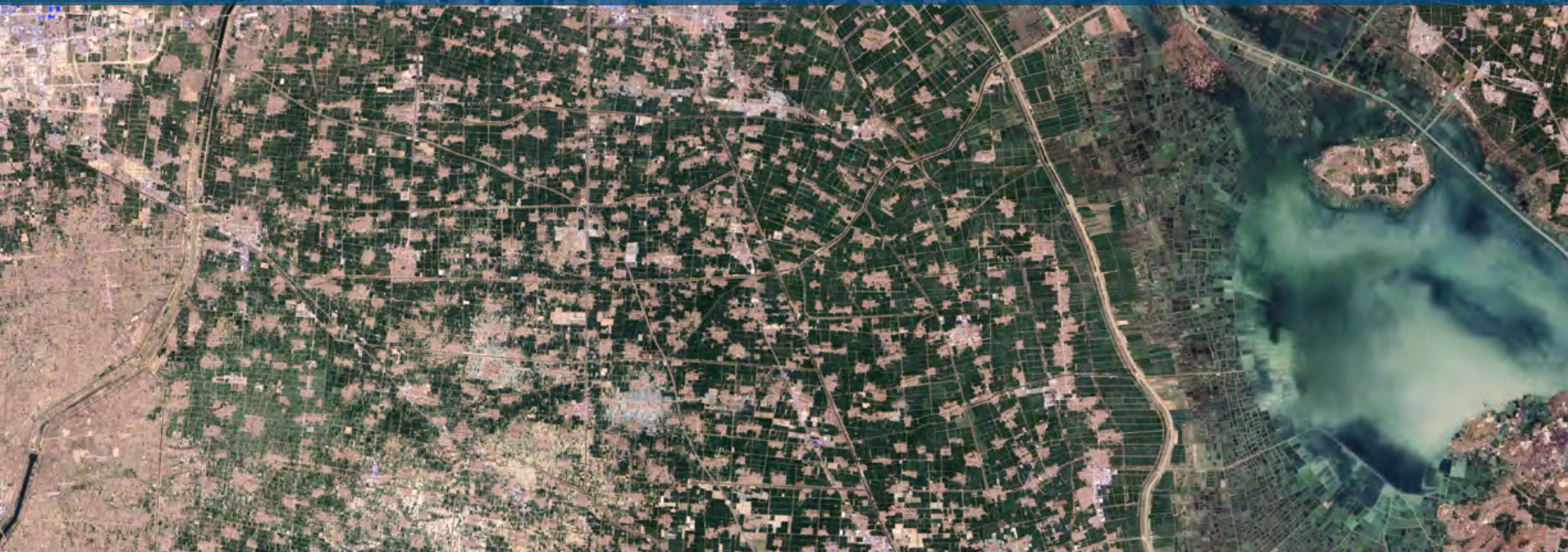
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

GLOBAL CHANGES

MIT JOINT PROGRAM ON THE SCIENCE & POLICY OF GLOBAL CHANGE
SUMMER 2016

IN THIS ISSUE:



OUR RESEARCH MISSION

At the Joint Program, our integrated team of natural and social scientists studies the interactions among human and Earth systems to provide a sound foundation of scientific knowledge. Such a foundation will aid decision-makers in confronting the interwoven challenges of future food, energy, water, climate and air pollution issues, among others.

Our mission is accomplished through:

- *Quantitative analyses of global changes and their social and environmental implications, achieved by employing and constantly improving an Integrated Global System Modeling (IGSM) framework;*
- *Independent assessments of potential responses to global risks through mitigation and adaptation measures;*
- *Outreach efforts to analysis groups, policymaking communities, and the public; and*
- *Cultivating a new generation of researchers with the skills to tackle complex global challenges in the future.*

IN THIS ISSUE

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY OF GLOBAL CHANGE

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SUMMER 2016 GLOBAL CHANGES

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The National Climate Plan Accelerator

Enabling the world to meet the 2°C Challenge

A key part of the Paris Agreement adopted at the U.N. Climate Change Conference (COP21) in December 2015 was a set of voluntary, climate-related actions submitted by nearly every country in the world. These actions, called Nationally Determined Contributions (NDCs), include quantitative targets for greenhouse gas (GHG) emissions reductions and goals for adapting to potential effects of climate change such as sea-level rise. Many NDCs are brief and contain few details that clearly define national goals or specify how they will be achieved. A central challenge is to ensure that participating countries implement their COP21 pledges and accelerate actions toward more ambitious goals.

Our analysis in the Joint Program has shown that collectively, the COP21 pledges fall far short of the Paris Agreement's overarching goal of limiting the rise in mean global surface temperature since preindustrial times to two degrees Celsius. Reaching that goal would require an 80-to-90-percent emissions reduction by the end of the century. Implementation of COP21 pledges will certainly slow the pace of global warming, but much more stringent commitments will be needed after 2025 (the Paris commitment period) to reach the 2°C target by 2100.

Toward that end, the Joint Program is well-equipped to help countries implement their NDCs in an effective manner and accelerate efforts to further reduce their GHG emissions. Models we've developed have already helped decision-makers in the U.S., Europe, Japan, Canada and elsewhere in thinking through their climate goals. A case in point is our China Energy and Climate Project (CECP), in which we've worked closely with faculty and students at Tsinghua University to develop China-specific versions of the models we use in the Joint Program. CECP research has informed China's plans to adopt a cap-and-trade system to reduce its GHG emissions, as well as the potential role of nuclear power and renewable electricity in its energy mix.

Building on this success, we are now joining together with other groups at MIT, most notably the Climate CoLab, to develop what we call the National Climate Plan Accelerator (NCPA). Led by a core group of universities around the world and a variety of other partner organizations, we envision the NCPA as a global online network to help countries create detailed, expert-validated plans to meet or exceed the goals in their NDCs. The NCPA will consist of four components: engagement, knowledge bases, evaluation and financing.

The first component, ***engagement***, is about catalyzing individuals and organizations at the subnational level (e.g. NGOs, municipalities, businesses) to develop project proposals and national plans to reduce emissions. Using the Climate CoLab's online crowdsourcing approach, it also involves learning about vulnerabilities of people and places to climate change, and thus better targeting adaptation projects and funding.

> *"The Joint Program is well-equipped to help countries implement their NDCs in an effective manner and accelerate efforts to further reduce their GHG emissions."*

To support this work, the second component, ***knowledge bases***, will enable people around the globe to easily access information on best practices for emissions reduction. Entries in these knowledge bases would range from details on effective policies and how to implement them, to low-carbon technologies and their readiness for large-scale deployment.

The third component, ***evaluation***, will draw heavily on the work of the Joint Program. Using our Integrated Global System Modeling (IGSM) framework, we can, with collaborating institutions around the world, help develop economic models for individual countries. We envision working with in-country experts to determine whether their nation's climate action plans will meet the goals they've laid out, the most effective policies to achieve them, and how they might accelerate beyond those goals.

The fourth element of the Accelerator, ***financing***, addresses a critical element of the Paris Agreement: how resource-limited countries will fund implementation of their NDCs. We hope to engage public and private organizations interested in investing in concepts for low-carbon energy technologies, other mitigation actions and climate-change adaptation.

We are now reaching out to collaborators around the globe to develop the NCPA network. Having initiated discussions with partners in China, Mexico, Brazil, Africa, India and Southeast Asia as well as major NGOs and funding agencies, we aim to launch NCPA as a pilot project and produce some preliminary results within the next year or two. It's an ambitious effort but one that we believe is at the scale needed to confront the massive challenge posed by the climate problem. If we look at climate change as too big of a problem to undertake, then we'll never solve it. ■

—John Reilly, Joint Program Co-Director

Water Problems in Asia's Future?

Study finds high risk of severe water stress in Asia by 2050

PHOTO: MIT NEWS

By Peter Dizikes, MIT News Office

Economic and population growth on top of climate change could lead to serious water shortages across a broad swath of Asia by the year 2050, a study by MIT scientists has found.

The study deploys detailed modeling to produce what the researchers believe is a full range of scenarios involving water availability and use in the future. In the paper, the scientists conclude there is a "high risk of severe water stress" in much of an area that is home to roughly half the world's population.

Having run a large number of simulations of future scenarios, the researchers find that the median amounts of projected growth and climate change in the next 35 years in Asia would lead to about 1 billion more people becoming "water-stressed" compared to today.

And while climate change is expected to have serious effects on the water supply in many parts of the world, the study underscores the extent to which industrial expansion and population growth may by themselves exacerbate water-access problems.

"It's not just a climate change issue."

"It's not just a climate change issue," says Adam Schlosser, a senior research scientist and deputy director at MIT's Joint Program on the Science and Policy of Global Change and a co-author of the study. "We simply cannot ignore that economic and population growth in society can have a very strong influence on our demand for resources and how we manage them. And climate, on top of that, can lead to substantial magnifications to those stresses."

The paper, "Projections of Water Stress Based on an Ensemble of Socioeconomic Growth and Climate Change Scenarios: A Case Study in Asia," was published in the journal *PLOS One*. The lead author is Charles Fant, a researcher at the Joint Program. The other co-authors are Schlosser; Xiang Gao and Kenneth Strzepek, who are also researchers at the Joint Program; and John Reilly, a co-director of the Joint Program and senior lecturer at the MIT Sloan School of Management.

Water impacts vary by region. China is impacted most by wealth and industrial growth, while India is more affected by population growth.

Teasing out human and environmental factors

To conduct the study, the scientists built upon an existing modeling framework developed previously at MIT, the Integrated Global System Modeling (IGSM) framework, which contains probabilistic projections of population growth, economic expansion, climate and carbon emissions from human activity. They then linked the IGSM to detailed models of water use for a large portion of Asia encompassing China, India and many smaller nations.

The scientists then ran an extensive series of repeated projections using varying conditions. In what they call the "Just Growth" scenario, they held climate conditions constant and evaluated the effects of economic and population growth on the water supply. In an alternate "Just Climate" scenario, the scientists held growth constant and evaluated climate-change effects alone. And in a "Climate and Growth" scenario, they studied the impact of rising economic activity, growing populations and climate change.

Approaching it this way gave the researchers a "unique ability to tease out the human [economic] and environmental" factors leading to water shortages and to assess their relative significance, Schlosser says.

This kind of modeling also allowed the group to assess some of the particular factors that affect the different countries in the region to varying extents.

"For China, it looks like industrial growth [has the greatest impact] as people get wealthier," says Fant. "In India, population growth has a huge effect. It varies by region."

The researchers also emphasize that evaluating the future of any area's water supply is not as simple as adding the effects of economic growth and climate change, and it depends on the networked water supply into and out of that area. The model uses a network of water basins, and as Schlosser notes, "What happens upstream affects downstream basins." If climate change lowers the amount of rainfall near upstream basins while the population grows everywhere, then basins farther away from the initial water shortage would be affected more acutely.

Future research directions

Other scholars who have examined the work say it makes a valuable contribution to the field.

"They're looking at a really important issue for the world," says Channing Arndt, an agricultural economist at the United Nations' World Institute for Development Economics Research, who thinks that the basic finding of the study "makes sense."

Arndt also believes that the ambitious scope of the study, and the way it evaluates the effects of climate change as well as economic and population growth, is a worthwhile approach. "Doing it in this integrated way is the right way to go about it," he adds.

The research team is continuing to work on related projects, including one on the effects of mitigation on water shortages. While those studies are not finished, the researchers say that changing water-use practices can have significant effects.

"We are assessing the extent to which climate mitigation and adaptation practices—such as more efficient irrigation technologies—can reduce the future risk of nations under high water stress," Schlosser says. "Our preliminary findings indicate strong cases for effective actions and measures to reduce risk."

The researchers say they will continue to look at ways of fine-tuning their modeling in order to refine their likelihood estimates of significant water shortages in the future.

"The emphasis in this work was to consider the whole range of plausible outcomes," Schlosser says. "We consider this an important step in our ability to identify the sources of changing risk and large-scale solutions to risk reduction." ■

Related Publication:

Fant, C., C.A. Schlosser, X. Gao, K. Strzepek and J. Reilly, 2016: Projections of Water Stress Based on an Ensemble of Socioeconomic Growth and Climate Change Scenarios: A Case Study in Asia, *PLOS One* 11(3): e0150633.

In the News:

Additional coverage of this research appeared in the Christian Science Monitor, Time, CNBC and Voice of America.

Winds of Change?

Study: China could go big on wind power — if it adjusts its grid operations

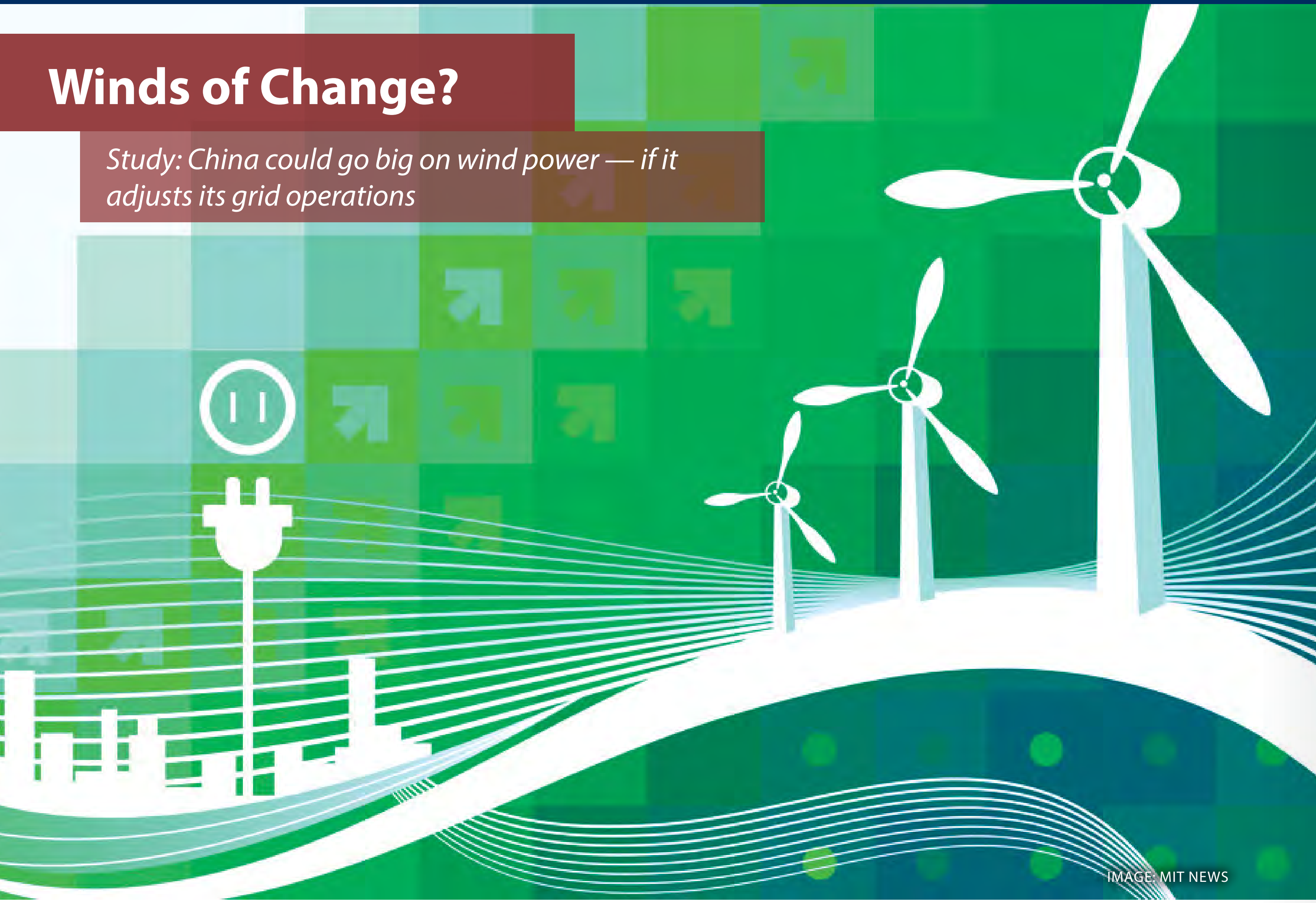

IMAGE: MIT NEWS

By Peter Dizikes, MIT News Office

China has an opportunity to massively increase its use of wind power—if it properly integrates wind into its existing power system, according to a newly published MIT study.

The study forecasts that wind power could provide 26 percent of China's projected electricity demand by 2030, up from 3 percent in 2015. Such a change would be a substantial gain in the global transition to renewable energy, since China produces the most total greenhouse gas emissions of any country in the world.

But the projection comes with a catch. China should not necessarily build more wind power in its windiest areas, the study finds. Instead, it should build more wind turbines in areas where they can be more easily integrated into the operations of its existing electricity grid.

> *Turbines should be built where they can be more easily integrated into China's existing electricity grid.*

"Wind that is built in distant, resource-rich areas benefits from more favorable physical properties but suffers from existing constraints on the operation of the power system," states Valerie Karplus, an assistant professor at the MIT Sloan School of Management, director of the Tsinghua-MIT China Energy and Climate Project (CECP), and a member of the MIT Energy Initiative. Those constraints include greater transmission costs and the cost of "curtailment," when available wind power is not used.

The paper, "Modelling the potential for wind energy integration on China's coal-heavy electricity grid," appears in *Nature Energy*. In addition to Karplus, the authors are Michael R. Davidson, a graduate student in MIT's Joint Program on the Science and Policy of Global Change and the MIT Institute for Data, Systems and Society; Da Zhang, a postdoc in the Joint Program; and Weiming Xei and Xiliang Zhang of Tsinghua University. Karplus and Zhang are the corresponding authors of the paper, and lead an MIT-Tsinghua collaboration focused on managing energy and climate change in China.

Co-existing with coal

While China has invested heavily in renewable energy sources in recent years, more investment in the sector will be needed if the country is to meet its pledge of having 20 percent of its energy consumption come from non-fossil fuel sources by the year 2030, as part of the Paris climate agreement of 2015.

> *New policies can help create the conditions for increased use of wind power—but they may be difficult to implement.*

While several previous studies have evaluated China's wind-energy potential based on the country's natural environment, the MIT study is the first to study how wind energy could expand, based on simulations of China's power system operations.

When operational constraints are considered, the MIT team found, China may only be able to use 10 percent of the physical potential for wind power cited in their analysis and other studies. Nevertheless, even harnessing that 10 percent would be enough for wind power to provide the study's estimated 26 percent of electricity by 2030.

A key challenge the study identifies is integrating wind power into a system that has traditionally been geared toward consumption of coal. Wind power, being intermittent, currently requires flexibility in the operation of the electricity system to ensure wind can be used when it is available.

That, in turn, requires flexibility in the delivery of electricity from coal-fired power plants, which accounted for over 70 percent of electricity generated in China in 2015. However, China has regulations determining high minimum output levels for many coal-powered electricity plants, to ensure the profitability of those plants. Reducing these requirements and creating more flexible generation schedules for coal would create more space for wind power.

"Renewable energy plays a central role in China's efforts to address climate change and local air quality," Da Zhang explains. "China plans to substantially increase the amount of wind electricity capacity in the future, but its utilization—and ultimately its contribution to these environmental goals—depends on whether or not integration challenges can be solved."

New policies possible?

As the researchers see it, new policies can help create the conditions for increased use of wind power—but may be difficult to implement. As Davidson notes, "establishing regulatory structures and policy incentives to capture these benefits will be difficult in China because of legacy institutions."

And as Karplus adds, current regulations have been designed to ensure profitability for power producers, rather than making them compete to lower costs. "Existing policies prioritize sharing benefits equally among participants rather than facing strict price competition," she says. "As electricity demand growth has slowed in recent years, the limited size of the pie means sharper conflicts between wind and coal."

To be sure, as Karplus notes, government planners in China have been experimenting with using energy markets that do not rely strictly on the system that uses a quota for coal power, but encourages competition for long-term contracts to deliver coal-based electricity, while creating additional markets for flexible operation.

Such market mechanisms could prove beneficial to renewable energy sources, principally wind and solar power. As Karplus concludes: "Our work shows the value of continuing these reforms, including introducing markets and relaxing the administrative constraints … for China's ability to utilize its present and future wind capacity to the fullest." ■

At MIT, the research was funded by a consortium of founding sponsors of CECP, supported through the MIT Energy Initiative: Eni, the French Development Agency (AFD), ICF and Shell. At Tsinghua University, researchers received separate support from government and industry sources. CECP is part of the MIT Joint Program.

Related Publication:

Davidson, M.R., D. Zhang, W. Xiong, X. Zhang and V.J. Karplus, 2016: Modelling the potential for wind energy integration on China's coal-heavy electricity grid. *Nature Energy* **1**, Article number: 16086 (2016).

In the News:

Additional coverage of this research appeared in the Washington Post and The Guardian.

The Geography of Carbon Pricing

Why some states could be impacted more than others

PHOTO: TOM BONNER, JEREMYLEVINE.COM

Aggregating CO_2 emissions consumption data at the state and regional levels, the study accounted for emissions embodied in common household goods, which vary from state to state depending on where those goods—or components thereof—were produced.

How much will your cost of living rise if a price is put on carbon? According to a new study in *The Energy Journal*, the answer may depend on where you live—and how policymakers define who's ultimately responsible for human-made carbon emissions.

On first glance, it might seem intuitive to impose a price on carbon where emissions are generated, from manufacturing facilities to power plants. But none of those point sources would be operating without the end-users of the goods and services that they produce. Consider windshield glass made in Ohio that's exported to Michigan for assembly into automobiles, which get shipped to New York auto dealers. If responsibility for carbon emissions embodied in that glass—through its manufacture, assembly and transport—is placed on the consumer, then a price on carbon would be imposed in New York.

"Looking at the point of emission of carbon dioxide (CO_2) can be misleading because some states like California seem relatively clean but import a lot of carbon-intensive consumer goods, so people in those states may be more responsible for CO_2 emissions than you would think," says the study's lead author Justin Caron, a former postdoctoral associate with the MIT Joint Program on the Science and Policy of Global Change who now serves as an assistant professor at the University of Montreal business school. "Getting statewide consumption and trade data has clarified who has the responsibility for the emissions and who should be taking action."

Using a data-driven carbon emissions accounting strategy that's far more comprehensive than earlier analyses, Caron and his coauthors—MIT Joint Program Co-Director John Reilly and Tufts University Professor of Economics Gilbert Metcalf—found that attributing CO_2 emissions to states based on consumption rather than production vastly changes the total emissions for which they are responsible. The researchers also determined that the CO_2 emissions embodied in the goods consumed by households varies widely among U.S. states and regions.

According to the study, the majority of CO_2 emissions attributable to households are not due to direct energy use (e.g., home electricity and heating fuel, gasoline) but rather are embodied in all other goods consumed by those households. Because the producers of imported goods—and hence their embodied emissions—vary considerably from state to state, some states are responsible for much more CO_2 emissions than others, and would be more adversely impacted under a uniform carbon-pricing policy.

"A carbon-pricing policy would impact the price of every good, not just energy, and these prices will differ among states."

"The differences in embodied CO_2 are reflected in all the goods that consumers buy," says Caron, noting that previous studies assumed that the carbon intensity of non-energy-related household goods was the same across the U.S. "So a carbon-pricing policy would impact the price of every good, not just energy, and these prices will differ among states."

To arrive at their findings, the researchers used a multi-regional input-output (MRIO) framework that allowed them to track CO_2 emissions in U.S. states and regions for different products throughout the whole global production chain of a consumer good. For example, MRIO can track the CO_2 emissions involved in the production of the components of a table, including steel and wood.

"The production chain tends to be very geographically dispersed," says Caron. "Using MRIO analysis allows us to take a dollar's worth of a table in Massachusetts and look at all the inputs required to produce that table, no matter where it was produced, and to track where CO_2 was emitted." Drawing upon data representing trade links among U.S. states and foreign countries, MRIO enabled the researchers to account for emissions of goods imported from all points of origin.

The authors determined that some of the largest net importers of embodied carbon are New York, Florida and California, as well as states in the New England and Mid-Atlantic regions, whereas Texas and the south-central and Mountain states are the largest net exporters.

The differences in the carbon intensity of production and consumption across regions could impact support for carbon-pricing policies in different states within those regions, and whether those policies will be based on production or consumption. This study's state-by-state estimates of CO_2 emissions production and consumption could inform efforts to ensure that national and regional carbon-pricing policies don't result in excessive economic hardship for particular states and regions. ■

The study was funded by the U.S. Department of Energy, Environmental Protection Agency and other sponsors of the Joint Program.

Related Publication:

Caron, J., G. E. Metcalf and J. Reilly, 2017: The CO_2 Content of Consumption Across U.S. Regions: A Multi-Regional Input-Output (MRIO) Approach, *The Energy Journal* 38(1): 1–22.

PHOTO: NASA

Towards a Political Economy Framework for Wind Power

Does China break the mold?

Two researchers at the MIT Joint Program on the Science and Policy of Global Change—Institute for Data, Systems and Society graduate student Michael Davidson and Sloan School of Management Assistant Professor Valerie Karplus—and Fredrich Kahrl of Energy and Environmental Economics Inc. have published a new working paper detailing political economy challenges of introducing and scaling wind power within an electricity system, with a focus on China.

The paper is part of a project, The Political Economy of Clean Energy Transitions, for the United Nations University's World Institute for Development Economics Research (UNU-WIDER), which provides economic analysis and policy advice aimed at promoting global sustainable and equitable development. The project seeks to improve understanding of how political economic factors impact clean energy transitions. The research was supported, in part, by sponsors of the MIT-Tsinghua China Energy and Climate Project (CECP), a project of the MIT Joint Program. ■

Related Publication:

Davidson, M.R., F. Kahrl and V.J. Karplus, 2016: Towards A Political Economy Framework For Wind Power: Does China Break The Mould? Helsinki: UNU-WIDER 2016/32.

PHOTO: RANDOMIX

Windmills in Turpan, China

Celebrating Five Years of Developing New Tools and Analysis for Energy and Climate Policy in China

The MIT-Tsinghua China Energy and Climate Project (CECP) marks its fifth anniversary in 2016

PHOTO: ISTOCKPHOTO / LUXIZENG

By Valerie Karplus

Since its inception, the CECP team has developed two new models of the global economic and energy system, authored 23 journal articles, prepared 22 Joint Program reports, and participated in numerous outreach activities around the world.

The Annual Stakeholders Meeting, held this year on April 23 at MIT, highlighted the team's work on technology and policy strategies for decarbonizing China's electricity system. Bringing zero-carbon energy sources into the electricity mix is essential to meet China's 2030 goal of obtaining 20 percent of the country's primary energy from non-fossil sources.

At the gathering of sponsors, collaborators and team members, the team showcased its efforts to design and apply modeling tools that capture the operational dynamics of China's electric power system. These tools have been developed alongside the team's two energy economic models—the China-in-Global Energy Model (C-GEM), which represents China's energy-intensive sectors and global trade linkages, and the China Regional Energy Model (C-REM), which resolves China's 30 provinces. Experts involved in the formulation of China's renewable energy policies and electricity system reforms discussed how to better integrate these efforts to improve the utilization of present and anticipated future renewable energy capacity in China.

Going forward, CECP will evolve into a new phase of research focused on energy and climate change management in China, studying how energy choices made in firms and households influence the impact of policies—such as energy conservation and emissions trading—at regional, national and global levels. This new phase will build on the strong collaboration that has been established between the Tsinghua University and MIT groups over the last five years. ■

CECP BY THE NUMBERS

- **1** team
- **5** years
- **2** global energy models
- **25** researchers, collaborators and affiliates
- **2** collaborating institutions
- **23** journal articles
- **22** reports
- **15** commentaries

MIT Outlines Progress on its Five-Year Climate Action Plan

Progress report underscores strong collaboration across campus to address climate change

By Rob Matheson, MIT News Office

The following is an abridged version of the original article:

Vice President for Research Maria Zuber released a report outlining progress in several key areas of MIT's five-year Plan for Action on Climate Change, underscoring strong collaboration across campus in addressing what the report calls "the urgent problem of global climate change."

The Institute first announced the multifaceted plan last October, presenting steps MIT will take to fight global climate change. The five-year plan will enhance efforts in five key areas of climate action, now called the "five pillars": improving understanding of climate change and advancing novel, targeted mitigation and adaptation solutions; accelerating progress toward low- and zero-carbon energy technologies; educating a new generation of climate, energy and environmental innovators; sharing knowledge about climate change, and learning from others around the world; and using the MIT community as a "test bed" for change.

The report provides updates on new and continuing initiatives that directly support those five pillars, including research grants, MIT's Environmental Solutions Initiative (ESI), low-carbon energy centers, energy-industry partnerships, academic conferences and contests focused on climate-change solutions, and tools to improve energy efficiency on campus.

The report also highlights a new Climate Action Advisory Committee (CAAC), methods for engaging external partners, and ways to communicate the plan's progress, including through a website and annual report.

Assembling the CAAC

Zuber is now finalizing membership of the CAAC, first announced in March in an agreement reached between MIT and the student-led group Fossil Free MIT. The CAAC, headed by Zuber, aims "to bring to bear on climate action the full depth and breadth of the MIT community's talent, experience, expertise and creativity," the report says.

MIT's Plan for Action on Climate Change
http://climateaction.mit.edu/

According to the report, CAAC membership will include: one director or representative each from the ESI, the MIT Energy Initiative (MITEI), the Center for Global Change Science, the Center for Energy and Environmental Policy Research, the Climate CoLab, the Joint Program on the Science and Policy of Global Change, the MIT Office of Sustainability, the Sloan Sustainability Initiative; two undergraduates, two graduate students, two postdocs and two alumni; one additional faculty member; two additional staff members; and any interested MIT Corporation members.

The primary responsibilities of the CAAC are to: consult on the implementation of the plan; develop a set of strategies and benchmarks for MIT's engagement with industry, government, and other institutions; and assist in finding ways to engage the broader MIT community in climate action.

Sustained engagement

The report stresses the need for more sustained engagement with governments, industries and other institutions of higher education in combating climate change. "While this strategy of engagement is reflected clearly in the plan's action items, it must go beyond these to fully leverage MIT's convening power," the report says.

Potential engagement opportunities include: direct interactions with other stakeholders, facilitated gatherings of industry and other partners in Cambridge and beyond, and town hall-style events with the MIT community.

The XXXIX MIT Global Change Forum, hosted by the Joint Program on the Science and Policy of Global Change in June, focused on "Corporate Strategy and Climate Change" to examine how public and private sectors can adapt to climate change. [See p. 18.] And the Center for Energy and Environmental Policy Research hosted a workshop in May for industry participants, academics and policymakers to examine research on energy and environmental policy.

The report says Zuber also plans to convene a forum in the coming months to explore ethical responsibilities of countries, industries, companies, institutions and individuals in limiting the increase in average global temperatures to 2 degrees Celsius over preindustrial levels. ■

MIT Joins Carbon Pricing Leadership Coalition

Led by the World Bank and IMF, coalition seeks to price emissions to tackle climate change

MIT News Office

MIT has formally joined the Carbon Pricing Leadership Coalition, a global partnership of governments, businesses and civil society organizations working together with the goal of applying a price on carbon emissions, the predominant cause of climate change.

Jim Yong Kim, president of the World Bank, and Christine Lagarde, managing director of the International Monetary Fund, officially launched the coalition at the Paris climate talks last November. Its membership includes more than 20 national and subnational governments, more than 90 major companies and dozens of leading nonprofit organizations. MIT is the second university to join the coalition after Yale.

L. Rafael Reif, the president of MIT, accepted the invitation to join the CPLC in a letter sent May 19 to the World Bank.

"Remarkable progress in low-carbon energy innovation and commercialization—happening here at MIT and at universities, companies and government labs around the world—is a reason for great optimism," Reif wrote in the letter. "Yet we know that without the right incentives in policy, advances in technology alone will not deliver the energy transformation we need to meet the climate challenge."

In MIT's Plan for Action on Climate Change, issued in October 2015, MIT's senior officers described carbon pricing as the kind of "systemic solution" than can help incentivize the switch to low- and zero-carbon sources of energy. Under carbon pricing, emitters of carbon pollution typically must pay a charge on each ton of carbon emissions they produce. This creates a market incentive for encouraging entities throughout the economy—from households to power plants—to shift to cleaner sources of energy.

Maria Zuber, MIT's vice president for research, said that over the last couple of years, as the MIT community discussed potential strategies for addressing climate change, carbon pricing emerged as a strong point of consensus.

"If you ask MIT economists and policy experts what we should do about climate change, chances are they will tell you: Put a price on carbon emissions," said Zuber. "Along with increased funding for clean energy research and development, carbon pricing is one of the most effective things we can do to speed up the transition to a zero-carbon economy."

"If you ask MIT economists and policy experts what we should do about climate change, chances are they will tell you: Put a price on carbon emissions."

Carbon-pricing policy, including its optimal design and implementation, is a significant area of focus for many MIT faculty members and researchers, including those affiliated with MIT's Center for Energy and Environmental Policy Research and Joint Program on the Science and Policy of Global Change. Sharing knowledge on best practices is a priority for the Carbon Pricing Leadership Coalition.

In his letter, Reif also noted that MIT is exploring how best to incorporate carbon pricing into the Institute's internal decision making. As a first step, the Department of Facilities is finalizing a carbon calculator for use in campus capital projects. ■

Carbon Pricing Leadership Coalition
http://www.carbonpricingleadership.org/

MIT's Plan for Action on Climate Change
http://climateaction.mit.edu

Video: President Reif on Carbon Pricing
https://www.youtube.com/watch?v=7W2v_O1NX8E

The Oil Industry's Troubles Aren't Bad Enough to Trigger Another Global Crisis

Cheap oil fuels other parts of the world economy

The following appeared in MarketWatch on April 14, 2016:

By John Reilly

The crash in the price of oil—from $108 a barrel in June 2014 to below $27 earlier this year—has rattled the stock market, triggered layoffs across the energy sector and plunged many oil-producing countries into crisis.

Oil has since rebounded significantly from its lows, to above $40 a barrel, but the price plunge since 2014 has put much pressure on oil companies. Reports have pointed to an increase in debt among oil producers, raising the specter of default on bankruptcy and default on debt, with follow-on effects beyond oil producers.

The upheaval also has sparked fears that oil's troubles will spread across the globe, echoing the crash in U.S. housing markets that pushed the world economy to the brink of collapse in 2008. Yet despite the woes oil is experiencing, it is unlikely that the repercussions will trigger another global financial crisis.

Looking at the numbers, the mortgage-debt crisis dwarfs what is currently happening in oil. According to a report in the Financial Times, the global oil and gas industry's debts rose to $3 trillion from $1.1 trillion between 2006 and 2014. Compare that to the $10 trillion of housing debt weighing on Americans in 2008.

Aside from the numbers, the impact will be different because of the nature of the oil industry and the role oil plays in the world economy. Boom and bust have been features of the oil business for many years. Companies that have been around for a while understand this, and have learned to adapt. Responding to earlier crises, they made significant cuts and improved efficiency. Because they run lean operations, these companies are better prepared to weather downturns. Also, the major players in the oil industry are not highly leveraged, and thus we have not seen anything like the cascade of failures among lenders and suppliers that made the housing bust so damaging.

Despite the woes oil is experiencing, it is unlikely that the repercussions will trigger another global financial crisis.

It is also important to note that the marginal cost of extracting oil from the ground is relatively low once the initial cost of developing a field is sunk. Even if prices are low, companies can continue to make money. It won't be as much as they would make in good times, but the businesses can still generate revenue and profits. When oil companies cut back, they halt or delay investments in new fields, but their existing wells continue to produce.

Although some smaller or newer oil companies have been forced out of business by the price collapse, the larger, established players are unlikely candidates for bankruptcy. What tends to happen in the oil business is consolidation, which has been a feature of the industry for nearly two decades: look at Exxon and Mobil; Chevron and Texaco; BP and Amoco, and other mergers that occurred in the 1990s and early 2000s—another time when oil prices were extremely low.

That round of mergers and acquisitions reduced the number of companies considerably, and so room for further consolidation may be limited. Also, many of the remaining companies are state-owned or state-controlled and thus not candidates for acquisition or merger unless governments that owned them decided to privatize the assets—an unlikely scenario. But smaller operators with potentially valuable mineral rights will become candidates for acquisition by cash-rich larger companies.

When weighing the fallout from the oil-price collapse, it is important to remember that whatever direction oil prices move, there will be winners and losers. While today the oil industry struggles, other industries, including transportation and manufacturing, are enjoying the benefits of low-cost oil. The fortunes of regions also rise and fall with the price of oil. When the price is high, Texas booms and New England struggles. Falling prices bring the reverse.

Perhaps the most serious consequence of today's cheap oil is the damage done to governments that rely heavily on tax revenue from oil production.

Perhaps the most serious consequence of today's cheap oil is the damage done to governments that rely heavily on tax revenue from oil production. Many of the big oil-producing countries depend heavily on oil revenue to deliver basic services. With the collapse in prices, governments have to cut support for everything from medical care to housing to road repair. Tight budgets, in turn, can fuel political unrest, which may destabilize governments.

The damage to governments is easy to see in Venezuela, Nigeria and Russia. But it also is apparent in wealthy countries such as Saudi Arabia, which has had to trim its domestic budget and pull back on investment outside of the country. Foreign nationals who traditionally have made up a large part of the Saudi workforce may find less opportunity there, which creates a spillover effect in their home countries.

But for most of the world, assessing the effects of the oil-price collapse is a process of calculating the many pluses and minuses. Oil industry workers may have much lighter paychecks these days, but consumers have a bit more in their wallets after filling the gas tank. ■

John Reilly is a senior lecturer at the MIT Sloan School of Management and co-director of the MIT Joint Program on the Science and Policy of Global Change.

PHOTO: GRANGERNITE

Detroit oil refinery

Computing the Ocean's True Colors

Stephanie Dutkiewicz' phytoplankton models project the future of the ocean as food source and carbon sink

When she was 17, Stephanie Dutkiewicz set sail from her native South Africa to the Caribbean islands. Throughout that three-month journey, she noticed that the color of the ocean shifted from place to place, but it wasn't until she took up oceanography in college that she came to understand why. Early on in her studies, she learned that ocean color varies from green to blue, depending on the type and concentration of phytoplankton (algae) in the area. As they use chlorophyll, a green pigment, to generate organic carbon through photosynthesis, these "plants of the sea" reflect light; the more phytoplankton in the ocean, the less blue and more green the color of the water.

Now a principal research scientist in MIT's Joint Program and Department of Earth, Atmospheric and Planetary Sciences (EAPS), Dutkiewicz remains focused on these drivers of ocean color. For more than a decade, she and her main research partner, EAPS Associate Professor Mick Follows, have been leading a team of a dozen MIT researchers and several collaborators from universities around the world to advance the Darwin Project, which aims to model the growth, loss and movement of phytoplankton around the world, the environments that they inhabit and how they affect one another.

Dutkiewicz is systematically probing phytoplankton behavior to home in on what traits distinguish one of thousands of phytoplankton species from another, which types will survive and thrive under different environmental conditions, and where different types are likely to live. Guided by laboratory, ship and satellite observations, she has represented as many as 100 different types of phytoplankton—other groups typically model no more than five—in complex computer models that simulate phytoplankton population dynamics in the ocean and project how those dynamics will change in coming decades.

Producing results that square with actual observations, these models, which comprise hundreds of thousands of lines of code, are generating the world's most complex 2-D and 3-D global maps of phytoplankton activity and ocean color. Visually arresting, the maps suggest profound implications for the future of the planet, from the sustainability of the ocean's food web to the pace of global warming.

"Since they are at the base of the food web, understanding which types of phytoplankton live where and projecting how these populations are likely to change will help us understand what will happen further up the food chain," Dutkiewicz explains. "And because the process by which these phytoplankton take carbon and sink it down into the deep ocean is responsible for storing about 200 parts per million (ppm) of carbon dioxide, they play an important role in the Earth's climate system."

Dutkiewicz models the growth, loss and movement of phytoplankton around the world, the environments that they inhabit and how they affect one another.

Stephanie Dutkiewicz in her office with display of phytoplankton model simulation

FACULTY FOCUS

Size matters

In an ongoing phytoplankton modeling study funded by the National Science Foundation, Dutkiewicz and Follows are investigating several distinguishing traits and their potential impact on the planet. Traits they've identified include those based on behavior, such as rates of nutrient uptake, temperature tolerance and light tolerance, and those based on size.

In the phytoplankton world, size matters. While all are microscopic, individual phytoplankton range in diameter from under one micrometers to more than 1000 micrometers, akin to the size difference between a mouse and Manhattan. As the ocean warms, its upper layers are expected to interact less with lower layers where nutrients are concentrated. As a result, smaller phytoplankton, which are best equipped to tolerate compromised nutrient conditions, will likely outnumber larger phytoplankton, which are more effective at storing carbon. Such changes may not only shift the oceanic food web to one based on smaller phytoplankton but also reduce the ocean's effectiveness as a carbon sink.

Most phytoplankton models, including those used by the Intergovernmental Panel on Climate Change (IPCC), usually resolve just two phytoplankton types: small and large. So when the ocean warms to a certain point in the coming decades, the modelled phytoplankton populations appear to shift dramatically, with small ones far outnumbering large ones. In reality, however, these shifts are expected to occur gradually.

"Because we include a more diverse size distribution in our model, we find that as we run out the 21st century, phytoplankton sizes don't quickly shift from big to small, but rather from big to slightly smaller," says Dutkiewicz. "So the impact might not be as large as the IPCC models predict."

To assess the impact of phytoplankton size and function on the climate, Dutkiewicz and her collaborators represent the global ocean as a set of location-based grid cells, each sized at a resolution that's fine enough to validate the model through satellite and ship observations. Within each grid cell, the model solves a set of equations that account for phytoplankton growth, movement, loss, carbon cycling and other population dynamics.

True colors

With funding from NASA, Dutkiewicz is also using the computer model to ground-truth satellite observations of phytoplankton concentrations in different parts of the ocean, which are based on how much light is emitted from the ocean surface. The light is reflected by chlorophyll in phytoplankton, which absorb more blue than green light. By measuring how much blue versus green light is emitted, the satellites estimate how much chlorophyll is present at a given location. Such estimates are crude at best, so Dutkiewicz is working to assess the level of uncertainty in chlorophyll ocean maps by representing reflected light in her phytoplankton models.

Her models produce true colors of the ocean today, and project ocean colors throughout the 21st century based on changes in phytoplankton population dynamics. For example, as the ocean warms and becomes more acidic, phytoplankton populations will change, thus altering chlorophyll levels and impacting how much light is reflected from the ocean surface.

Computer simulations based on Dutkiewicz' phytoplankton models have produced global maps of ocean color like this "Living Liquid" exhibit at the San Francisco Exploratorium—an interactive touchscreen table showing photoplankton types in different colors (Source: San Francisco Exploratorium)

"Tracking this could help us identify a real, climate-change-driven signal that stands out from the year-to-year, natural variability in phytoplankton populations across the globe," she says.

Dutkiewicz' career path as an oceanographer has uniquely positioned her to pinpoint such signals. As a PhD student in physical oceanography at the University of Rhode Island, she originally focused on capturing the movement of ocean currents. When she came to MIT in 1998 as a postdoctoral fellow in the EAPS Department, she studied how physics alters the biology of phytoplankton (e.g. how ocean currents move their biological cargo), and built a numerical model of the marine ecosystem based on one type of phytoplankton. Now modeling up to 100 times as many types, she is perhaps the most qualified person in the world to explain not only why the colors of the ocean vary from place to place, but also what those colors might portend for the future of the planet. ■

Related Publications:

Dutkiewicz, S., A.E. Hickman, O. Jahn, W.W. Gregg, C.B. Mouw and M.J. Follows, 2015: Capturing optically important constituents and properties in a marine biogeochemical and ecosystem model, *Biogeosciences* **12**(14): 4447–4481.

Dutkiewicz, S., J.J. Morris, M.J. Follows, J. Scott, O. Levitan, S.T. Dyhrman and I. Berman-Frank, 2015: Impact of ocean acidification on the structure of future phytoplankton communities, *Nature Climate Change* **5**(11): 1002-1006.

How Might a Steep Decline in Aerosols Impact the Climate?

EAPS PhD student Daniel Rothenberg targets one of climate modeling's biggest unknowns


PHOTO: LAUREN WADSWORTH PHOTOGRAPHY

Air pollution from power plants, internal combustion engines and other artificial sources impacts not only human health but also the global climate. The more particles we emit into the atmosphere, the more water droplets are likely to form around those particles inside clouds. Clouds with more droplets are thicker and brighter, so they reflect more solar radiation, thereby cooling the climate system in a process called the aerosol indirect effect. While much is known about the physics of how aerosols impact cloud formation, it's hard to measure just how big a role the indirect effect plays in offsetting global warming. Today's estimates of the magnitude of the indirect effect are highly uncertain; it may well have masked as much as 80 percent of warming during the 20th century due to carbon dioxide (CO_2) emissions alone.

Reducing that uncertainty will become critical throughout the 21st century as more and more countries significantly reduce their greenhouse gas emissions in pursuit of the Paris Agreement's goal of capping the rise in global mean surface temperature since preindustrial times at 2 degrees Celsius. Any major cut in airborne particulates will reduce the indirect cooling effect considerably, resulting in additional warming that climate models will need to estimate as precisely as possible.

To help meet this challenge, Daniel Rothenberg, a Joint Program PhD student in the Department of Earth, Atmospheric and Planetary Sciences, has spent the past two years developing concepts and software aimed at reducing the uncertainty in the magnitude of the indirect effect.

"If the sensitivity of the indirect effect is strong, then you might expect a much stronger warming associated with aerosol reduction in the future, and that makes the 2°C goal even more difficult to achieve," says Rothenberg. "That our current models haven't been able to reduce the uncertainty is a specter hanging over the climate community's head, so it's important to determine how strong these effects might be."

Rothenberg has spent the past two years developing concepts and software aimed at reducing uncertainty in the magnitude of the indirect cooling effect of aerosols.

Modeling Droplet Activation

Toward that end, Rothenberg has incorporated a sub-model of the physics of aerosol-cloud interaction into a widely used climate model called the Community Earth Systems Model (CESM). This sub-model represents droplet activation, the process by which individual aerosol particles become cloud droplets, the building blocks out of which clouds are formed. Just as dew condenses on grass and leaves on a cold morning, water vapor in the atmosphere condenses onto airborne particulates. Drawing on research that pinpoints which particles tend to form cloud droplets, the sub-model projects how many cloud droplets form based on the level and type of ambient pollution.

"Rather than relying primarily on approximations used in previous aerosol-cloud interaction models, the method that Daniel developed is much more physically-based and thus the best choice now for studying the climate response to the aerosol indirect effect," says Joint Program Senior Research Scientist Chien Wang, Rothenberg's advisor.

Supported by funding from the National Science Foundation and developed in consultation with Wang and other prominent atmospheric scientists, Rothenberg's droplet activation sub-model is described in a paper he co-authored with Wang in the Journal of the Atmospheric Sciences. It's unique among aerosol-cloud physics models in its focus on droplet activation and its impact on climate.

"How you represent how aerosols influence clouds—the fundamental droplet-activation process—contributes a huge amount of uncertainty to the aerosol indirect effect," says Rothenberg. "This ends up being a very big lever you can pull on your model, to make it either much more or less sensitive to aerosol pollution."

Upon graduation this year, Rothenberg aims to pursue postdoctoral studies centered on the potential impact of aerosols on the climate in coming decades. By collaborating with experts on policy being considered in China, India and other countries, identifying likely emissions-reduction policy scenarios, and running simulations of those scenarios with his customized version of the CESM, he hopes to provide a more accurate read on the likely climate response to such policies.

Science, software and policy

Rothenberg's career aspirations and foundational work at MIT combine three interests—science, software and policy—that he has cultivated from an early age.

Shortly before starting first grade in Louisville, Kentucky, a severe thunderstorm sent him beneath the bedcovers, where he fixated on each rolling detail of a local TV meteorologist's live report. By the time he reached high school, his fear of extreme storms morphed into a passion to learn more about the weather, a stint as a volunteer at the local office of the National Weather Service, and a decision to study meteorology at Cornell University. Guided by Professor Natalie Mahowald (one of Joint Program Co-Director Ronald Prinn's PhD students in the 1990s), Rothenberg completed a senior research thesis on how volcanoes impact the carbon cycle and the climate, and graduated magna cum laude with a B.S. degree in Atmospheric Science. He also emerged intent on learning more about aerosols and other components of the climate system whose impact on the climate are highly uncertain. Graduate studies in MIT's Program in Atmospheres, Ocean and Climate (PAOC) provided a natural pathway to dig deeper.

Rothenberg's interest in software was kindled by high school computer science courses that showed him how fun, interesting and impactful computer programming could be, and introduced him to the concept of open-source software development. At MIT he developed an open-source, modular modeling framework for studying droplet activation from diverse aerosol populations.

Rothenberg's policy acumen taps into a lifelong fascination with politics, activism as president of the Young Democrats in high school, and insights from a Cornell course in environmental governance. At MIT, he served on the MIT Science Policy Initiative (SPI) executive board as Liaison to the National Science Policy Group. The SPI, through visits to congressional offices and federal agencies, trains graduate students on how to advance policies that support science and use science to inform policy.

To wind down from a typical day's work in science, software and policy, Rothenberg turns to the violin. A classically trained violinist, he has participated in ensembles ranging from the Louisville Youth Symphony Orchestra to the MIT Symphony Orchestra, contributed to recordings of pop and indie rock musicians, participated in community musical theater productions and accompanied touring musicians.

"Playing the violin is fun and challenging, but in a different way than my research," says Rothenberg. "I get to exercise a different part of my brain." ■

For more information about Daniel Rothenberg, visit www.danielrothenberg.com.

Related Publication:

Rothenberg, D. and C. Wang, 2016: Metamodeling of Droplet Activation for Global Climate Models, *Journal of Atmospheric Sciences* 73: 1255–1272.

XXXIX (39th) MIT Global Change Forum

Corporate strategy and climate change

The Global Change Forum invites government, industry, NGO and research group representatives to discuss the evolving science and policy of global environmental change. The Forum is designed to promote interaction among disparate stakeholders and provide an informal, "off-the-record" setting for independent assessment of studies and policy proposals.

Corporate challenges and opportunities of climate change was the focus of the XXXIX MIT Global Change Forum, held June 15–17 at the Royal Sonesta Hotel in Cambridge, Massachusetts. While noting the risks that climate change poses for corporations, such as disruptions to operations and global supply chains, the keynote talk at the opening reception highlighted a number of business opportunities that it presents, from developing low-carbon technologies to making supply chains more efficient. The presentation stressed that the private sector has a key role to play in the transition to a low-carbon energy system capable of addressing the Paris Agreement's aspiration to cap the rise in mean global surface temperature since preindustrial times at 2 degrees Celsius (3.6 degrees Fahrenheit). Through collaboration with government and civil society, corporations can significantly reduce climate-change-related risks both to themselves and the world at large.

Six sessions explored climate-change-related challenges and opportunities for corporations in six domains: land and agriculture, financing climate mitigation and adaptation, future directions in energy, supply chain risks, water resources and adaptation strategies, and the implementation of the Paris Agreement.

The two land and agriculture talks emphasized that the main challenge in feeding the world is not to boost food production but to improve income opportunities and access to nutritious food for those who are hungry—all while limiting environmental impact and coping with regional water and land-use stress. Attendees learned about Climate-Smart Agriculture (CSA), an approach to empowering the agricultural sector to respond to a changing climate. CSA methods are aimed at sustainably increasing food system productivity and resilience, and decreasing greenhouse gas emissions.

Speakers on the financing essential to achieving climate mitigation and adaptation envisioned the private sector playing a key role in enabling the transition to a zero-carbon economy. According to one estimate, moving to a zero-carbon electric power system could take a $12 trillion investment in renewable power generation over the next 25 years to achieve. New approaches, from public policies to private investment vehicles, will be needed to draw that level of investment from the private sector. Direct investment in sustainable energy technologies can provide an attractive risk-return ratio for corporate investors, as long as governments maintain an investor-friendly policy environment.

The session on future directions in energy, underscored dramatic changes in the global energy mix that will be needed to restrict the rise in global temperature to 2–3°C above preindustrial levels. This entails a significant shift in energy supply from fossil fuels to nuclear, wind, solar, hydro and bioenergy and in lowering energy demand through energy efficiency. This shift is best achieved by targeting emissions reductions from all sources, rather than focusing on specific types of low-emission technologies. The electricity supply industry is expected to be one of the simplest sectors to decarbonize, most likely through new finance, pricing and regulatory models.

In highlighting risks to corporate supply chains posed by a changing climate, the two presenters noted that extreme events in one geographical location along a supply chain can trigger massive disruptions in the delivery of products ranging from disk drives to automobiles, as well as global food and energy price increases. Climate models can be enhanced to project the occurrence of extreme events, but such estimates come with significant uncertainties. One viable approach to tracking climate impacts on supply chains in the agricultural and forestry sectors is to position land-use monitoring systems in close proximity to producers.

The 39th Global Change Forum marked the 25th anniversary of the Joint Program. A registration table featured the agenda for the first Global Change Forum and copies of the first Joint Program Report.

PHOTOS: DIMONIKA BRAY

The talks on water resources and adaptation strategies underscored the vulnerability of urban infrastructure—including roads, bridges and drainage systems—to extreme temperatures, precipitation and flooding. Aggressive climate mitigation policies could significantly reduce impacts (by as much as 25 to 35 percent in the U.S.). So could adaptation measures, particularly those designed to counter the effects of extreme heat and protect coastal infrastructure. Both approaches could lower maintenance and disruption costs.

In the final session of the Forum, panelists examined what it will take to implement the Paris Agreement. The discussion centered on challengers and likely pathways toward implementation of national commitments, and the need for reliable, independent estimates of anthropogenic emissions of greenhouse gases to verify national claims. Verification will depend on significant improvements in Earth-observing and economic data collection systems; quantification of natural sources and sinks using observations and models, quantifying processes leading to anthropogenic emissions; and other relevant measurement and modeling capabilities. Surface and space-based climate monitoring will play an important role in this process, delivering observations of atmospheric greenhouse gas levels, measuring oceanic heat uptake, quantifying Arctic sea ice retreat and other planetary vital signs.

The Forum also featured a celebration of the Joint Program's 25th anniversary, in which its cofounders shared their recollections of the Program's origins and development into a world-class research organization. They described early efforts to secure MIT and external funding for a program on "the science and policy of global decision-making" that would unite MIT's Center for Global Change Science (CGCS) and Center for Energy and Environmental Policy Research (CEEPR) to advance global climate-change assessment and enable science-based policy design. They recalled the planning of the first Global Change Forum, held in September of 1991, with a format that remains in place today; the evolution of an Integrated Global System Modeling framework representing human activity and environmental change; and the cultivation of government, foundation and industry sponsors. ■

SAVE THE DATE: XL GLOBAL CHANGE FORUM

The 40th MIT Global Change Forum will be held the week of March 27–31, 2017 in Washington DC/VA environs.

For further information, please visit: http://globalchange.mit.edu/sponsors-only/forum

By Invitation Only

PHOTO: AGU

PRESS CONFERENCE: HOW MUCH OF A DIFFERENCE WILL THE PARIS AGREEMENT MAKE?

MIT STUDY PROJECTS END-OF-CENTURY CLIMATE UNDER DIFFERENT SCENARIOS

Signed in December by climate negotiators from around the globe, the Paris Agreement centers on pledges from 188 countries to reduce their manmade greenhouse gas emissions, with the ultimate goal of capping the rise in global mean surface air temperature (SAT) since preindustrial times at 2 degrees Celsius. Toward that end, these pledges, which cover the years 2020–2030, are expected to be reviewed and strengthened periodically, but do not commit nations to any course of action after 2030. As a result, projections of the long-term climate impact of the Paris Agreement vary widely.

A useful way to assess that impact is to simulate the effects of policies that extend the Agreement's 188 pledges (known as Nationally Determined Contributions, or NDCs) to the end of the century. In a new study that takes this approach, a team of climate scientists and economists from the MIT Joint Program on the Science and Policy of Global Change led by Research Scientist Andrei Sokolov finds that by 2100, the Paris Agreement reduces the SAT considerably, but still exceeds the 2°C goal by about 1°C.

One of the study's co-authors, Joint Program Principal Research Scientist Erwan Monier, discussed the team's results at the General Assembly of the European Geosciences Union on April 21 in a panel/press conference, "Historical Responsibilities and Climate Impacts of the Paris Agreement."

Using the MIT Integrated Global System Modeling (IGSM) framework, which combines a human activity model with a climate model of intermediate complexity, the researchers project the climate impact of a "no climate policy" case and three scenarios that effectively extend the NDCs to 2100. The scenarios considered range from a pessimistic world where no further action is specified past 2030 to a world where the same level of commitment as in the Paris agreement is extended until the end of the century.

Assuming a climate system response to anthropogenic greenhouse gas emissions that's of median strength, the three scenarios reduce the SAT in 2100 between 0.6 and 1.1°C relative to the "no climate policy" case. But because the climate system takes many years to respond to emissions reductions, in 2050 the SAT falls by only about 0.1°C in all three cases. Meanwhile, the rise in SAT since preindustrial times exceeds 2°C in 2053, and in 2100, reaches between 2.7 and 3.6°C—far exceeding the 2°C goal.

"The Paris agreement is certainly a step in the right direction, but it is only a step," said Monier. "It puts us on the right path to keep warming under 3°C, but even under the same level of commitment of the Paris Agreement after 2030, our study indicates a 95 percent probability that the world will warm by more than 2°C by 2100." ■

SEE VIDEO →

COOL THE PLANET OR TURN UP THE HEAT?

JOINT PROGRAM IMMERSES MIT OPEN HOUSE VISITORS IN CLIMATE SCIENCE AND POLICY

In December 2015, 40,000 people from around the world met in Paris to work on solutions to climate change. On April 23, 2016, about the same number attended MIT's Open House for a peek "Under the Dome" at nearly 80 departments and labs, part of a series of events marking the 100th anniversary of the Institute's move from Boston to Cambridge. Not all came to learn about climate change, but those seeking an introduction to the subject could find it, thanks to the Joint Program on the Science and Policy of Global Change.

At a table inside a tent set up next to MIT's Walker Memorial, Joint Program PhD students and postdocs showed visitors how to work a Climate Calculator to see if they could make the choices needed to reduce the global average temperature enough to save the world from the most disastrous consequences of climate change. They also invited children and adults to spin a Greenhouse Gamble roulette wheel to compare the likely impact of different climate policies on the rate of global warming. An adjacent table featured a video on how Joint Program researchers are combining scientific knowledge with policy analysis to inform decision-making on global environmental challenges that include climate change, air pollution, food insecurity, water shortages, biodiversity loss and more.

In collaboration with MIT Climate CoLab, the Joint Program also offered visitors two 30-minute workshops in a nearby classroom.

In the first, "Intro to the Science of Climate Change," postdoctoral associate Benjamin Brown-Steiner clarified the difference between climate and weather, and explored trends and scientific understandings of changes in temperature, humidity, droughts and other climactic conditions, and their expected impact on our lives and planet. PhD student Paul Kishimoto followed with "Paris Climate Talks: Outcome and Next Steps," in which participants discussed the achievements of the Paris climate talks; why it was lauded by some and panned by others; and what further actions are likely in the years and decades to come.

Special thanks to Ben and Paul; to our table facilitators Michael Davidson, Sae Yun Kwon, Cícero Zanetti de Lima and Qinjian Jin; and to our logistics volunteers Kirby Ledvina, Amanda Chi Wen Giang, Dimonika Bray and Melissa Fox. ■

Two generations take a spin at the Greenhouse Gamble wheel

PHOTO: DIMONIKA BRAY

MINIMIZING RISK THROUGH SCIENCE-BASED PROJECTIONS OF GLOBAL CHANGE

JOINT PROGRAM HOLDS FIRST ANNUAL MIT EARTH SYSTEM MODEL (MESM) SCIENCE RETREAT

The first annual MIT Earth System Model (MESM) science retreat was held on April 14–15 at the MIT Endicott House in Dedham, MA. Drawing Joint Program researchers, sponsor representatives and collaborators from the Marine Biological Laboratory (MBL), the retreat focused on the MESM and its main components, computational infrastructure and application, and how it informs decision-making on global environmental challenges. During the two-day conference, participants engaged in lively discussions of the model's current capabilities and next steps in its development.

Enabling science-based policymaking on global change

In opening remarks, Joint Program Co-Director Ronald Prinn described how the MESM and MIT Economic Projection and Policy Analysis (EPPA) model comprise an Integrated Global System Modeling (IGSM) framework. This framework, which represents the complex interplay between the environment and economic/human activities at the global scale, enables projections of global environmental and economic changes, and science-based policies aimed at addressing them.

Noting that these projections come with considerable uncertainties, Prinn emphasized the need to evaluate proposed policies based on their ability to lower the probability of dangerous environmental and economic outcomes. Toward that end, the MESM serves as a "numerical control" that allows researchers to assess the likely impacts of human development on the environment and economy.

"Because we do not have another Earth without human influence to serve as a 'control,' we won't ever be able to validate the impacts of human development on the environment," said Prinn. "But if we form computer models of the system, and gain confidence in these models through comparison with observations, we can apply them as 'numerical control' experiments."

Deputy Director Adam Schlosser next highlighted the MESM's basic structure and function. Drawing on data from ground, air, water and space-based sensors and accounting for uncertainties about how the Earth system functions, the MESM projects global and regional environmental responses to human and natural activities. The model consists of four main components—land, ocean, atmosphere and cryosphere—and represents their interactions and the processes that shape their evolution.

Modeling land, ocean and atmosphere

Six presenters explored these components in depth, identifying new features and directions for model development and research applications.

Joint Program Deputy Director Adam Schlosser musically enhanced his presentation on the MESM's four main components.

Joint Program Principal Research Scientist Erwan Monier (front left) coordinated the first annual MESM science retreat and spoke on the model's atmosphere component. Principal Research Scientist Stephanie Dutkiewicz (front right) presented details on the MESM's ocean component.

During the two-day conference, participants engaged in lively discussions of the model's current capabilities and next steps in its development.

Research Scientist Xiang Gao showed how she used the Community Land Model (CLM), a land subcomponent representing land biogeophysics and water resources, to study global and regional environmental changes ranging from permafrost degradation to evolving water stress levels. MBL Research Associate David Kicklighter described how he applied the Terrestrial Ecosystem Model (TEM), another land subcomponent representing land biogeochemistry, to simulate land carbon and nitrogen dynamics. Emphasizing the key role that the ocean plays in heat and carbon uptake and storage, Research Scientist Jeffery Scott described MITgcm, an ocean subcomponent that provides a 3-D model of ocean dynamics—a critical tool in representing regional climate change. Focusing her talk on the modeling of ocean biochemistry and ecosystems within the MESM, Principal Research Scientist Stephanie Dutkiewicz discussed a simple model of carbon flows in/into the ocean, and DARWIN, a complex marine ecosystem model that she has used to project changes in phytoplankton biomass and its uptake of atmospheric carbon dioxide.

Principal Research Scientist Erwan Monier detailed the use of 2-D and 3-D atmosphere models in the MESM. He observed that while the 2-D model is sufficient to represent environmental changes at the global scale, the 3-D model is needed to simulate climate impacts at the regional level, including those associated with extreme weather events. Postdoctoral Associate Benjamin Brown-Steiner described various subcomponents of the MESM focused on atmospheric chemistry, noting that those representing a simple-to-moderate level of complexity are sufficient for most studies of long-term climate change.

Underscoring the MESM's need for substantial computer resources, Scott discussed the structure and long-term development of high-performance computing at the Joint Program. Research Scientist Andrei Sokolov demonstrated the model's number-crunching capabilities in an overnight run that produced results for 22 distinct sets of parameters, selected by attendees, to represent uncertainty in the climate response to atmospheric greenhouse gas levels.

Keynote: Biological feedbacks to the climate system

In an evening presentation, MBL Distinguished Scientist Jerry Melillo showed how over multiple decades, climate change has impacted soil carbon dynamics, shifting soil's role from that of carbon sink to carbon source. Tracing a 25-yearlong experiment at the Harvard Forest Long Term Ecological Research program since its inception in 1990, Melillo found that in 36-square-meter plots of soil heated 5°C above ambient temperatures, the plots lost a significant amount of soil carbon as the soil microbial community underwent substantial changes. Melillo noted that a key modeling challenge is to appropriately represent microbial dynamics in Earth system models.

New developments

On the second day of the workshop, participants discussed the future development of the MESM and upcoming research that will exploit its capabilities. Planned improvements to the model's 2-D version include an upgrade of the land biogeochemistry TEM framework, new treatment of land-use change disturbances, and improved ocean modeling. Anticipated changes to the 3-D version include new crop, water-quality and methane models; flexible chemistry modeling; and improved modeling of feedback between Earth and human systems. Attendees also discussed efforts to enhance the MESM's accuracy in modeling water, energy, air and land.

Joint Program sponsor representatives emerged from the retreat with business-relevant knowledge.

Prinn concluded the workshop by highlighting the 2°C Challenge Study, a Joint Program and MIT Energy Initiative-led project outlined in the MIT Plan for Action on Climate Change that seeks to produce a roadmap of scientific, technological and policy options aimed at keeping the mean global surface temperature from rising above the 2°C threshold. The Study will use the IGSM framework to model different policy scenarios.

Takeaways

Joint Program sponsor representatives emerged from the retreat with business-relevant knowledge.

"The MESM retreat provided an outstanding platform for relevant discussions regarding Earth systems modeling through multi-disciplinary discussions and brainstorming between academics and industry," said Eric Sucre, Production Forestry Research Manager & Senior Scientist at the Weyerhaeuser Company. "These interactions with industry sponsors are drivers for long-term success in complex global climate-change forecasting as they can provide operational relevance. The breadth of the entire MIT IGSM framework provided great insight for Weyerhaeuser."

Arthur Lee, a Chevron Fellow at Chevron Services Company, agreed.

"This [retreat] helps Chevron in understanding the latest scientific developments in climate change and the actions that could be taken to address the issue." ■

SAVE THE DATE:
7TH ANNUAL EPPA RETREAT

September 29–October 2, 2016

The 7th annual EPPA (Economic Projection and Policy Analysis) Model Training Retreat will be held at the Sunday River Grand Jordan Resort in Newry, Maine.

By Invitation Only

Recent Research Project Grants

USE OF SOIL-MOISTURE RETRIEVALS TO REFINE GLOBAL LAND TRACE GASES EMISSIONS AND THEIR CLIMATE FEEDBACKS (NEW)

Project Leaders: Xiang Gao, C. Adam Schlosser, Eri Saikawa (Emory University)

Recent studies have suggested that the combined effect on climate of increases in the concentrations of several trace gases (principally CH_4 and N_2O) could rival or even exceed that of the increasing concentration of carbon dioxide (CO_2), due to their much stronger abilities in absorbing infrared radiation. Despite their high potential for climate feedback, the specific sources, magnitudes and changes of these trace-gas emissions are still not well understood. Since the state and amount of water in the soil is a key player in modulating these emissions, the project proposes to use the unprecedented global high-resolution land surface soil moisture and freeze/thaw state from the Soil Moisture Active Passive (SMAP) product together with other land-based observations to improve the performance of the Community Land Model's (CLM) soil moisture simulations, enhance the N_2O and CH_4 modules and thereby reduce uncertainties in the emission estimates over a majority of the Earth's land surfaces. These anticipated improvements will ultimately support greater confidence in assessing the fate of various key trace-gas emissions and the relative contributions of these natural emission changes (separate and combined) to the climate feedbacks under various climate-change scenarios.

Sponsor: U.S. National Aeronautics and Space Administration (3 years)

DYNAMICS OF ENERGY USE IN CHINA (RENEWED)

Project Leaders: Valerie Karplus, John Reilly, Niven Winchester

At global climate talks in Paris in December 2015, China committed to a number of targets to further curb emissions and reduce energy intensity. Meeting these targets depends on technology choices and behavioral responses by consumers and firms across the economy, and also on the design of government policies. How these choices and responses are likely to evolve with rising disposable income is a source of considerable uncertainty in future projections of energy use and GHG emissions. Future energy demand in China is highly uncertain given rapidly evolving factors such as economic development and reforms, demographic change, urbanization and environmental policy. In the China Energy and Climate Project within the Joint Program, researchers are working to understand and model the Chinese energy system, including the role of these rapidly evolving factors, and its response to energy and environmental policy. Extending an existing cooperative research agreement focused on the structure and dynamics of energy demand in China, this project will investigate micro-level phenomena and trends in China's energy and economic system, which are essential to improving the realism of modeling activities. These studies will examine usage trends in China's iron and steel and cement industries; road transportation, especially the dynamics of freight utilization; and household energy use and dynamics, linking to the impacts of changing land use including suburbanization.

Sponsor: U.S. Energy Information Administration (1 year)

MILESTONES

Steven Barrett, associate professor in the Department of Aeronautics and Astronautics, Finmeccanica Career Development Professor of Engineering, and director of the Laboratory for Aviation and the Environment, was named as one of MIT's newly tenured associate professors for 2016. The main goal of his research is to advance understanding of the environmental impacts of aviation, and to develop strategies that mitigate these impacts.

Kenneth Strzepek, a research scientist with the Joint Program, was elected to the Board of Directors of The Center for Water Security and Cooperation. The position comes with responsibilities and decision-making powers that will shape the operations and future success of the CWSC.

COMINGS & GOINGS

Tochukwu *(Tox)* Akobi completed a Master's degree and left to join the Boston Consulting Group in Houston, Texas as a consultant.

Lincoln Berkley began work as a summer intern developing an app for the Joint Program website.

Thomas Brewer arrived as a visiting scholar with CEEPR from the International Center for Trade and Sustainable Development in Switzerland.

Hui-Chih Chai arrived as a visiting researcher from the Institute of Nuclear Energy Research in Taiwan.

Sergio Franklin arrived as a visiting scholar with CEEPR from the Superinterndecia de Saguaros Privados in Brazil.

Wei-Hong Hong arrived as a visiting researcher from the Institute of Nuclear Energy Research in Taiwan.

Chiao-Ting Li completed a postdoctoral term and left to join the HIWIN Corporation in Taiwan as a R&D engineer.

Claire Nicolas completed her stay as a visiting doctoral student from the University of Paris.

Bhargavi Ramanathan completed her involvement in an undergraduate research project.

Christopher Wang began participating in an undergraduate research project.

Mei Yan was appointed as a research scientist to advance the development of the USREP model.

Xiaohann Zhang finished her stay as a visiting doctoral student and returned to Tsinghua University.

IN THE NEWS

Mar 30 - *Voice of America* - Study: Asia at Risk for Serious Water Shortages

Mar 31 - *TIME* - Asian Countries Could Experience Widespread Water Shortages by 2050

Mar 31 - *BangaloreMirror* - Asia may face a severe stress on water by 2050

Apr 1 - *Christian Science Monitor* - India and China will suffer severe water stress by 2050, says study

Apr 1 - *TechTimes* - High Risk Of Severe Water Shortage In Parts Of Asia By 2050, New Study Predicts

Apr 8 - *The Globe and Mail* - Canada can be part of the solution to Asia's looming water crisis

Apr 12 - *The Conversation* - Has China's coal use peaked? Here's how to read the tea leaves

Apr 13 - *Poets & Quants* - 2016 Best 40 Under 40 Professors: Valerie Karplus, Sloan School of Management

Apr 14 - *MarketWatch* - Opinion: The oil industry's troubles aren't bad enough to trigger another global crisis

Apr 14 - *Reuters* - By 2050 Asia at high risk of severe water shortages: MIT study

Apr 18 - *Inter Press Service* - Climate Change (I): Will the Middle East Become 'Uninhabitable'?

Apr 21 - *Eos* - New Climate Studies: Worse Risks at 2°C Rise, Higher Rise Likely

Apr 24 - *USA Today* - Climate change is real, but Paris treaty won't fix it: Column

May 3 - *Mother Nature Network* - What you need to know about aerosol sprays

May 16 - *Fortune* - Shell Looks for a Hedge Against Climate Change

May 17 - *Governance Now* - Scary scarcity of water

May 18 - *Greenwire* - CARBON MARKETS: What will it take to build a global emissions trading system?

May 25 - *Washington Post* - This Texas fight shows just how conflicted we still are about 'clean coal'

Jun 3 - *Bloomberg* - Why This Hurricane Season Is So Important to Scientists

Jun 8 - *Voice of America* - India Backs Enactment of Paris Climate Deal This Year

Jun 17 - *Washington Post* - It's the First New U.S. Nuclear Reactor in Decades

Jun 20 - *North American WindPower* - MIT: China Needs To Make Some Adjustments To Reach Its Wind Power Potential

Jun 20 - *Science Daily* - How China Can Ramp Up Wind Power

Jun 23 - *Climate Central* - Wind at China's Back to Amp Up Its Renewables

Jun 30 - *Deutsche Welle* - Climate change is making our summers more extreme

Jun 30 - *National Geographic* - Remember the Ozone Hole? Now There's Proof It's Healing.

Jun 30 - *USA Today* - Study: Ozone hole over Antarctica beginning to heal

Jun 30 - *NY Times* - Ozone Hole Shows Signs of Shrinking, Scientists Say

Jul 1 - *Bloomberg* - An Environmental Victory (and Cautionary Tale)

Jul 7 - *New York Times* - Carbon Capture Is Technically Feasible, and It Can Be Financially Feasible

Jul 8 - *The Straits Times* - Coal Use Can Cause Water Stress in Asia

JOINT PROGRAM REPORTS

298. Modeling Regional Carbon Dioxide Flux over California using the WRF-ACASA Coupled Model

297. Electricity Investments under Technology Cost Uncertainty and Stochastic Technological Learning

296. Statistical emulators of maize, rice, soybean and wheat yields from global gridded crop models

295. Are Land-use Emissions Scalable with Increasing Corn Ethanol Mandates in the United States?

294. The Future of Natural Gas in China: Effects of Pricing Reform and Climate Policy

293. Uncertainty in Future Agro-Climate Projections in the United States and Benefits of Greenhouse Gas Mitigation

292. Costs of Climate Mitigation Policies

291. Scenarios of Global Change: Integrated Assessment of Climate Impacts

290. Modeling Uncertainty in Climate Change: A Multi-Model Comparison

289. The Impact of Climate Policy on Carbon Capture and Storage Deployment in China

288. The influence of Gas-to-Liquids and natural gas production technology penetration on the crude oil-natural gas price relationship

JOINT PROGRAM REPRINTS

2016-12. Uncertainty in future agro-climate projections in the United States and benefits of greenhouse gas mitigation (*Environ. Res. Lett.*)

2016-11. Impact of Aviation on Climate: FAA's Aviation Climate Change Research Initiative [ACCRI] Phase II (*Bull. Amer. Meteor. Soc.*)

2016-10. Energy caps: Alternative climate policy instruments for China? (*Energy Economics*)

2016-9. Cross-country electricity trade, renewable energy and European transmission infrastructure policy (*J. Environ. Econ. Mgmt.*)

2016-8. Transient Climate Impacts for Scenarios of Aerosol Emissions from Asia: A Story of Coal versus Gas (*J. Climate*)

2016-7. Climate and Land: Tradeoffs and Opportunities (*Geoinform. & Geostat. Overview*)

2016-6. Projections of Water Stress Based on an Ensemble of Uncertain Socioeconomic Growth and Climate Change: A Case Study in Asia (*PLoS ONE*)

2016-5. Determinants of Crop Yield and Profit of Family Farms: Evidence from the Senegal River Valley (*Experimental Agriculture*)

2016-4. Metamodeling of droplet activation for global climate models (*J. Atmos. Sci.*)

2016-3. Climate extremes and ozone pollution: a growing threat to China's food security (*Ecological Soc. Of America*)

2016-2. Carbon emissions in China: How far can new efforts bend the curve? (*Energy Economics*)

2016-1. Long-term economic modeling for climate change assessment (*Econ. Modelling*)

2015-34. The Global Energy, CO_2 Emissions, and Economic Impact of Vehicle Fuel Economy Standards (*J. Transp. Econ. & Pol.*)

2015-33. The Response of the South Asian Summer Monsoon to Temporal and Spatial Variations in Absorbing Aerosol Radiative Forcing (*J. Climate*)

2015-32. The Observed State of the Water Cycle in the Early 21st Century (*J. Climate*)

2015-31. Anthropogenic Aerosols and the Distribution of Past Large-Scale Precipitation Change (*Geophys. Res. Lett.*)

PEER-REVIEWED STUDIES & PENDING REPRINTS

Climate Policy Scenarios in Brazil: A Multi-Model Comparison for Energy (*Energy Economics*)

Agriculture, forestry, and other land-use emissions in Latin America (*Energy Economics*)

Atmospheric histories and global emissions of halons H-1211 [$CBrClF_2$], H-1301 [$CBrF_3$], and H-2402 [$CBrF_2CBrF_2$] (*J. Geophys. Res.*)

Constraints from Observations and Modeling on Atmosphere-Surface Exchange of Mercury in Eastern North America (*Elementa: Science of the Anthropocene*)

Baseline projections for Latin America: base-year assumptions, key drivers and greenhouse emissions (*Energy Economics*)

Very-heavy precipitation in the greater New York City region and widespread drought alleviation tied to western US agriculture (*PLoS ONE*)

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MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

COVER PHOTO: NANSI LAKE, IN CHINA'S SHANDONG PROVINCE. ABOUT 53 PERCENT OF THE LAKE HAS BEEN CONVERTED TO AQUACULTURE PONDS AND FARMLAND. CREDIT: NASA

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