GLOBAL CHANGES

MIT JOINT PROGRAM ON THE SCIENCE & POLICY OF GLOBAL CHANGE

FALL 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.*

UPCOMING EVENTS

Dec 15, 2016 • 10:30 am EST

SPONSORS-ONLY WEBINAR

The 2° Challenge: Results from the 2016 Food, Water, Energy & Climate Outlook

Presenter: John Reilly, Co-Director, MIT Joint Program

Mar 29–Mar 31, 2017

XL MIT GLOBAL CHANGE FORUM

New Challenges in Global Change Research

Airlie House, Warrenton, VA, USA

Mar 29, 2017 • 2:00–5:00 pm EST

XL MIT GLOBAL CHANGE FORUM

Meeting of the Joint Program Sponsors

Airlie House, Warrenton, VA, USA

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY OF GLOBAL CHANGE

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FALL 2016 GLOBAL CHANGES

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Why 2°C is Important, and How to Get There

Last December at the 21st annual meeting of the Conference of the Parties (COP21) to the U.N. Framework Convention on Climate Change (UNFCCC), nearly 200 countries signed on to the Paris Agreement, pledging to reduce greenhouse gas emissions in pursuit of an international goal to limit the rise in global average temperature to "well below" 2°C above preindustrial levels. In October, the European Union voted to ratify the accord, rendering it legally binding by exceeding the minimum requirement of ratification by at least 55 countries, representing 55 percent of global emissions. While this marks a significant step forward in international efforts to stabilize the climate, there is now a broad scientific consensus that the initial pledges made by signatories of the Paris Agreement will not, by themselves, enable the world to meet the 2°C goal and thus prevent the worst effects of climate change.

Our analysis of the Paris Agreement, included in our 2016 Food, Water, Energy and Climate Outlook (see p. 4), shows that even if all COP21 commitments are met and sustained to the end of the century, we will still end up with a global average temperature of 3.1–5.2°C above preindustrial levels by 2100, depending on whether the climate response to atmospheric greenhouse gas levels is low, medium or high (Outlook Fig. 8 (top left)). We also concluded that under these conditions, significant threats to food and water security would remain, ranging from more frequent droughts and crop failures to higher water stress in densely populated regions of the world.

Ronald Prinn, Joint Program Co-Director

Why we need to keep the rise in global average temperature below 2°C

The 2°C target is an aspirational but very challenging goal, but the closer we get to achieving it, the less the odds of serious impacts on natural and human systems. The multiple risks of allowing 3°C warming are certainly untenable. Specifically, the Intergovernmental Panel on Climate Change (IPCC, WG2, 2014) in its Fifth Assessment of climate change impacts, extensively reviewed current knowledge of the impacts of global average temperature rises above preindustrial (circa 1875) from 0°C to over 5°C. For unique and threatened ecosystems, areas hit by extreme weather events, geographical distribution of impacts, global total impacts and areas experiencing large-scale singular events, the levels of added risk rose from undetectable to moderate for a 1°C rise, moderate to high for 2°C, and high to very high for 3°C and above.

Sea-level rise is an exemplar of the risks to be avoided. The record of past temperatures and sea levels deduced from polar ice cores and other data shows that the last time polar temperatures were about 4°C over preindustrial (116,000 to 129,000 years ago), global sea levels were 5–10 meters ➲

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(16–32 feet) higher than present (IPCC, WG1, 2013). This sea-level rise indicates melting of much of the Greenland and West Antarctic ice sheets. Due to amplification of polar warming, a polar temperature of 4°C over preindustrial corresponds to a global average temperature of about 2°C over preindustrial. The risks to food production, water resources and human health if we do not meet the 2° C target are more difficult to quantify, because of the required improvements in the accuracy and spatial resolution of climate projections, but they are likely to be very substantial.

Actions needed to achieve the 2°C goal

Analyzing what it will take to achieve the 2°C goal in the 2016 Outlook using our Integrated Global System Modeling (IGSM) framework, we showed that depending on the climate response (Outlook Fig. 26), we'll need to lower annual greenhouse gas emissions from about 55,000 million metric tons today to about 10,000–20,000 million metric tons in 2100 (Outlook Fig. 25).

Achieving that reduction will require an enormous shift in global energy use. With just the Paris Agreement, fossil fuels account for 70 percent of the global energy mix in 2100 (see Fig. 1 below). In the 2°C scenario runs for the 2016 Outlook, that number would range from 3 to 15 percent, depending on which alternative energy sources—nuclear, bioenergy, renewables, or carbon capture and storage (CCS) predominate (see Fig. 2 below and Outlook Figs. 27, 29 and 33).

The gap between the Paris Agreement's current emissions path and what's needed to stay below 2°C is daunting, to say the least. And despite this great challenge to meet the 2°C goal, there is now discussion in some circles of lowering that to 1.5°C. We will discuss what will be needed to meet this this new target at a later date, but it will surely demand a large-scale anthropogenic carbon sink. ■

—Ronald Prinn, Joint Program Co-Director

2016 Food, Water, Energy and Climate Outlook
http://globalchange.mit.edu/Outlook2016

IPCC Fifth Assessment Report
https://www.ipcc.ch/report/ar5

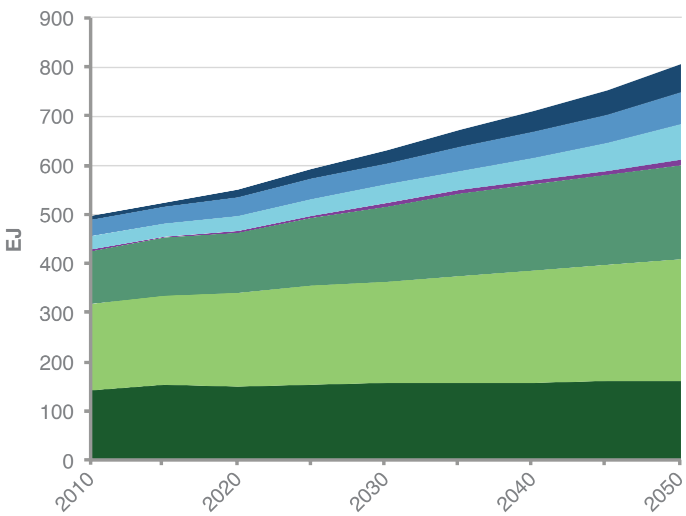
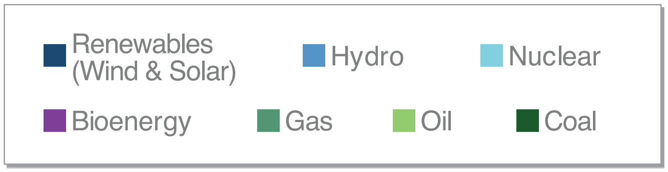
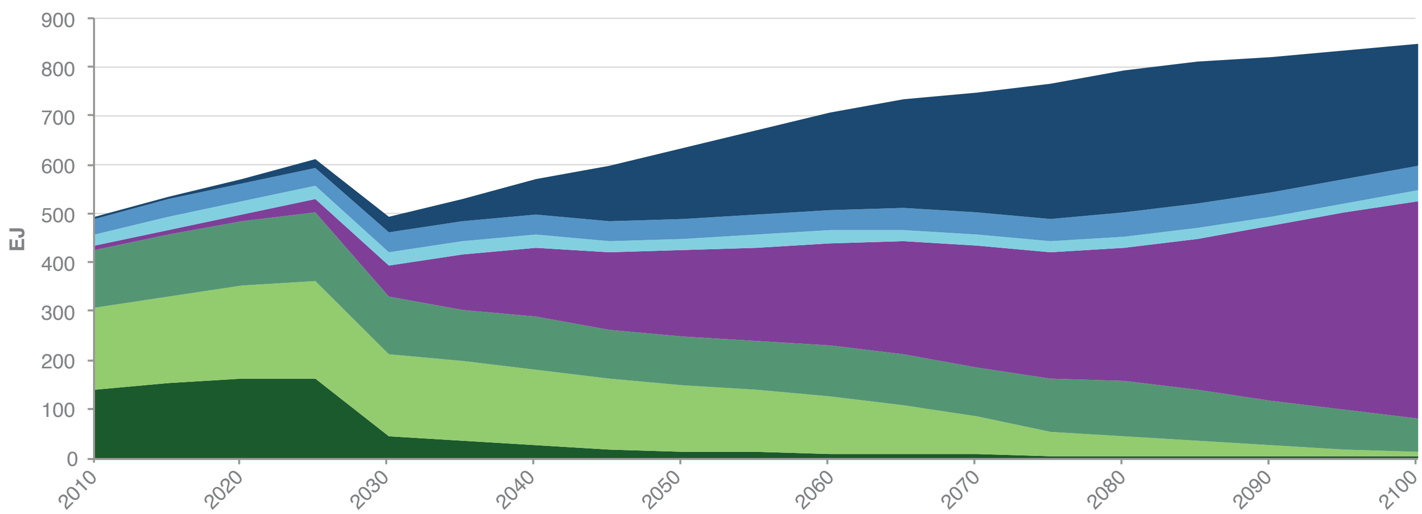


Fig. 1: Global primary energy use (exajoules) under COP21 [Reference: Outlook Fig. 4]

Fig. 2: Global primary energy (exajoules) under the 2°C scenario with low renewables costs and constrained nuclear and median climate response [Reference: Outlook Fig. 31]





Tropical Storm Relief

Crop damage assessment method could enable more precise, timely delivery of food aid

An aerial view shows flooded rice fields after Typhoon Haiyan hit Iloilo Province, central Philippines.

Producing torrential rain and wind gusts exceeding 180 miles per hour as it made landfall in the Philippines, Typhoon Haiyan left more than 6,000 dead and 4 million homeless. The November 2013 storm also obliterated thousands of hectares of crops, mostly rice, the staple food for about 90 percent of the population. Host to six to nine tropical cyclones per year since 1970, and a citizenry that consumes more rice than it produces, the Philippines has for many years augmented its homegrown supply of rice with imports based on seasonal climate forecasts and agricultural production surveys. But import orders must be modified on the fly when extreme weather events exact a heavier toll on production than expected.

In the aftermath of Haiyan, the Philippine government approved the import of an extra 355,000 metric tons of rice based on initial rough estimates of rice production damage and subsequent, more accurate assessments drawn from time-consuming surveys in hundreds of villages. Seeking to enable a more rapid response, researchers have now developed a method that can provide a more immediate and precise estimate of typhoon-inflicted rice damage in the Philippines.

Developed by Elodie Blanc, a research scientist at the MIT Joint Program on the Science and Policy of Global Change, and Eric Strobl, an associate professor of economics at Ecole Polytechnique in France, the method is described in the *Journal of Applied Meteorology and Climatology.*

"Our method provides a faster, more accurate and easier-to-obtain estimate of the impact of typhoons on rice production, and could empower governments in the Philippines and other tropical storm-prone nations to respond more quickly," says Blanc, who is also developing the technique for use in Taiwan and Burma. "Our full methodology could be applied not only to other countries but also to other crops."

To quantify the impact of typhoons on rice production at the province level in the Philippines, Blanc and Strobl applied a set of simple algorithms to publicly available satellite data. First, they used satellite-based spectral measurements of the Earth's surface to pinpoint the location and growth phases of Philippine rice fields at a 500-meter resolution. Next, they modeled wind and rain-driven damage to these fields using typhoon-track data and rainfall measurements, resulting in a provincial-level rice damage index that decision-makers can use to adjust imports.

Their analysis showed that typhoons caused dramatic reductions in local rice production within three months of a typhoon's landfall, with losses of up to 12.5 million metric tons between 2001 and 2014. Using a statistical method called extreme value theory to predict future losses, they determined that a storm like Haiyan—estimated to have reduced rice production by 260,000 metric tons—is likely to recur once every 13 years.

As climate change continues to increase the frequency and intensity of tropical cyclones and other extreme weather events, the researchers expect to see rising demand for their crop damage assessment technique. ■

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

Related Publication:

Blanc, E. and E. Strobl, 2016: Assessing the Impact of Typhoons on Rice Production in the Philippines. Journal of Applied Meteorology and Climatology, *Journal of Applied Meteorology and Climatology*, April issue.

Joint Program 2016 Outlook: After Paris, Food and Water Resources Still At Risk

MIT report projects global impacts of COP21, identifies emissions paths and energy technology advances needed to limit global warming to 2°C

If all pledges made in last December's Paris climate agreement (COP21) to curb greenhouse gases are carried out to the end of the century, then risks still remain for staple crops in major "breadbasket" regions and water supplies upon which most of the world's population depend. That's the conclusion of researchers at the MIT Joint Program on the Science and Policy of Global Change in the program's signature publication, the *2016 Food, Water, Energy and Climate Outlook*, now expanded to address global agricultural and water resource challenges.

Recognizing that national commitments made in Paris to reduce greenhouse gas emissions fall far short of COP21's overarching climate target—to limit the rise, since preindustrial times, in the Earth's mean surface temperature to two degrees Celsius by 2100—the report advances a set of emissions scenarios that are consistent with achieving that goal.

According to the authors, meeting the 2°C target will require "drastic changes in the global energy mix." To explore what those changes might entail, MIT Joint Program researchers and contributors from the MIT Energy Initiative and the Energy Innovation Reform Project identify current roadblocks to commercializing key energy technologies and systems, and the breakthroughs needed to make them technically and economically viable.

To project the global environmental impacts of COP21 and model emissions scenarios consistent with the 2°C target, the *2016 Outlook* researchers used the MIT Joint Program's Integrated Global Systems Modeling (IGSM) framework, a linked set of computer models designed to simulate the global environmental changes that arise due to human causes, and the latest U.N. estimates of the world's population.

Implications for agriculture and water resources under COP21

Assuming a global emissions path based on COP21, Joint Program researchers used statistical models they developed that replicate complex, numerically demanding globally gridded crop models to project the future productivity of the Earth's breadbasket regions. The projections show overall increased yields through 2100 of maize in the U.S. and wheat in Europe, but taking advantage of these increases would likely require a significant shift northward of farming operations from where these crops are currently produced. The results also show an overall increase for upland rice in Southeast Asia and soybean in Brazil, with a more mixed pattern of yield increases and decreases appearing within these broad regions.

The authors attribute much of agriculture's gains from climate change to increases in carbon dioxide concentrations, which can act like a fertilizer and also improve crops' water-use efficiency. However, they note research indicating that such yield increases may be accompanied by reductions in nutrient and protein content. They also caution that while climate change may give some areas an advantage, extreme heat and drought linked to a changing climate are likely to increase the frequency of major crop failures. In addition, significant disparities in yield changes across breadbasket regions could lead to costly relocations of farming operations. Finally, the crop models upon which this report's statistical models are based constitute an important, but recent, development, and will require more work to better represent current yields if there is to be confidence in future projections.

The *2016 Outlook* also projects that under COP21, the water stress index (WSI), a common measure relating water use to water availability, will increase in most regions as a result of increasing demand due to population and economic growth (particularly in developing countries), as well as from changes in climate. The largest relative increase in the WSI is found in Africa, mainly driven by increases in population and economic growth.

The authors conclude that approximately 1.5 billion additional people will experience stressed water conditions worldwide by 2050, of which approximately one billion will experience heavily to extremely stressed water conditions. Uncertainty in the climate change pattern plays a role in both where people will face water stress and what level of water stress they will face.

"Our results indicate that even the COP21 climate-mitigation actions are insufficient to curtail all risks of increasing global water scarcity by midcentury," says Adam Schlosser, deputy director of the MIT Joint Program. "To make salient risk reductions in unmet water demands by 2050, many nations will need to consider broad adaptive measures that increase the efficiency of water consumption as well as viable options to increase water-storage potential. Our continued analyses will be bringing the most cost-effective options to bear."

"The Paris Agreement made energy projections particularly important, as it calls for a goal that requires an energy system based on a radically different fuel mix than what's been developed to date."

Implications for energy and climate under COP21

As detailed in the *2015 Outlook* and reviewed in the 2016 report, assuming that COP21 pledges are met and retained in the post-2030 period, the global mean surface temperature is projected to rise 3.1–5.2°C above preindustrial levels by 2100, far higher than the 2°C threshold identified by the United Nations Framework Convention on Climate Change as necessary to avoid the most serious impacts of climate change, from rising sea levels to more severe precipitation patterns to increased wildfires. The global mean precipitation increase ranges from 3.9 to 5.3 percent by 2050 relative to the preindustrial level, and 7.1 to 11.4 percent by 2100.

By the MIT Joint Program's estimate, the planet's emissions path under COP21 will result in atmospheric greenhouse gas (GHG) levels that far exceed those consistent with the Paris Agreement's 2°C goal. Even with low climate sensitivity to GHG emissions, on this path, the 2°C target will be passed shortly after 2050. The *2016 Outlook* therefore lays out three global emissions path scenarios—based on the global climate exhibiting low, medium or high sensitivity to atmospheric GHG levels, respectively—consistent with keeping the global temperature rise below 2°C, and assesses prospects for low-cost, low-carbon energy technologies that could support those scenarios.

"The Paris Agreement made energy projections particularly important, as it calls for a goal that requires an energy system based on a radically different fuel mix than what's been developed to date," says Sergey Paltsev, deputy director of the Joint Program. "In our report we show that the timing of this shift and the exact contribution of a particular technology will depend on many economic and political variables. Such uncertainty about future costs and technologies supports a conclusion that governments should not try to pick the 'winners,' rather the policy and investment focus should be on targeting emissions reductions from any energy source."

Prospects for low-cost, low-carbon energy technologies

Depending on how technology, policy, the economy and public opinion evolve, a variety of different energy technologies such as nuclear, renewables, biomass or carbon capture and storage (CCS) could play a dominant role in enabling an emissions pathway consistent with the 2°C goal. In detailed analyses of energy technologies where innovation could facilitate a lower-carbon future, the *2016 Outlook* examines technical and economic barriers and hoped-for breakthroughs in nuclear energy, biomass energy, solar electricity, electricity storage, the electricity grid and CCS.

Alongside these analyses, Joint Program researchers, by assuming different mixes of costs and technology-cost ranges estimated by the International Energy Agency, portray scenarios in which one or another of these advanced technologies plays a dominant role. These scenarios are illustrative, and not necessarily tied to specific advances described in the contributed perspectives.

"While it's hard to predict exactly which of these technology advances will prove out, I'm confident that with substantial R&D investment, we'll see significant advances—and cost reductions—in one or more of them." says John Reilly, co-director of the Joint Program. "As a result, the cost of stabilizing greenhouse gases will come down to a level where countries will find it much easier to move forward on climate policy." ■

Related Publication:

2016 Food, Water, Energy and Climate Outlook
http://globalchange.mit.edu/Outlook2016

Gauging Impact of Climate Change on U.S. Agriculture

New approach tracks key factors affecting crop yields, enabling early adaptation

Water stands between the raised beds of corn verification plot on April 15, 2015.

To assess the likely impact of climate change on U.S. agriculture, researchers typically run a combination of climate and crop models that project how yields of maize, wheat and other key crops will change over time. But the suite of models commonly used in these simulations, which account for a wide range of uncertainty, produces outcomes that can range from substantial crop losses to bountiful harvests. These mixed results often leave farmers and other agricultural stakeholders perplexed as to how best to adapt to climate change.

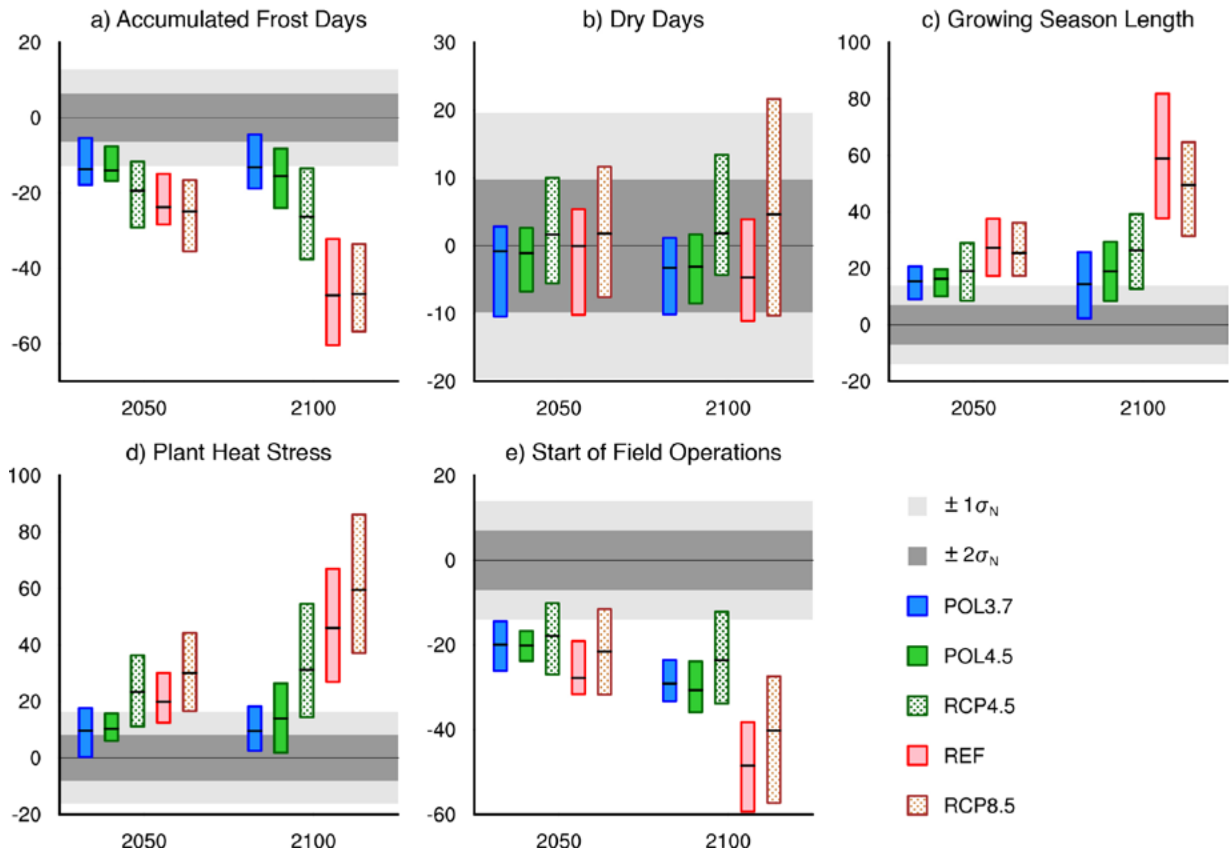
Now, in a study published in *Environmental Research Letters* and highlighted as the lead story on environmentalresearchweb.org's Environmental Research Roundup on July 27, 2016, a research team at MIT and the University of California, Davis, has devised a way to provide these stakeholders with the additional information they need to make more informed decisions. In a nutshell, the researchers complement the results of climate/crop model runs with projections of five useful indices of agriculture/climate interaction—dry days, plant heat stress, frost days, growing season length and start of field operations—that clarify what's driving projected yields up or down.

"Our work provides an alternative way to look at the fate of agriculture under climate change that provides information that's more relevant to farmers than existing climate/crop models."

"It's very difficult to investigate the impact of the climate on agriculture because models don't agree even on the sign of projected yield, or indicate the mechanism behind it," says the study's lead author Erwan Monier, a principal research scientist with the MIT Joint Program on the Science and Policy of Global Change. "Our work provides an alternative way to look at the fate of agriculture under climate change that provides information that's more relevant to farmers than existing climate/crop models."

Using the MIT Integrated Global System Modeling (IGSM) framework, which accounts for key sources of uncertainty and incorporates all five agro-climate indices, Monier and his collaborators ran simulations to estimate the potential effects of climate change on agriculture in the U.S. by 2100.

Under a scenario in which greenhouse gas emissions are unconstrained, the model projected that the U.S. will experience fewer frosts, a longer growing season, more heat stress and an earlier start of field operations by the end of the century. When greenhouse gas emissions reduction policies—one aimed at capping the rise in global mean



Projected changes in five land management stakeholder-relevant indices over the U.S. under different greenhouse gas emissions scenarios—in 2050 and 2100 relative to present day. The U.S. as a whole is projected to experience fewer frosts, a longer growing season length, an earlier start of field operations and an increase in heat stress. [Figure 4 in Related Publication.]

surface temperature between pre-industrial times and 2100 at 2 degrees Celsius, the other targeting a 2.5°C cap—were applied, projected changes in four out of the five indices were cut in half.

This suggests that aggressive greenhouse gas mitigation could sharply reduce the effects of climate change—both adverse ones, such as increased heat stress, and beneficial ones, such as a longer growing season.

The research team also determined that these climate mitigation policies would prevent changes in any of the five indices from exceeding those that arise from natural year-to-year variations in the climate that we already experience, thus limiting the severity of climate-related impacts on agriculture for the rest of the century.

Enabling these results is a new, more efficient, integrated approach to modeling the impact of climate on agriculture and estimating the benefits of climate mitigation efforts.

Rather than relying on the traditional approach of using a multi-model ensemble (the standard one, the CMIP5, comprises more than 30 different climate models) to estimate the uncertainty in the impact of climate change on agriculture, the researchers used multiple simulations of a single model where key sources of uncertainty are explored by varying several model assumptions. These include the response of the global climate system to changes in atmospheric greenhouse gas levels, the natural variability in the climate system, and the emissions scenario selected.

Bypassing the need to run multiple climate models through international coordinated efforts among multiple climate research institutes, the MIT model delivers a similar range of results with far greater efficiency. And because it integrates both climate and economic projections, it provides a more direct estimate of the economic benefit of climate mitigation. ■

The study was funded by the U.S. Environmental Protection Agency, Department of Energy and National Science Foundation.

Related Publication:

Monier, E., L. Xu and R. Snyder, 2016: Uncertainty in future agro-climate projections in the United States and benefits of greenhouse gas mitigation, *Environmental Research Letters,* Volume 11, Number 5.

Meeting Climate Goals through International Carbon Markets

Linking emissions trading systems in developed and developing countries could yield environmental, economic benefits

Recognizing the substantial costs involved in addressing climate change through both mitigation and adaptation measures, the Paris Agreement stipulates that developed countries provide at least $100 billion a year in climate financing to developing countries, and support their transition to lower-carbon economies through international cooperation. One avenue for such cooperation is to link carbon markets—emissions trading systems that put a cap on carbon—in developed and developing regions.

This arrangement could boost the price of carbon in developing countries and thereby accelerate their efforts to shift away from carbon-intensive fuels. But studies show that it could also sharply reduce the carbon price in developed countries, thus shifting abatement from developed to developing countries. While linking carbon markets would lower the costs of reducing emissions in developed countries, and developing countries would be compensated for undertaking additional abatement via revenue from selling emissions rights, the practice would ultimately stifle energy-efficiency improvements and development of low-carbon technologies in developed countries.

This outcome could be prevented, however, if carbon-trading nations fine-tune the terms of engagement, according to a new MIT Joint Program on the Science and Policy of Global Change study in *Energy Economics*. By setting a limit on the number of emissions permits a developed country can import from a developing country, steep decreases in the carbon price in developed countries can be avoided, says Niven Winchester, a principal research scientist at the Joint Program and co-author of the study.

"If the U.S. trades with a developing country that has a lower carbon price, then our carbon price will come down—eventually matching the lower carbon price—and so will our incentive to decarbonize," Winchester explains. "With the goal of restricting the carbon price reduction in the developed country, we examined the impact of imposing a limit on the volume of permits exported from the developing country."

Using the Joint Program's Economic Projection and Policy Analysis (EPPA) model, Winchester and his collaborators—lead author Claire Gavard, now an environmental economist at the Center for European Economic Research in Germany, who conducted part of her doctoral research at the Joint Program, and Joint Program Deputy Director Sergey Paltsev—estimated the carbon-price and emissions-reduction impacts of a range of permit volume limits on emissions trading between the U.S. and China, the European Union and China, and among all three regions in the year 2030. The limit was defined as a percentage of the total amount of emissions allowed in the developed country.

The researchers projected that meeting recently-pledged national emissions targets at the Paris climate talks through

Vice Premier of China Zhang Gaoli, whose portfolio includes environmental issues, speaks with U.S. Secretary of State John Kerry at the outset of a meeting about climate change and other topics at the Great Hall of the People in Beijing, China, on November 11, 2014.

unlimited emissions trading between the U.S. and electricity and energy-intensive sectors in China would result in a common carbon price of $24 per ton* of carbon dioxide, a 70 percent price decrease in the U.S. (down from $80/ton, the estimated U.S. carbon price without international trading of emissions permits). When imported emissions were limited to 10 percent of the U.S. emissions cap, the U.S. carbon price fell to $51/ton, a 37 percent decrease, and the carbon price in China rose from $17/ton to $19/ton. In the E.U.–China case, the European carbon price fell by 59 percent under unlimited carbon trading, and 31 percent when a 10 percent emissions permit import limit was imposed.

These results, along with others produced in the study, suggest that linking carbon markets could be a win-win proposition for developing and developed countries.

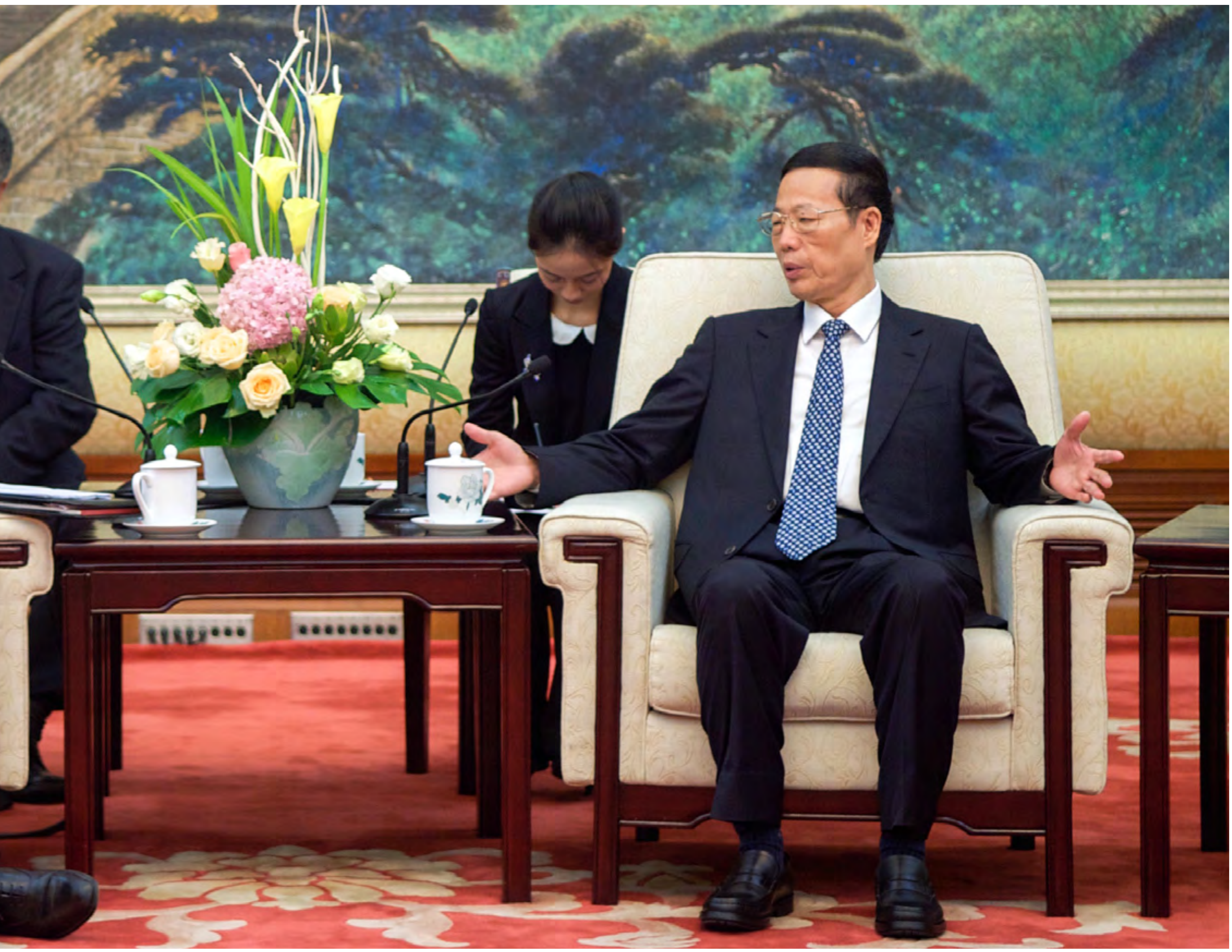
"The opportunity to buy permits in China for $19 and sell them for $51 to the U.S. would present a strong financial incentive for China to link emissions trading markets with the U.S.," says Winchester. "The U.S. would also benefit by taking advantage of low-cost emissions reductions elsewhere while still maintaining incentives to reduce emissions domestically." ■

The EPPA model used in the study is supported by the U.S. Department of Energy, Environmental Protection Agency and other government, foundation and industrial sponsors of the Joint Program.

Related Publication:

Gavard, C., N. Winchester & S. Paltsev, 2016: Limited trading of emissions permits as a climate cooperation mechanism? US–China and EU–China examples, *Energy Economics* **58:** 95–104.

** In the study, the word "ton" refers to a metric ton, or 2,240 pounds.*



3 Questions: Maria Zuber on Stepping up MIT's Response to Climate Change

MIT's vice president for research discusses the challenges ahead for MIT and the world

MIT News Office

Photo: Maria Zuber

At this time last year, MIT President L. Rafael Reif announced the Institute's five-year plan for responding to the risks posed by climate change. Maria Zuber, vice president for research and the E.A. Griswold Professor of Geophysics, has been coordinating MIT's climate action efforts since the plan's announcement. She recently shared with MIT News highlights from the plan's first year of implementation—as well as her thoughts on what needs to happen for the world to avoid the worst impacts of climate change.

Q: The Plan for Action on Climate Change includes a number of components focused on the campus, including a goal of reducing campus carbon emissions 32 percent by 2030. What kind of progress has the Institute made on this front?

A: It's important to underscore that the 32 percent goal is a floor, not a ceiling. Students and faculty have challenged us to become a carbon-neutral campus, and we aspire to do that as soon as we can. We are committed to making investments both on campus and off campus that will lead to a reduction in our overall carbon footprint. Our approach includes a range of strategies, from the expanded use of on-site and off-site renewables, to robust investments in energy efficiency and high-performance building design standards, to efforts to engage our community to reduce consumption.

And we've just taken a big step in the right direction with a new agreement to purchase power from a solar farm in North Carolina, in partnership with two other organizations in Greater Boston: Boston Medical Center and Friends of Post Office Square. The Department of Facilities and the Office of Sustainability really led the charge here, and they deserve great credit. This agreement is good news for a lot of different reasons, but let me give you three:

First, this single solar purchase will address approximately 17 percent of MIT's campus carbon emissions. To give you a sense of the scale you need to achieve this, consider that the new solar development—called Summit Farms—covers 650 acres, while MIT's campus is just 168 acres. At Summit Farms, 255,000 solar panels will generate 60 megawatts of electricity. MIT has agreed to purchase 44 of those megawatts.

Second, we believe Summit Farms demonstrates to other organizations that there is a collaborative model that works for developing renewable energy projects that otherwise wouldn't get built. We intend to share our experience on this project far and wide, because we want everyone—would-be power customers, developers, banks and so on—to know that this makes good sense from both an economic perspective and an environmental perspective.

Finally, on an issue that I spend a lot of time thinking about, Summit Farms will create hundreds of new construction jobs. Many people don't realize this, but the solar industry now employs more than 209,000 people in the United States—roughly triple the number of jobs in the coal mining industry. If we are going to meet the world's climate goals, then we have to do a better job of telling the story of the economic opportunities available in the transition to clean energy, and we have to make sure that these opportunities are broadly available in communities around the country.

Q: This year you established a Climate Action Advisory Committee to "consult with and advise" you on the implementation and assessment of the plan. Can you give us an update on the committee's work?

A: A major focus of the plan was the idea of engagement — that obviously no single institution can solve climate change on its own, so what we need is to engage with industry, government and civil society to develop the kind of multifaceted solutions that reflect the complexity and urgency of the climate threat. With that in mind, the new committee's first charge is to help come up with ideas for engagement, along with ideas for assessing whether or not we're having the kind of impact we want to have.

We had the first committee meeting of the fall semester on Oct. 4, and we began with a conversation about the politics of climate change. Climate change is a technological problem, a business problem, an urban design problem — the list goes on. But ultimately it is a political problem, and we want to do what we can to inform the debate with high-quality research and analysis, grounded in the best science.

I was really impressed with the quality of the discussion we had in the committee. We have students, postdocs, staff, faculty, alumni and Corporation members all thinking hard about what MIT can do to engage productively with other organizations.

You know, 2014 was the warmest year on record—until 2015 replaced it. And unfortunately, 2016 is set to break the record yet again. Climate change is not just something for future generations to worry about—it's happening now. And I think the members of the committee share a sense that we all need to roll up our sleeves and help solve this problem.

"I always remind people that MIT has been doing excellent work on climate change and related issues for decades. I think the Plan for Action on Climate Change has helped to amplify all of this great work, and I think it has inspired more people to join the effort."

Q: How would you say that the MIT community has responded to the fact that climate change is now a top priority for the Institute?

A: I always remind people that MIT has been doing excellent work on climate change and related issues for decades. This year, for example, the MIT Joint Program on the Science and Policy of Global Change celebrated its 25th anniversary. I think the Plan for Action on Climate Change has helped to amplify all of this great work, and I think it has inspired more people to join the effort.

We have members of the MIT community coming up with creative ways to extend the plan's reach. For example, two members of the group MIT Alumni for Climate Action Leadership developed an idea for building an online community of learners and doers, and that idea, in collaboration with the Office of Digital Learning and the Office of Communication, became ClimateX, which is now in a pilot phase.

Let me give you another example: The Environmental Solutions Initiative, along with faculty members who teach the General Institute Requirements, is working to make sustainability-focused content available for embedding into the GIRs. This will ensure that all undergraduates have the opportunity to be exposed to these issues during their time at MIT.

Actions like these, happening all across our community, demonstrate the incredible enthusiasm that members of the MIT community have for doing their part to address climate change.

I also want to make a plug for the forum on climate change ethics that my office is sponsoring on the evening of Nov. 17. The idea for the forum came from Fossil Free MIT, which has done incredible work to organize the event. It will be an important opportunity for our community to discuss the ethical responsibilities facing individuals and institutions in responding to climate change. We're thrilled that Professor Dale Jamieson from New York University has agreed to keynote the forum. I encourage members of the MIT community to mark their calendars for what I know will be a fascinating conversation. ■

MIT Climate Action
http://climateaction.mit.edu

Making China's Economic Transition Work for Global Climate and the Local Environment

Valerie Karplus and Michael Davidson

When it was first announced in late 2014, China's climate pledge was a bold and unprecedented step that gave new confidence to global efforts to mitigate climate change. This pledge, enshrined in the 2015 Paris Climate Agreement, commits the country to peak its emissions at latest by 2030 through steady reductions in carbon intensity and deployment of non-fossil energy. As the world's largest energy user and emitter, and second largest economy, China's move placed a significant dent in global emissions projections at the time.

Today, the combination of China's economic slowdown and proactive government realignment of internal priorities toward more sustainable growth has led to lower projections of the country's emissions trajectory. The question is no longer whether or not China will be able to meet its pledge—indeed, a peak sooner than 2030 looks well within reach, suggesting China's climate pledge was both prudent and credible. Instead, the question now is whether or not—and how—China can achieve further progress on climate change while advancing its own development goals. Any effort to accomplish this will require strong central coordination in policy making, a commitment to incentives for demand to guide new energy investments, and redoubled capacity for monitoring and implementation.

Expectations exceeded but new challenges emerge

Indeed, it is noteworthy that China has met or exceeded most of the energy and climate goals it has set so far. Take for example progress during the Twelfth Five-Year Plan (2011–2015). China's energy intensity and carbon intensity reduction goals of 16 percent and 17 percent, respectively, were both exceeded by a few percent. The country overshot its original 90 GW target for wind deployment by a large margin, with 145 GW installed at the end of 2015. Solar capacity hit 43 GW, exceeding the original goal—viewed by many as ambitious—of 35 GW.

But there are also some worrisome signs that energy system investment—especially in coal—has not adjusted in the face of slower-than-expected growth. In 2015, electricity demand grew by only 0.5 percent, while new capacity in the electric power system expanded by 9.5 percent. Although non-fossil sources nuclear, hydro, wind, and solar accounted for over half of the incremental capacity at about 72 GW, new coal capacity accounted for 52 GW in 2015, the largest increase since 2009. The new capacity will exacerbate an existing glut and could lock in substantial carbon emissions for decades unless the course correction mentioned below is pursued and strengthened.

Another pressing issue is the increasing integration woes of China's renewable energy investments. In the first half of this year, over 1/5 of all wind energy in the country was unable to be utilized (curtailed), with that fraction rising to over a half in certain areas. In a recent study in *Nature Energy,* we analyzed how much of China's wind potential could be cost-effectively integrated in 2030, and the results were striking: reaching 30 percent of total projected electricity demand, wind could deliver three-fourths of China's target of 20 percent of primary energy from non-fossil sources in 2030. Adding in solar, hydro, and nuclear, China has the opportunity to exceed this target by a large margin.

To achieve this, we found, requires at least two major changes to current practice: first, reducing preferential treatment for wind in high-resource areas located far from demand centers, which would ensure new build decisions more strongly reflect integration challenges; and second, increasing the flexibility of power system operation, in particular the dispatch of coal generators, to accommodate the variability of wind and solar. China has already made some changes to deployment patterns, by forbidding new projects in high curtailment regions early this year, and accelerating approvals of new capacity growth in previously untapped regions like Guizhou.

Reforming power system operations is much more challenging, and China still has a long road ahead. Establishing markets for electricity, as proposed in last year's power sector reform document, could create crucial price signals to incentivize flexibility and improve system efficiency, while also pushing out inefficient or excess generators that currently receive guaranteed electricity quotas. Under typical market designs (known as spot markets), wind and solar are big winners since their marginal cost is near zero. Unfortunately, steps toward the creation of efficient short-term markets have been slow. Acknowledging the importance of short-term flexible operations, the central government has created pilot programs at select coal plants to explore the technical potential for plants to provide more space for renewable energy, but without incentives it is difficult to see how these will be scaled up to deliver widespread relief.

Wind field in Northwest China

More broadly, policy makers will need to move beyond supply-push policies that help to rapidly expand infrastructure and boost GDP, to market-based discipline—for instance, by removing subsidies, ensuring investors rely on the market for cost recovery, and by pricing carbon—that will ensure investment decisions respond to changing demand conditions. The recent cancellation of plans for new coal construction is a positive step, but has come too late to avoid a worsening of short-term overcapacity. Plans to launch a national emission trading system (ETS) in 2017 will introduce a price on carbon emissions, but there is much work left to make it a fully functioning market. Meanwhile, removing administrative supports that target specific levels of new capacity would impose discipline on investments that are far outpacing demand growth. The announcement that new coal plants will not be granted annual generation quotas is a step in the right direction, as are several new administrative efforts to promote grid integration of renewables. However, already approved plants and co-generation facilities are excluded.

Renewable energy not only brings changes to the grid, it also hits budgets and priorities of local governments, who cling on to tax revenues and employment of coal and energy-intensive industries even more tightly amidst slowing growth. Worrisome is that initial steps of market-based electricity pricing have taken the form of bilateral contracts between primarily coal and large consumers, suggesting that the first beneficiaries of reduced electricity costs will be the very energy-intensive industries that China is trying to transition away from. Allowing market pressures to push down prices while at the same time putting more renewable energy on the grid will be a crucial determinant of the pace of environmental progress. There must also be much more candid conversation on how to transition old industries and their workers—crucial elements of a real reform agenda.

Opportunities at the G20 to connect the local and the global

The upcoming G20 meeting in Hangzhou offers China the chance to reaffirm its intention to make best efforts to peak emissions before 2030, and to promote a green, low carbon economic transition, not in spite of, but because of, the potential for sustainable economic benefits. All countries need to do more to address climate change. Highlighting the progress China has made—and remaining challenges it faces—in evolving its institutions to support its increasing focus on sustainable development could catalyze greater dialogue and information sharing within the G20. This would go a long way toward expanding the global clean energy economy under the country's leadership.

The benefits of redoubled efforts to accelerate a clean energy transition in China should come as good news for its policy makers—the actions that enhance climate change mitigation can be beneficial for emerging clean industries and also help deal with country's major air pollution problems. Incentivizing stakeholders that have long benefited from the status quo to participate will determine how much reforms can deliver—for both the economy and the climate. ■

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Modeling Plausible Futures

C. Adam Schlosser assesses long-term risks to regional water and energy systems

Last spring Joint Program Deputy Director and Senior Research Scientist C. Adam Schlosser and colleagues published a paper in the journal *PLOS One* that projected a "high risk of severe water stress" in much of Asia by midcentury. Attributing the projection to rising demands driven by population and economic growth and exacerbated by climate change, they estimated that within 35 years, one billion more people in the area would be affected. The region in question is home to about half of the global population, so this finding matters. News outlets from the Christian Science Monitor to Time picked up the story, disseminating it to millions of potential readers.

"The response to this study illustrates the kind of scientific finding that makes people—including decision-makers and other stakeholders—listen and react," says Schlosser. "We presented not only the science but also its potential impact on people's lives. That's a hallmark of the Joint Program."

Assessing risk

So, too, is a methodology that underlies not only the Asia water-stress study but much of Schlosser's research: the practice of running a computer model multiple times under varying assumptions (e.g., about the climate, population growth or economic growth) to produce an exhaustive range of plausible future scenarios for a particular aspect of global change (e.g. water availability), and qualify each scenario with a level of uncertainty. In the vernacular, this is known as the application of Monte Carlo methods. By "rolling the dice" hundreds to thousands of times under different assumptions about Earth and human systems, Schlosser and colleagues can determine the odds of outcomes that policymakers are either targeting or trying to prevent. This information can then help guide decision-makers on how best to "weight the dice" to minimize risk to lives and infrastructure.

"We'll never be able to completely eliminate all uncertainty, but there are opportunities to constrain the uncertainty and give people an outlook of the future that we can act upon."

"The challenge with addressing and quantifying risks is to identify the bounds of your knowledge and everything in between, and then to simulate that environment with computer models," notes Schlosser. "That demands that we not only use models in creative ways but also bring to bear observations that can help us isolate meaningful signals in the results we obtain from those models."

Applying Monte Carlo methods to the Joint Program's Integrated Global System Modeling (IGSM) framework to simulate the response of Earth and human systems to global change and assess risks that may lie ahead in the coming decades, Schlosser is now working to identify potential threats to regional water supplies and ecosystems, optimal locations for renewable energy generation around the globe, and trends in extreme events and their potential impact on the built environment.

Charting the future of water supplies, renewable energy and the grid

Having recently upgraded the Water Resource Systems (WRS) model used in the Asia water-stress study (an extension of the IGSM framework) to more precisely represent water-demand sectors (regional watersheds) and the quality of water within them, Schlosser aims to simulate a large number of plausible futures for the U.S. water supply. The goal of his research team is to pinpoint any significant threats to the water system and project when water availability may become severely stressed by changes in the agricultural, energy, industrial and other sectors of the economy.

Over the next two years, he plans to explore the range of risks that different climate pathways pose for the U.S. water system, and how those risks may be avoided through mitigation or adaptation measures, such as efficiency improvements in water use (e.g. irrigation) and transport. He also aims to account for the uncertainty in runoff changes that occur under climate change, and their impact on risks to water demand sectors.

Another key research objective of Schlosser's is to determine how regional patterns of precipitation and temperature will impact the deployment of renewable energy technologies such as wind turbines and photovoltaics. As the world shifts away from fossil fuels and toward lower-carbon energy sources, it will become increasingly important to identify the prime locations where wind and solar power can thrive. By enhancing the IGSM framework to generate multiple simulations of wind and clouds on a regional basis, Schlosser aims to provide policymakers with more precise estimates of the times and locations at which wind and solar energy resources will be plentiful and reliable.

"In a world where wind and solar farm installations are ubiquitous, it would be very beneficial if the science of climate predictability could tell when and where those fundamentally intermittent resources are the most reliable without constantly relying on backup technologies which are the very same greenhouse gas-emitting technologies we're trying to avoid in the first place," he says.

Schlosser is also applying Monte Carlo methods to assess the risk to infrastructure posed by extreme weather events that range from storms to heatwaves. He and colleagues first developed a technique that draws upon the Joint Program's climate model and those used by the institutions that have participated in the Intergovernmental Panel on Climate Change (IPCC) to explore how precipitation extremes shift under various climate policies—and which policies are likely to minimize the likelihood of shifts in extreme precipitation events that threaten infrastructure and livelihoods.

In a pilot project conducted in collaboration with the MIT Lincoln Laboratory, they next looked at how human-induced changes in climate affect the occurrence of heatwaves that could damage expensive transformers that are critical to the functioning of the electric power grid in the U.S. Northeast. The next step is to expand this analysis and evaluate the grid more comprehensively, so as to provide actionable information for how to make the grid more stable, reliable and environmentally responsible.

"Our approach shrinks down the range of possible outcomes," says Schlosser. "We'll never be able to completely eliminate all uncertainty, but there are opportunities to constrain the uncertainty and give people an outlook of the future that we can act upon."

Yearning for winter

Schlosser came to this work out of a love for snow. Growing up in Rhode Island, he lived for snow days, when he could trade reading, writing and arithmetic for sledding, skating and skiing. Over the years, as climate change emerged as a global threat, his affinity for winter storms and activities fueled a growing concern about how winter would change on a warmer planet. That led to an interest in hydrology. Studies of hydrology in graduate school at the University of Maryland, where he received a PhD in meteorology, deepened his focus on winter processes and raised his awareness about the challenges in representing hydrology in climate or earth system models.

After completing postgraduate work in climate predictability at NOAA's Geophysical Fluid Dynamics Laboratory and further research at the Center for Ocean Land Atmosphere Studies, he served as a research scientist at the NASA Goddard Spaceflight Center, where he developed an ongoing program, the NASA Energy and Water Cycle Study, that uses multiple observations to generate a comprehensive picture of the global water and energy cycle. While Schlosser's work at Goddard nurtured his scientific curiosity, there was something missing that he would find in his next position at the Joint Program, and keep him here for 12 years and counting.

"Throughout my career, my research has been personally compelling from a scientific discovery standpoint, but there's nothing like advancing science that can make a substantive contribution to decision-making, strategic planning and policy formation concerning critical global challenges," he says. "I never had an appreciation for that until I came here." ■

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): eo150633.

NASA Energy and Water Cycle Study

nasa-news.org

Rethinking How We Get Around

IDSS PhD student Paul Kishomoto probes the future of transportation in China

Some policy analysts worry that if per capita wealth in China continues to escalate and approaches that of the United States, automobile ownership could quadruple. The likely consequences: extreme traffic congestion and even higher concentrations of air pollution and planet-warming carbon emissions. But researchers are all over the map as to how much massive increases in personal wealth in China will impact private car ownership levels and vehicle travel. Complicating their estimates are vast regional differences in economic growth rates; the emergence of vehicle ownership restrictions in some of China's most densely populated cities; and common, yet unproven, assumptions that China's car ownership growth will resemble that of the U.S., South Korea and other countries during periods of rapid economic expansion.

Since 2012, MIT Joint Program Research Assistant Paul Natsuo Kishimoto has been applying new data sources and analytical methods to get an accurate read on how vehicle ownership and mileage are likely to change in China in the coming decades, and the costs and benefits of vehicle ownership restrictions. Using household survey data and public statistics on different Chinese cities, Kishimoto is working to characterize the relationship between rising income and transportation-related consumption, and how vehicle ownership restrictions would alter that relationship.

"What we're trying to do is to use data sources and methods that other people have not used, and that are more flexible and sophisticated, to do this estimation," says Kishimoto, who is pursuing this research in preparation for his PhD thesis for the Engineering Systems program of the MIT Institute for Data, Systems and Society (IDSS). "Our goal is to determine how much people spend on private vehicles as a fraction of their income; how that changes as their incomes rise, public transit options emerge and vehicle ownership restrictions are imposed; and how these transportation choices are likely to impact the nation's energy use, greenhouse gas emissions and air pollution levels."

The research could inform policymakers not only in China, but also in other developing countries where rapidly rising incomes could translate into considerably more cars on the road.

Kishimoto comes to this work as a result of his own experiences of living with—and without—access to a privately-owned automobile. Growing up in the suburbs of Toronto, he first saw himself as a "math nerd" with an affinity for fighter jets and dreams of building far-out, futuristic aircraft. In his early double-digits, he announced to his parents, both math teachers, his intention to become an aerospace engineer. As an aerospace engineering major at the University of Toronto, he expected to realize his childhood dream, but the experience of living in a city for the first time altered his flight path.

Paul Kishimoto is a recent recipient of a fellowship from the Martin Family Society of Graduate Fellowships in Sustainability.

"It was revelatory that you didn't need a car to get everywhere," he recalls. "I had not given much thought that there was another way that your life could be organized other than having mom and dad drive you everywhere, borrowing a vehicle or getting picked up, or, perhaps, not going to certain places at certain times. In the city you just walk out the door, get on a bike or get on transit; things are within walking distance. I started realizing that this was a consequence of planning decisions, of policy. That in the suburb where I had grown up, somebody had made a choice at some point that we're going to build subdivisions instead of building a dense urban form that's more walkable and livable."

"We're trying to apply innovative methods and combine datasets in novel ways to get a better understanding of how transportation will evolve in China."

As Kishimoto completed his bachelor's degree in aerospace engineering and commenced work on a master's, this realization—alongside a growing interest in sustainability and climate change—began to take center stage. Anticipating a career that would not likely offer opportunities to work directly on such concerns, he made a course correction. He left the master's program, sought out a course of study that reflected his appreciation for the value of applying scientific and technological expertise to decision-making—from municipal transportation planning to global climate policy—and found it in the MIT Technology & Policy Program (TPP).

From 2010 to 2014, both during and immediately after completing his TPP master's program, Kishimoto worked as a research assistant and associate at MIT. After a one-year stint working on a classroom-oriented version of the Integrated Global System Modeling (IGSM) framework, he began collaborating with the Joint Program's China Energy and Climate Project (CECP) leader Valerie Karplus (now an assistant professor at the Sloan School of Management) on developing the China Regional Energy Model (C-REM) model, which projects energy demand and its associated environmental impacts in China under different policy scenarios. Once accepted to the MIT Engineering Systems program as a PhD candidate, he continued this work with a focus on adding representation of household transportation to C-REM, all while co-authoring two journal papers on the environmental, climate and economic impacts of global and Europe-based fuel economy standards.

"The future growth of China's household vehicle fleet is one of the greatest sources of uncertainty in energy and environmental impact scenarios," says Karplus. "Paul is one of the few scholars piecing together novel sources of data on consumer behavior to quantify the underlying drivers of this growth. His results have the potential to change the way stakeholders approach the design of China's urban transportation systems in the coming decades."

In the past two years, Kishimoto has served as a Joint Program research assistant while developing his PhD thesis on modeling the future of transportation in China and its potential environmental and climate impacts. His work applies innovative analytical methods to myriad data—on the country's fast-growing economy, burgeoning wealth, rapidly expanding transportation infrastructure, and assortment of transportation policies—to project how China's transportation system is likely to evolve in the next few decades. Such knowledge could empower decision-makers to steer China's transportation future—and that of other developing countries—in a more sustainable direction.

"Compared to the developed world, the state of transportation systems in China is less well-understood, and because it's such a large, populous country, unrestricted or poorly guided growth could lead to significant negative consequences for the environment and climate," says Kishimoto. "That's why we're engaged in the work we're doing. We're trying to apply innovative methods, including those developed at the Joint Program, and combine datasets in novel ways to get a better understanding of how transportation will evolve in China, and the kinds of regional and global impacts that may result if no corrective policy action is taken."

After earning his PhD (most likely by the end of 2017), Kishimoto hopes to return to Canada and start a program much like TPP—graduate education for engineers and scientists on connecting technical knowledge to policymaking. He sees this education as increasingly important not only for policy wonks who lack a science and engineering mindset, but also for scientists and engineers who need to better understand the societal implications of their innovations. Drawing on extensive leadership and teaching experiences at the University of Toronto and MIT, Kishimoto envisions spearheading a Canadian version of TPP while serving as a faculty member focused on transportation, energy and policy analysis.

And continuing, as is his wont, to engage people in conversations about transportation and its impact on the quality of their lives, the environment, climate and other societal concerns.

"I encourage them to think about transportation not just on a day-to-day basis, but in terms of systemic issues and how they can contribute to the broad changes needed to take us toward sustainability." ■

More information about Paul Kishimoto is available at his website, http://paul.kishimoto.name.

Related Publications:

Kishimoto, P.N., V.J. Karplus, M. Zhong, E. Saikawa, X. Zhang, and X. Zhang (August 2016). Impact of Coordinated Policies on Air Pollution Emissions from Road Transportation in China. MIT Joint Program *Report 299*.

Kishimoto, P.N., D. Zhang, X. Zhang, and V.J. Karplus (2015). "Modeling Regional Transportation Demand in China and Impacts of a National Carbon Policy." *Transportation Research Record*, 2454:1–11 (doi:10.3141/2454-01).

ENGAGING INDUSTRY IN ADDRESSING CLIMATE CHANGE

AT CLIMATE WEEK CONFERENCE, MIT JOINT PROGRAM LAYS OUT THE 2°C CHALLENGE FOR OIL AND GAS PRODUCERS

The mission of the Oil and Gas Climate Initiative (OGCI), a two-year-old organization comprised of ten major oil and gas companies, is one not commonly associated with the industry: to catalyze practical action to reduce greenhouse gas emissions. Intent on confronting the challenge of climate change head-on, the OGCI committed last October to support the Paris climate agreement's target of capping the rise in mean global surface temperature since preindustrial times at two degrees Celsius by 2100, and has been working ever since to develop a plan for the industry to help advance this objective.

To that end, the OGCI held its second Low Emission Roadmap Roundtable on September 23 at the World Economic Forum in New York City. During the three-hour event, timed to coincide with the city's annual Climate Week, the OGCI sought input from stakeholders as they develop practical steps for reducing the industry's emissions. While the formal membership of the OGCI represents about 20 percent of global oil and gas production, invitations were open to a broader group of industry and environmental non-governmental organizations. To bring academic rigor to the discussion of how to help reduce greenhouse gas emissions in alignment with the 2°C goal, the OGCI partnered in the Roundtable with the MIT Joint Program on the Science and Policy of Global Change.

Early in the event, Joint Program Co-Director John Reilly previewed a set of scenarios illustrating the significant transformation of the global energy system that's needed, and various technology paths that could be pursued, to achieve the 2°C goal. These scenarios were released on September 28 in the Joint Program's 2016 Food, Water, Energy and Climate Outlook.

"A key to understanding steps that industry can take to reduce greenhouse gas emissions are estimates of emissions pathways consistent with stabilization of greenhouse gases in the atmosphere," said Reilly, who is also a senior lecturer at the Sloan School of Management. "Our contribution to the discussion was to develop illustrative pathways and to suggest the potential role of a variety of low-carbon technologies in enabling deep emissions cuts, emphasizing that uncertainty in climate response and in technology development call for a risk-based planning process."

The Low Emission Roadmap Roundtable featured **Valérie Quiniou-Ramus**, co-chair of the OGCI Low Emission Roadmap work stream and vice president, Total; **Vidar Helgesen**, Minister of Climate and the Environment of Norway; MIT Joint Program Co-Director **John Reilly**; MIT Joint Program Co-Director Emeritus **Henry Jacoby** (event moderator); **Bjorn Otto Sverdrup**, senior vice president, Statoil; and **Granville Martin**, managing director, Sustainable Finance, JPMorgan Chase.

"The MIT Joint Program's input at the Low Emission Roadmap Roundtable helps us to determine what oil and gas companies should focus on to enable an efficient energy transition to zero net emissions"

Joint Program Co-Director Emeritus Henry D. Jacoby, William F. Pounds Professor of Management (Emeritus) at the MIT Sloan School, who moderated the Roundtable, added, "There is a growing effort in the international negotiations to involve non-state actors in managing climate risk, and this OGCI effort is a timely response." To that end, the Roundtable included opening presentations by Vidar Helgesen, the Minister of Climate and Environment of Norway, two executives of OGCI companies—Bjorn Otto Sverdrup of Statoil and Valérie Quiniou-Ramus of Total—and Granville Martin from JP MorganChase. The event covered both the intentions and plans of the OGCI member companies and active discussion of ways they could make their most effective contribution to the goals of the Paris Agreement.

The OGCI chose to partner with the MIT Joint Program because it is "one of the key research centers that's driving the thinking around the energy transition, with strong technical capabilities," says OGCI Executive Board Chair Gerard Moutet. "The MIT Joint Program's input at the Low Emission Roadmap Roundtable, along with that of OGCI stakeholders, helps us to determine what oil and gas companies should focus on to enable an efficient energy transition to zero net emissions," said Moutet.

Informed by the Joint Program's analysis that a sharp turn in the current direction of the energy system is needed, the discussion centered on how fast the system could respond; whether a technological revolution was already underway that would sweep aside the fossil energy industry; the need to protect and expand forest carbon sinks; and prospects for global carbon pricing, which many in attendance deemed essential to providing enough incentive for investment in low and zero-carbon sources of energy. Practical steps the OGCI is considering to reduce greenhouse gas emissions include improving the energy efficiency of their operations and products, developing carbon capture and storage, reducing carbon dioxide and methane emissions by utilizing gas instead of flaring it, and developing and deploying new low-carbon energy technologies.

Viewing private sector engagement as essential to solving the climate problem, the Joint Program has for 25 years engaged with industry, including OGCI member companies, on comprehensive studies of the impact of the changing climate, and the need to transform the energy system.

"Through its comprehensive modeling and analysis, the MIT Joint Program provided us with useful insights into the nature and timeline of changes that will be needed to transition to a lower-carbon energy system," said Charlotte Wolff-Bye, host and organizer of the Roundtable, co-chair of the OGCI Low Emission Roadmap work stream and vice president for Sustainability at Statoil.

Oil and Gas Climate Initiative
http://www.oilandgasclimateinitiative.com

MIT, QUÉBEC RESEARCH INSTITUTIONS LAUNCH INITIATIVE TO ANALYZE LOW-CARBON ENERGY POLICY OPTIONS FOR NEW ENGLAND/QUÉBEC REGION

QUÉBEC PREMIER AND MIT VICE PRESIDENT FOR RESEARCH SPEAK AT BOSTON SIGNING CEREMONY; HYDRO-QUÉBEC CEO PLEDGES FUNDING

By 2020, the state of Massachusetts is committed to reducing its greenhouse gas emissions at least 25 percent compared with 1990 levels, all while up to 25 percent of its electricity generation facilities are expected to go offline. Angling to shore up its energy resources without driving up emissions levels, the state recently passed a bill requiring Massachusetts to procure long-term contracts that tap 1,600 megawatts of offshore wind power and 1,200 megawatts of hydropower or other renewables by 2025. (One megawatt can power up to 1,000 homes.) Massachusetts Governor Charlie Baker, who signed the bill into law, argues that a significant infusion of Canadian hydropower will be needed to enable the state to meet its impending energy and climate deadlines.

"This research collaboration can help to provide a shared foundation for the development of sound energy strategies in New England, Québec and beyond."

Aiming to equip decision-makers in the New England/Québec region with the knowledge they'll need to evaluate this and other cross-border, low-carbon energy and climate policy options, the MIT Joint Program on the Science and Policy of Global Change and two Montréal-based ➲

research institutions—the business school Hautes Études en Commerce (HEC), and Ouranos, a climate-change think tank—launched a new collaboration on energy, economy and climate policy analysis at a signing ceremony on August 28 in Boston.

Convened during the Conference of New England Governors and Eastern Canadian Premiers, the ceremony featured remarks by representatives of all three signatories, including MIT Vice President for Research Maria Zuber on behalf of the Joint Program; by Éric Martel, president and CEO of Hydro-Québec, a state-owned electricity supplier and one of the world leading producers of hydropower; and by Québec Premier Philippe Couillard.

Combatting climate change through a clean energy economy

"New England, Québec and the Eastern Provinces of Canada have strong ties through trade and an important opportunity to work and to contribute to a solution to climate change by providing clean energy at a reasonable cost to consumers," said Zuber. "This research collaboration can help to provide a shared foundation for the development of sound energy strategies in New England, Québec and beyond."

Martel announced Hydro-Québec's intention to provide partial funding support for the research collaboration.

"At Hydro-Québec, we are convinced of the necessity of such studies which will help decision-makers to choose low-carbon energy policy options for the New England and Québec region," he said. "So what could be better than to bring together some of the top researchers in the field, those working at MIT, Ouranos and HEC Montréal?" said Martel. "Hydro-Québec is happy to be part of such promising, forward-looking research."

Noting Québec's aim to become more ambitious in tapping its renewable energy resources, including its vast hydropower capacity, Premier Couillard emphasized the need for evidence-based policymaking guided by science and independent analysis.

"We want to . . . take this opportunity to become even more efficient in terms of dropping our emissions and mitigating and adapting North America to climate change," he said.

Advancing tools to assess cross-border energy, economic and climate policies

The primary goal of the initiative is to develop advanced technical analysis in support of energy, economic and climate-related decision-making by public and private sector leaders in New England and Québec. Informed by that goal, the three parties will work together to develop modeling tools needed to examine the economic relationships between New England and Québec.

These new tools will enable the researchers to perform integrated assessments of energy/economic/climate policy in Québec and New England, which will be needed to

"What could be better than to bring together some of the top researchers in the field, those working at MIT, Ouranos and HEC Montréal?"

Québec Premier **Philippe Couillard** delivers remarks after Professor **Pierre-Olivier Pineau**, Chair in Energy Sector Management at HEC Montréal; MIT Vice President for Research **Maria Zuber**; and Ouranos Executive Director **Alain Bourque** sign an agreement to launch a new research collaboration to analyze cross-border, low-carbon energy policy options.

Québec Premier **Philippe Couillard** looks on as Professor **Pierre-Olivier Pineau**, Chair in Energy Sector Management at HEC Montréal; MIT Vice President for Research **Maria Zuber**; and Ouranos Executive Director **Alain Bourque** sign the cross-border research collaboration agreement.

demonstrate how expanding hydropower in New England and other proposed policies to integrate low-carbon, renewable energy sources into the regional electricity system, will benefit Québec, individual New England states, and the region as a whole.

The initiative also aims to model the energy, economic and climate impacts of the Western Climate Initiative (WCI), a framework for developing carbon cap–and–trade systems among the U.S. State of California and several Canadian provinces. By modeling Québec—and potentially Ontario and other provinces and states, researchers could model energy and economic relationships among existing and prospective WCI members, enabling each to better understand the economic and environmental implications of participation in the WCI.

Each party to the new research collaboration contributes unique expertise. The MIT Joint Program has substantial experience in developing global and regional energy-economic models that simulate the economy-wide effects of different policies and technologies; HEC Montréal provides significant expertise in the energy sector, with a focus on electricity markets and climate policy, and in-depth knowledge of Québec's policies and energy system; and Ouranos contributes a strong capability to evaluate climate policy risks and opportunities.

All three research groups are united in their quest to provide an evidence-based foundation for policy throughout the region that addresses climate change and promotes a clean energy future, which Zuber described as the "defining issue of our time."

"Climate change is a global problem, but one that will affect all of us, regionally and personally," she observed. "I am full of optimism that by working together, we can create a future that we and our children and our grandchildren will want to live in." ■

"By working together, we can create a future that we and our children and our grandchildren will want to live in."

Hydro-Québec President and CEO **Éric Martel**; Professor **Pierre-Olivier Pineau**, Chair in Energy Sector Management at HEC Montréal; MIT Vice President for Research **Maria Zuber**; Premier Philippe Couillard; and Ouranos Executive Director **Alain Bourque**, after the signing ceremony.

2016 EPPA WORKSHOP HIGHLIGHTS MODEL IMPROVEMENTS

Since its creation in the early 1990s, the Economic Projection and Policy Analysis (EPPA) model has expanded its initial emphasis on energy and emissions to include representation of agriculture and land use. The 7th annual EPPA model training workshop, held at the Jordan Grand Resort Hotel in Newry, Maine on September 30–October 1 and attended by more than 25 Joint Program students, staff, sponsor representatives and guests, showcased basic features and latest developments in the model, and how to use it to assess policy impacts.

To lay the groundwork for the training, Joint Program Deputy Director Sergey Paltsev introduced the concept of computable general equilibrium (CGE) modeling, which captures economy-wide interrelationships among profit-maximizing producers and consumption-maximizing consumers, and assumes that prices adjust until supply equals demand. CGEs quantify impacts of different policies on production, consumption, prices and resource allocation, enabling decision-makers to pinpoint the tradeoffs among different goals, such as the economy-wide and sectoral impacts of different trade, energy and climate policies.

Recent and upcoming developments

Joint Program Co-Director John Reilly introduced EPPA, the Program's CGE model of the world economy with regional and sectoral detail that fully treats demand/supply, capital/investment, and trade implications of growth, policies and alternative technologies. A major thrust of recent EPPA development has been to incorporate agriculture and land use into the model, as well as to perform regional analyses. A case in point, said Reilly, is a 2016 Joint Program study that used a CGE model of the U.S. economy (USREP) that's based on EPPA to assess the impact of trade, energy and climate policies—including a national carbon tax—on consumers in different U.S. states and regions.

Research Scientist Henry Chen described the structure of the latest release of the model, EPPA6, which consists of 18 geographical regions, 14 economic sectors and 15 "backstop" energy technologies, and draws on economic, energy and population data. He noted several recent and upcoming changes to the EPPA model, including a comprehensive representation of land-use change; more precise modeling of first-generation biofuels; and disaggregation of agriculture, forestry, household transportation and construction sectors.

Chen showed attendees how to run simulations of business-as-usual and policy-based emissions scenarios, and determine the impacts of a policy on GDP, emissions and energy use. In one exercise, he illustrated how the model could be used to estimate—based on the year of implementation—how much of a global carbon tax would be needed

Foreground: **Gokce Akin-Olcum**, a research economist with the Environmental Defense Fund; **Xuegin Zhu**, a visiting scholar from the Netherlands; Joint Program Research Assistants **Emil Dimantchev** and **Christoph Tries**; and MITEI Postdoctoral Associate **Nidhi Santen** at the EPPA model training workshop.

"This knowledge will help me understand the outcomes and results obtained with EPPA, and to compare them with other models."

to keep the global average surface temperature below two degrees Celsius by 2100.

"The longer you delay policy implementation, the higher the carbon price will be, and the more dramatic cuts to CO_2 will be necessary," he said.

Sharper focus on the food/water/energy nexus

Principal Research Scientist Niven Winchester described how EPPA has expanded over the years to model agriculture, food and forestry production.

"EPPA started out as an energy-focused model, but now the focus has to be on food as well," said Winchester, "because of the interaction between the energy system and the food system, and the impact of climate change on both."

For instance, the model currently represents bioenergy production and land-use change (including conversions from rain-fed to irrigated land), and can be linked to a globally gridded crop model to obtain projections of selected crop yields. Using the Global Trade Analysis Project (GTAP) database, EPPA developers are now working to further disaggregate agriculture into ten sectors including several specific crops, and to represent lumber and construction sectors.

Reilly delivered a second presentation on recent and ongoing enhancements in EPPA that account for interconnections among food, energy and water resources. The goal

2016 EPPA model training workshop participants.

is to improve the biophysical and economic representation of the agricultural sector as it affects land use, water, energy and greenhouse gas emissions. Based on inputs such as economic growth, diets, prices and policies, this improved version of EPPA will be better equipped to determine how climate change and emissions reduction policies will impact crop yields, water use, deforestation and the economy.

More precise energy technology modeling

Research Scientist Jennifer Morris explored how EPPA represents energy technologies and their relative costs. These technologies include conventional fossil fuel generation (coal, natural gas and oil), carbon capture and storage (CCS, on coal, natural gas and biomass), nuclear, and renewables (hydro, wind, solar and biomass). Recognizing the problem of intermittency associated with wind and solar, EPPA models not only single energy technologies but also combinations, such as wind with natural gas or biomass backup. To illustrate EPPA's capability to project how an emerging technology penetrates the market, Morris compared the projected global energy mix under COP21 with policies designed to place the world on a 2°C emissions path.

Research Scientist Mei Yuan described USREP, which uses U.S. and state-based data on population, energy, greenhouse gas emissions, household transportation and taxes to model 10 economic sectors, 9 representative households distinguished by income level, 6 greenhouse gases and a pooled electricity and national fuel market. She noted that to improve the model's electricity representation, efforts are underway to link it to a detailed electric power sector model, the MIT EleMod model.

MIT Energy Initiative postdoctoral associate Nidhi Santen explored the advantages of such a hybrid model that combines a top-down economy-wide model (USREP) with a bottom-up model of the U.S. electricity sector (EleMod). For example, Santen observed that a hybrid model can more accurately assess the potential of renewables deployment and policy costs. To illustrate the concept, she showed how the use of a hybrid model with more electricity sector details makes it possible to more realistically capture the long-term adaptation of a system to the penetration of wind power.

Joint Program sponsor representatives in attendance found the workshop improved their understanding of the EPPA model and other economic models that inform their work.

"The workshop was a useful introduction to the EPPA6 model, some of its intricate hypotheses and their implications," said Oskar Lecuyer, research officer at the Agence Française de Développement. "This knowledge will help me understand the outcomes and results obtained with EPPA, and to compare them with other models."

Keith Balter, director of economic research for the Hancock Natural Resource Group, left with a clearer sense of the "efforts underway to build out the forestry and agriculture sectors of the model, and the implications for extracting region-specific projections of climate-related changes in timber and farm productivity." ■

Recent Research Project Grants

ASSESSING ECOSYSTEM VULNERABILITY TO CLIMATE CHANGE THROUGH OPTICS, IMAGERY & MODELS

Project Leader: Stephanie Dutkiewicz

This project aims to understand pathways in which ocean ecosystems are subject to change and to quantify states of ecological vulnerability. The researchers propose to use existing satellite measurements, particularly ocean color, *in situ* datasets, along with numerical model output and theory, to address spatial, temporal and depth-dependent changes to marine ecosystems with a focus on how best to detect these changes and characterize vulnerability using satellite measurements. The project is designed to analyze how ecosystems have changed over the last few decades and how they will continue to change in a future warming world, and how well we can capture these changes from satellite measurements; how interconnected are deep and surface communities, how much they differ in terms of vulnerability, and how they are changing in relation to each other; what are the regional variations in vulnerability of the marine ecosystems; and how we can best determine and quantify ecological vulnerability metrics using a combination of ocean color imagery and a numerical model. By producing such vulnerability, this project seeks to better inform marine ecosystem monitoring, management and policymaking.

Sponsor: NASA Ocean Biology and Biogeochemistry Program (3 years)

QUANTIFYING THE CLIMATE IMPACTS OF INTERNATIONAL SHIPPING

Project Leaders: Chien Wang and Ronald Prinn

This project seeks to advance our understanding of the climate impacts of ship emissions and to better assist relevant policymaking aimed at mitigating such emissions. It is apparent that exclusion of detailed dynamical aerosol-climate interactions in the coupled ocean-atmosphere system in previous studies has been a major bottleneck in revealing the full spectrum of climate impacts associated with pollutants emitted by international shipping. This analysis will thus emphasize the much more complex climate impacts of particulate matter induced by international shipping, both through direct emissions (e.g., black carbon and organic carbon) and gas-to-particle production (e.g., sulfate aerosols formed by ship emitted sulfur dioxide). These impacts range from changes in surface temperature to amounts and distributions of clouds and precipitation. The climate impacts of aerosols, particularly those occurring through indirect effects, cannot be simply extrapolated based on the forcing-response relationship for the long-lived greenhouse gases. Using their "state-of-the-science" interactive aerosol–climate system model, CESM-MARC, which includes all the major components from atmosphere, ocean, land and cryosphere, the researchers aim to determine the full consequences for climate resulting from the multiple aerosol–cloud–climate interactions associated with ship emissions. Through model simulations, they propose to quantify the difference in climate impacts between two future shipping scenarios, one with fuel sulfur content at its current 3.5 percent level, and another with a proposed reduction of sulfur level to 0.50 percent, both targeted at a timeframe around 2020–2025.

Sponsor: Concawe (1 year)

ECONOMIC AND ENERGY PROSPECTS OF TAIWAN IN THE 21ST CENTURY: A GLOBAL MODELING APPROACH BASED ON THE MIT EPPA MODEL

Project Leader: John Reilly

The research objective is to examine the effects of energy and climate policies in Taiwan, an important manufacturing economy heavily exposed to international trade. This collaboration will engage the expertise of the Institute of Nuclear Energy Research (INER) of Taiwan to build a global energy economic model where Taiwan is explicitly identified, based on the latest version of the MIT Economic Projection and Policy Analysis (EPPA) model, version 6. The new model will be global in scope, with regional details, including realistic economic and policy scenarios in regions that are of mutual interest to MIT and INER, such as Taiwan, Korea, China, the U.S. and Europe. Model scenarios will be developed in collaboration with INER experts, and the new model will be used to investigate how broader policies may affect the general economy of Taiwan, and the rest of the world. To facilitate the collaborative effort, the Joint Program will host up to two visiting scholars from INER for 6 to 12 months during the first year of collaboration. In addition, two MIT researchers will travel to Taiwan to teach a two-day EPPA training course for INER staff in 2016. Under this collaboration, MIT researchers will coauthor papers with INER experts on topics of mutual interest.

Sponsor: INER, Government of Taiwan (3 years)

MILESTONES

Timothy Cronin joined the Department of Earth, Atmospheric and Planetary Sciences as an assistant professor affiliated with the MIT Joint Program and Center for Global Change Science. A climate physicist interested in problems relating to radiative-convective equilibrium, atmospheric moist convection and clouds, and the physics of the coupled land-atmosphere system, Cronin's long-term research goals center on major questions in climate science, including the importance of clouds in global climate sensitivity and determinism, and the coupled dynamics of the land surface–atmosphere system. *– MIT School of Science*

Associate Professor **Colette Heald** was appointed as associate department head of the Department of Civil and Environmental Engineering (CEE). Heald, who won the American Geophysics Union James B. Macelwane Medal last year in recognition of her significant contributions to the geophysical sciences, joined MIT in 2012. She studies atmospheric gases and particles, and how they affect air quality and climate. *– Marilyn Siderwicz, MIT Department of Civil and Environmental Engineering*

In 2017, after earning his PhD from the EAPS Department, MIT Joint Program-affiliated graduate student **Jimmy Gasore** aims to return to Rwanda to continue work on the Advanced Global Atmospheric Gases Experiment (AGAGE) climate observatory that he helped establish. A first for Africa and one of 13 around the world, the station can detect greenhouse gases and air pollutants throughout the continent. In August, Gasore's work was highlighted in an article in *Nature*.

IN THE NEWS

Jul 22 - *Chicago Tribune* - Editorial: The ozone hole is finally on the mend

Jul 22 - *chinadialogue* - How China Can Stop Wasting Wind Energy

Jul 29 - *Washington Post* - Storing Carbon Underground May Be Safer Than We Thought

Aug 10 - *BBC World Service* - Middle East: Too Hot to Handle? (Radio Clip)

Aug 11 - *Inside Climate News* - Uncertainty Can't Be an Excuse for Climate Inaction, Researchers Argue

Aug 11 - *Washington Post* - Turns out Wind and Solar have a Secret Friend: Natural Gas

Aug 24 - *ChinaFAQs* - Making China's Economic Transition Work for Global Climate and the Local Environment

Aug 25 - *NY Times* - California's Emissions Goal Is a 'Milestone' on Climate Efforts

Aug 31 - *Nature.com* - Rwanda: From Killing Fields to Technopolis

Sep 2 - *NY Times* - Hurricane Season Is Heating Up. So Is the Planet. Coincidence?

Sep 13 - *Wall Street Journal* - Why a Price on Carbon Alone Isn't the Golden Ticket

Sep 16 - *AZO CleanTech* - MIT Team Develops Future-Oriented Computer Models of Ocean's Colors Based on Phytoplankton Population

Sep 20 - *Mercury News* - Scientists to Trump: Climate change is real

Oct 10 - *Scientific American* - World Leaders Try to Ban Another Greenhouse Gas

Oct 13 - *Washington Post* - We're Placing Far Too Much Hope in Pulling Carbon Dioxide Out of the Air, Scientists Warn

Oct 19 - *City Journal* - Another Climate Landmark

Nov 1 - *Bulletin of Atomic Scientists* - The Complicated Geopolitics of Renewable Energy

JOINT PROGRAM REPORTS

304. The Impact of Oil Prices on Bioenergy, Emissions and Land Use

303. Scaling Compliance with Coverage? Firm-level Performance in China's Industrial Energy Conservation Program

302. 21st Century Changes in U.S. Heavy Precipitation Frequency Based on Resolved Atmospheric Patterns

301. Combining Price and Quantity Controls under Partitioned Environmental Regulation

300. The Impact of Water Scarcity on Food, Bioenergy and Deforestation

299. The Impact of Coordinated Policies on Air Pollution Emissions from Road Transportation in China

JOINT PROGRAM REPRINTS

2016-18. Assessing the Impact of Typhoons on Rice Production in the Philippines (*Journal of Applied Meteorology and Climatology*)

2016-17. Uncertainties in Atmospheric Mercury Modeling for Policy Evaluation (*Current Pollution Reports*)

2016-16. Limited trading of emissions permits as a climate cooperation mechanism? US–China and EU–China examples (*Energy Economics*)

2016-15. Interprovincial migration and the stringency of energy policy in China (*Energy Economics*)

2016-14. Modelling the potential for wind energy integration on China's coal-heavy electricity grid (*Nature Energy*)

2016-13. Pathways to Mexico's climate change mitigation targets: A multi-model analysis (*Energy Economics*)

PEER-REVIEWED STUDIES & PENDING REPRINTS

Air Quality Co-Benefits of Sub-National Carbon Policies (*Journal of the Air & Waste Management Association*)

Airborne Observations of Mercury Emissions from the Chicago/Gary Urban/Industrial Area during the 2013 NOMADSS Campaign (*Atmospheric Environment*)

Chemical cycling and deposition of atmospheric mercury in Polar Regions: review of recent measurements and comparison with models (*Atmos. Chem. Phys.*)

Costs of IQ Loss from Leaded Aviation Gasoline Emissions (*Environ. Sci. Technol.*)

Cross-country electricity trade, renewable energy and European transmission infrastructure policy (*Journal of Environmental Economics & Management*)

Hydrofluorocarbon [HFC] Emissions in China: An Inventory for 2005–2013 and Projections to 2050 (*Environ. Sci. Technol.*)

Importance of Integration and Implementation of Emerging and Future Research into the Minamata Convention (*Environ. Sci. Technol.*)

Origin of oxidized mercury in the summertime free troposphere over the southeastern U.S. (*Atmos. Chem. Phys.*)

PCBs in the Arctic atmosphere: determining important driving forces using a global atmospheric transport model (*Atmos. Chem. Phys.*)

Reducing CO_2 from Cars in the European Union: Emission Standards or Emission Trading? (*Transportation*)

Source waters for the highly productive Patagonian shelf in the southwestern Atlantic (*Journal of Marine Systems*)

Southern Ocean warming delayed by circumpolar upwelling and equatorward transport (*Nature Geoscience*)

Splitting the South: Explaining China and India's Divergence in International Environmental Negotiations (*Global Environmental Politics*)

Teaching and Learning from Environmental Summits: COP-21 and Beyond (*Global Environmental Politics*)

The complicated geopolitics of renewable energy (*Bulletin of the Atomic Scientists*)

The Future of Natural Gas in China: Effects of Pricing Reform and Climate Policy (*Climate Change Economics*)

ARRIVALS & DEPARTURES

ARRIVALS:

Amy Dale, a postdoctoral associate

Emil Dimantchev, a visiting master's student

Jessica Farrell, a research assistant

Bora Kat, a visiting Fulbright Scholar from the Scientific & Technological Research Council of Turkey

Shaina Ma, an undergraduate research assistant from Wellesley College

ChaeRin Park, an undergraduate research assistant from Wellesley College

Christoph Tries, a visiting master's student

Mengying "Mandy" Wu, a research assistant

Xueqin Zhu, a visiting professor from the Environmental Economics & Natural Resources Group, Wageningen University, Netherlands

DEPARTURES:

Hui-Chih Chai, a visiting researcher from the Institute of Nuclear Energy Research, returned to Taiwan

Melissa Fox, administrative assistant to Joint Program Co-Director Ronald Prinn, retired after more than 10 years of service

Kyung-Min Nam completed his visit and returned to the University of Hong Kong

Ninad Rajpurkar completed his doctoral term and returned to India

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Our work is funded by an international partnership of government, industry and foundation sponsors, and by private donations. Our sponsor consortium provides the long-term substantial commitment needed to support our dedicated and specialized staff, and to realize a coordinated integrated research effort.

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U.S. Government Funding

U.S. Department of Agriculture [USDA]
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National Aeronautics & Space Administration [NASA]
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Department of Energy [DOE]
Environmental Protection Agency [EPA]
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Federal Aviation Administration [FAA]
National Science Foundation [NSF]

Global Changes is published triannually by the MIT Joint Program on the Science and Policy of Global Change, and is made available to the public one month after its release to our program membership. All articles are written by Mark Dwortzan unless otherwise noted.

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