowing how humans and societies will respond.

Making this Bayesian approach to systemic risk useful will require that scientists and decision-makers codesign risk indicators—and update each other's prior assumptions about the best approaches. Such interactions will identify the data that can be brought to bear on the question of interest. Societies that are making big investments in climate impacts assessment—for example, California, which does regular evaluation of the state's exposure to climate risks (see the photo), such as wildfires and storm surge—are showing how science and policy communities can work in tandem. But such assessments remain the exception.

By itself, Bayesian logic will not be enough. Often the right questions about systemic risk are not apparent. To complement Bayesian analysis, "big data" analytics do not always start with questions, but can spot things to ask questions about. New techniques of empirical analysis and data mining are well suited to probing complex systems whose emergent properties—and risks—are often hard to fathom. For example, machine learning, which can recognize patterns in unstructured or unrelated data sets, could be used to diagnose hard-to-perceive ecological responses to slowly changing climate patterns.

A few societies—mainly in the world's richer countries—are poised to improve how they think about systemic risk. It is crucial that these insights spread to the rest of the world. Science along with policy support can help by showing how to apply these methods with replicable pilot projects. In Paris, the wealthier governments, which are most responsible for warming emissions, reaffirmed their commitment to financial help for less-developed countries to manage climate risks. Some of those funds should be earmarked for risk assessments to help the least-developed societies prepare. International science should work with local teams of scientists and decision-makers to pilot appropriate local examples. For example, the techniques being used in the California climate assessments could be demonstrated in reduced form within highly vulnerable, least-developed countries.

"...the real transformative potential lies with address[ing] climate...as a risk-management problem."

MAKING SCIENCE MORE RELEVANT

Full-blown efforts to manage climate risks will be extremely expensive. Even in the least-developed countries, the cost will likely far exceed new funds promised under the Paris Agreement. Leverage will be essential so that societies of all types build and embed effective risk management. Although local circumstances vary enormously and each society must work out its own details, a common set of indicators, well-established models, and case studies can help.

The good news is that governments, nongovernmental organizations and businesses are poised to do this if the scientific community can organize climate risk information in ways that align better with policy needs. Much of the needed data and many methods already exist. What is missing are demonstrations of how these data and methods can be used and improved for understanding systemic risks. In practice, it will be hard to work out the best examples within large intergovernmental processes in which formal decision-making requires consensus. Formal agreements on the best approaches to risk indicators are unlikely. Instead, volunteers are needed to show the way. The United States (*10*) and the European Union (*11*) are developing climate services that will provide more concrete assessments of risk and response. Such national efforts, along with local ones, should be designed with an eye to what they teach the rest of the world about what works. Similarly, commercial attention to climate risk management is rising quickly as data and analysis tools become available. Already, many firms are reporting their exposure to regulatory risks, as demanded by many shareholders and a growing number of stock exchanges. Science should help decision-makers understand their true exposure to risk and the full range of management options. The role of international policy processes should be to ensure that such experimentation with methods and approaches happens more globally.

The ultimate aim of scientific efforts on indicators should be more-robust decision support systems that can work at all levels of government, in firms, and in other social institutions. With the right tools and indicators, the practice of risk management can scale quickly through policy and commerce. For all its diplomatic difficulties, the hard work to turn the Paris process into a reality has just begun. There will be political squabbles and setbacks. Yet the task remains to build a more effective decentralized, yet global, system for risk management. ■

REFERENCES AND NOTES

1. R. O. Keohane, D. G. Victor, *Nat. Clim. Change* **6**, 570 (2016).
2. United Nations, "Adoption of the Paris Agreement" (UN, Paris, 2015).
3. D. G. Victor, C. F. Kennel, *Nature* **514**, 30 (2014).
4. S. Briggs, C. F. Kennel, D. G. Victor, *Nat. Clim. Change* **5**, 969 (2015).
5. C. Rapley, talk presented at *Global Climate Observation: The Road to the Future*, Amsterdam, 2 to 4 March 2016.
6. UN, "Matters relating to science and review: Research and systematic observation" (UN, Bonn, 2016).
7. World Meteorological Organization, "The Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC" (WMO, Geneva, 2003).
8. D. King, D. Schrag, Z. Dadi, Q. Ye, A. Ghosh, *Climate Change: A Risk Assessment* (commissioned by the U.K. government, London, 2015); http://bit.ly/2dmYgi8.
9. J. M. Melillo, T. C. Richmond, G. W. Yohe, Eds., *Climate Change Impacts in the United States: The Third National Climate Assessment* (U.S. Global Change Research Program, Washington, DC, 2014).
10. A. C. Janetos, M. A. Kenney, *Front. Ecol. Environ.* **13**, 403 (2015).
11. R. B. Street, *Clim. Serv.* **1**, 2 (2016).

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