GLOBAL CHANGES

MIT JOINT PROGRAM ON THE SCIENCE & POLICY OF GLOBAL CHANGE
FALL 2015

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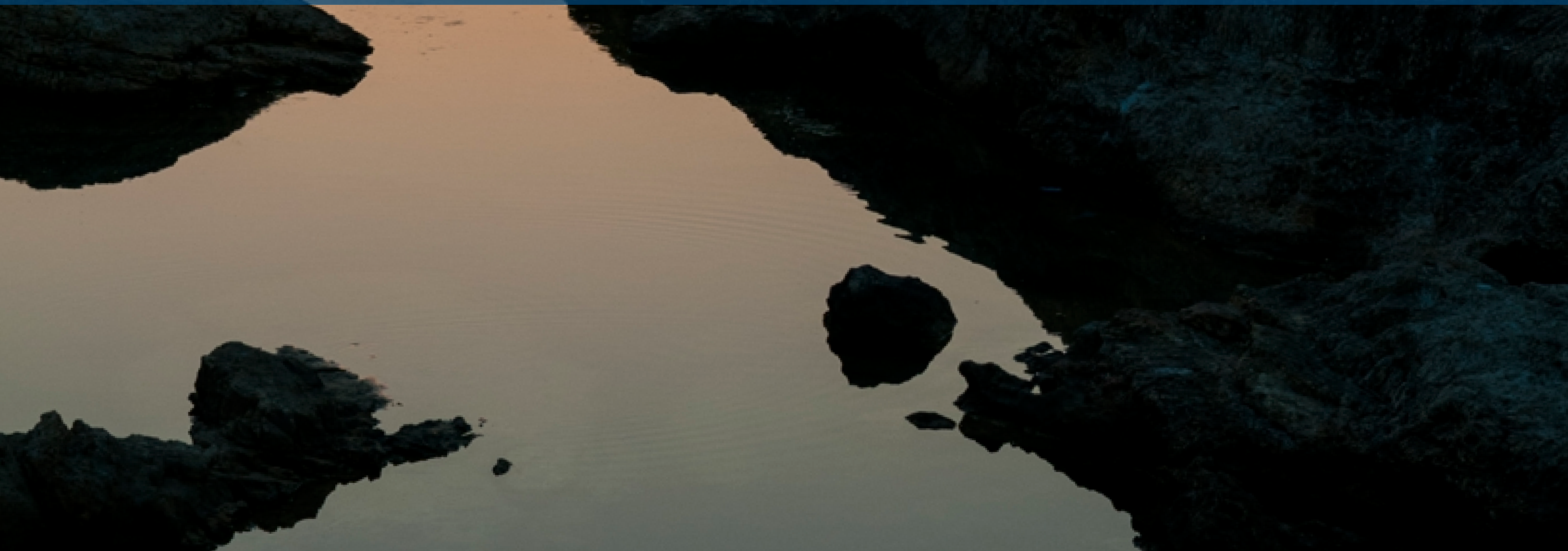

GLOBAL CHANGE

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.*

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FALL 2015 GLOBAL CHANGES

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From Climate Conversation to Climate Action

The Joint Program figures prominently in MIT's Plan for Action on Climate Change

Anyone following the climate issue realizes that the 21st meeting of the Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change will take place in Paris in December. As you will see throughout this edition of *Global Changes*, the Joint Program has been deeply engaged in this topic, from analyzing participating countries' Intended Nationally Determined Contributions (INDCs) to organizing policy symposiums featuring our researchers.

Meanwhile, student-led demands for colleges and universities to divest from fossil fuel companies have spread across campuses in the U.S. Concerns of students at MIT led to a yearlong Conversation on Climate Change focused on the most effective ways the Institute could address the climate challenge. The committee formed to facilitate the campus-wide conversation consisted of students, staff and faculty, including our former Co-Director Jake Jacoby and Executive Director for Research Anne Slinn.

Published in June, the committee's final report called for the Institute to "take bold action to contribute to the solution of the climate challenge" and identified possible actions under the broad headings Science and Truth, MIT as a Living Laboratory, and Accelerating Solutions. Specific ideas included establishing an Ethics Advisory Council, setting an internal campus carbon pricing policy and enhancing support for research and development toward climate solutions. The report discussed pros and cons of divestment but did not make a recommendation.

In response, MIT President Rafael Reif announced a Plan for Action on Climate Change on October 21. The Action Plan calls for engagement with industry as a source of solutions rather than pursuing a divestment strategy. It recognizes the continued need for science to provide a foundation for understanding the complexities of the global warming problem, and proposes to take on "the 2°C challenge."

Toward that end, eight new low-carbon energy centers will be established through the MIT Energy Initiative (MITEI), with five announced immediately. The Action Plan sets a goal of $300 million in new funding for R&D at these centers. Among other things, the president pledged to reduce campus CO_2 emissions by 32 percent by 2030, to institute shadow carbon pricing and to educate leaders in industry and government about climate change.

The Joint Program figures prominently in the Plan, which calls on its co-directors, together with MIT atmospheric scientist Susan Solomon and MITEI Director Robert Armstrong, to lead a new study, *The 2°C Challenge: Accelerating the Transition to a Zero-Carbon Future*. Funded at $3 million over the next three years, the study will seek to evaluate the sustainability of low-carbon technologies at large scale. Accounting for uncertainties in the global climate system and economy, its overarching goal is to identify pragmatic paths forward and the R&D and policy choices needed to make the 2°C target achievable.

This will be a challenging task. As we progress we will want to pursue conversations with our sponsors for help in identifying practical solutions for reducing greenhouse gas emissions.

—John Reilly, Co-Director

"As we progress we will want to pursue conversations with our sponsors for help in identifying practical solutions for reducing greenhouse gas emissions."

MORE INFORMATION:

CLIMATE AT MIT

p. 12 – *2015 Energy and Climate Outlook*

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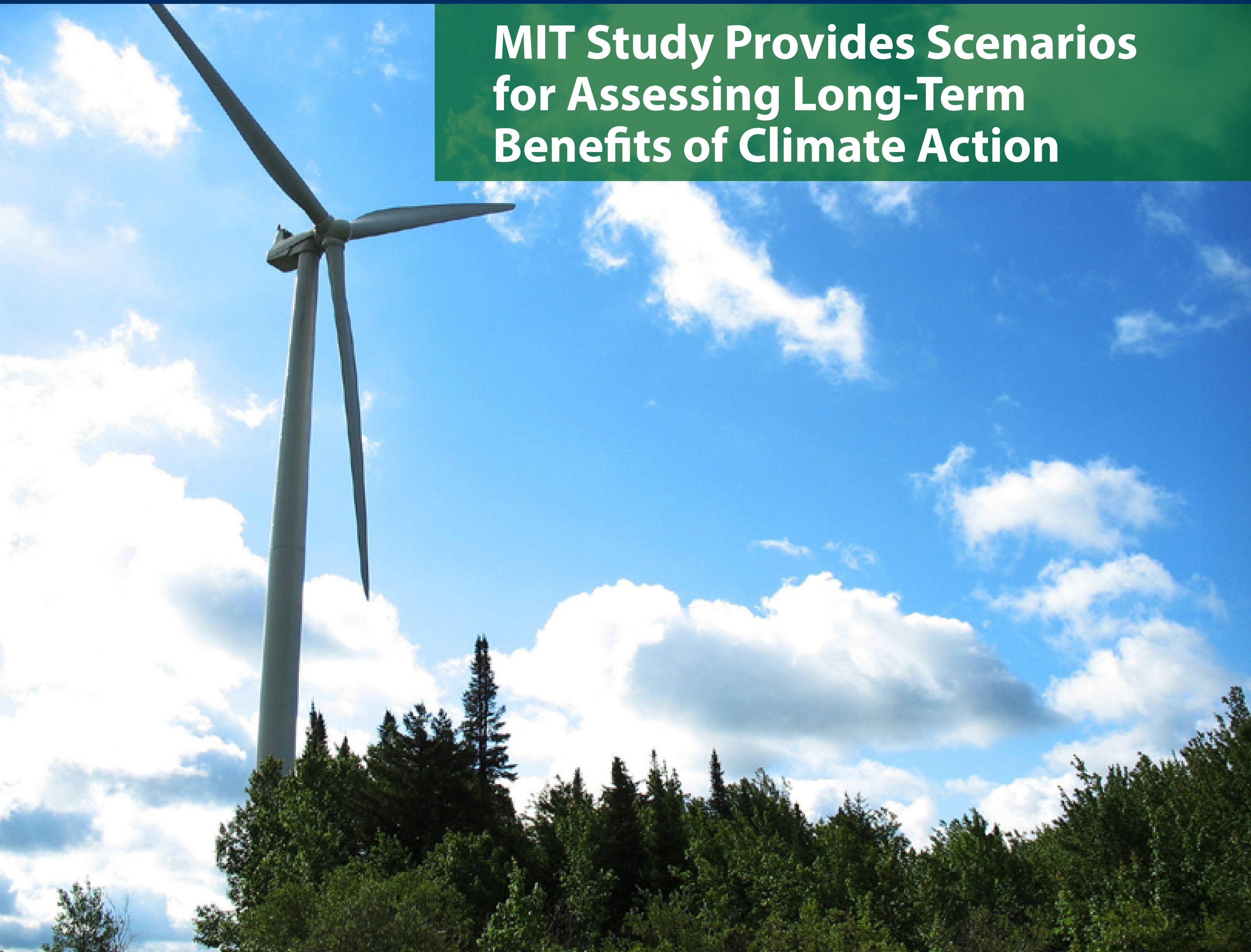
MIT Study Provides Scenarios for Assessing Long-Term Benefits of Climate Action



EPA uses scenarios to evaluate gains for agriculture, health and other global concerns

PHOTO: PAUL CRYAN, U.S. GEOLOGICAL SURVEY

An MIT study is enabling EPA researchers to quantify economic, health and environmental benefits that could result from climate action.

Since the 1990s, scientists and policymakers have proposed limiting Earth's average global surface temperature to 2° Celsius above pre-industrial levels, thereby averting the most serious effects of global warming, such as severe droughts and coastal flooding. But until recently, they lacked a comprehensive estimate of the likely social and economic benefits—from lives saved to economies preserved—that would result from greenhouse gas emissions reduction policies designed to achieve the 2°C goal.

Now a team of Joint Program researchers has published a study in *Climatic Change* that provides scenarios that climate scientists can use to estimate such benefits. The study projects greenhouse gas emissions levels and changes in precipitation, ocean acidity, sea level rise and other climate impacts throughout the 21st century resulting from different global greenhouse gas (GHG) mitigation scenarios. The scenarios include a business-as-usual future and one aimed at achieving significant GHG emission reductions limiting global warming since pre-industrial times to 2°C. Research groups convened by the U.S. Environmental Protection Agency have already begun using the MIT projections to evaluate the benefits of a 2°C emissions reduction scenario for agriculture, water, health and other global concerns.

"The U.S. EPA used our scenarios for a report on the benefits of global climate action, which, to my knowledge, is the most comprehensive analysis to date to quantify the economic, health and environmental benefits for the United States from greenhouse gas emission mitigation," says Sergey Paltsev, coauthor of the *Climatic Change* study and a senior research scientist and deputy director at the Joint Program. "We have much more experience defining the cost of mitigation than the benefits. The goal of this project was to put a dollar value on damages from climate change in a number of sectors."

"The goal of this project was to put a dollar value on damages from climate change in a number of sectors."

Putting a Dollar Value on the Benefits of Climate Action

Using its Integrated Global System Modeling (IGSM) framework, which tracks climate, socioeconomic and technological change over time, to produce its greenhouse gas emissions and climate change projections, the MIT team ran global policy scenarios through simulations designed to capture a range of uncertainty in the climate's response to changes in average global temperature.

According to the team's estimates, with no policy implemented between now and 2100, increases in global temperature will range from 3.5 to 8°C, precipitation from 0.3 to 0.6 millimeters per day and sea level from 40 to 80 centimeters. Ocean acidity will also rise, threatening marine life and commercial fisheries.

Global GHG emissions reduction policies, which lower greenhouse gas concentrations, would reduce these climate impacts considerably.

Based on the MIT projections, the EPA report, *Climate Change in the United States: Benefits of Global Action*, shows that a 2°C stabilization would save thousands of lives threatened by extreme heat and billions of dollars in infrastructure expenses, while preventing destruction of natural resources and ecosystems. Prepared as part of the ongoing Climate Change Impacts and Risk Analysis (CIRA) project, an EPA-led collaborative modeling effort among teams in the federal government, MIT, the Pacific Northwest National Laboratory, the National Renewable Energy Laboratory and several consulting firms, the report estimates how climate change would impact 20 sectors in health, infrastructure, electricity, water resources, agriculture and forestry, and ecosystems. In more than 35 studies, the EPA-funded researchers pinpointed a large number of climate impacts that could be averted, or at least reduced, by a 2°C stabilization, from lost wages due to extreme temperatures, to damage to bridges from heavy river flows.

By enabling scientists to calculate damages incurred under different global mitigation scenarios on each impact sector, the IGSM-based projections are empowering them to put a dollar value on the benefits of more aggressive climate action.

A Long-Term Problem

The MIT study found that the intended effects of more stringent climate policy would not be realized until the second half of the century, when they would begin to outweigh the effects of natural climate variability. By the end of the century, however, climate policies would result in significantly lower temperatures, greenhouse gas emissions and climate impacts than the no-policy option.

"Even in aggressive emissions reduction scenarios, we don't see a response in climate and temperature until mid-century, but by 2100 the response is dramatic," says Paltsev. "It's hard to achieve global consensus on such policies because the costs must be paid now and the benefits come later." But this CIRA project, which only captures some of the impacts of climate change, demonstrates that the benefits to the U.S. of global climate action can be substantial, and that they grow over time.

Paltsev cautions that by delaying action until more negative effects of climate change are felt, the world will have fewer options at its disposal to stabilize the global climate. ■

This research was partially funded by the EPA; the IGSM is supported by a consortium of government, industry and foundation sponsors of the MIT Joint Program.

Related Publications:

Sergey Paltsev, Erwan Monier, Jeffery Scott, Andrei Sokolov & John Reilly, 2015: Integrated economic and climate projections for impact assessment. *Climatic Change* 131(1): 21–33.

EPA, 2015: *Climate Change in the United States: Benefits of Global Action.* United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001.

RESEARCH REPORTS
MIT JOINT PROGRAM ON THE SCIENCE AND POLICY OF GLOBAL CHANGE

RESEARCH REPORTS

Vehicle Fuel Economy Standards as Global Climate Policy

How much can they deliver and at what cost?

Over the past decade, many countries and regions seeking to reduce climate-warming carbon dioxide emissions have adopted more aggressive fuel economy standards designed to boost the efficiency of new, light-duty cars and trucks. Economists, however, generally argue that a more cost-effective way to reduce CO_2 emissions is to price carbon through a system such as cap–and–trade, in which emitters across all sectors of the economy pay for each ton of CO_2 they put into the atmosphere. Impacts of these two approaches have been previously compared on a national and regional level, but until now have not been evaluated on a global scale.

To fill this gap, Joint Program researchers have compared the worldwide economic, environmental and energy impacts of currently planned fuel economy standards (extended to the year 2050) with those of region-specific carbon prices designed to yield identical CO_2 emissions reductions. Their study, which appears in the *Journal of Transport Economics and Policy*, shows that such stringent fuel economy standards would cost the economy 10% of global Gross Domestic Product (GDP) in 2050, compared to only 6% under carbon pricing.

This finding reinforces economists' contention that improving the efficiency of motor vehicles through fuel economy standards will yield significantly less CO_2 emissions reduction per dollar than an economy-wide instrument that encourages such cutbacks where they are cheapest—principally in the electric power and industrial sectors. But the fuel economy standards modeled in the study did prove beneficial in terms of fuel consumption: they reduced fuel used in passenger vehicles by 47% relative to a no-policy scenario in 2050, versus only 6% under carbon pricing.

“Many developed countries are choosing very expensive ways to reduce CO_2 emissions, but if that's a top priority, they should go with a price on carbon,” says the study's lead author Valerie Karplus, assistant professor of Global Economics and Management at the Sloan School of Management. “If they're more focused on energy independence, fuel economy standards can deliver, but a tax on gasoline would be more cost-effective.”

“The new paper by Professor Karplus and her colleagues provides important new insights into the role of efforts by nations around the world to reduce petroleum use and greenhouse gas emissions from the transportation sector,” says Jonathan Rubin, a professor at the Margaret Chase Smith Policy Center and School of Economics at the University of Maine. “The research shows that the often-used policy of requiring fuel economy improvements, while capable of reducing petroleum use, is significantly more expensive than other, economy-wide options which are more cost-effective at reducing greenhouse gas emissions.”

Capturing the Interwoven Responses of a Global Economy

To arrive at their findings, the researchers used the MIT Economic Projection and Policy Analysis (EPPA) model to estimate the impact of fuel economy and carbon pricing policies. The fuel economy scenario simulated the impacts of extending current fuel economy mandates past their expiration dates through 2050. The carbon pricing scenario consisted of a patchwork of national and regional cap–and–trade policies designed to achieve the same CO_2 emissions reductions by 2050 as the fuel economy standards produced in each market.

> *“What makes our study unique is that we used a global model that captures market linkages around the world, rather than within a single nation, region or sector.”*

An important feature of the study was its ability to capture, via the EPPA model, two major effects of national and regional fuel economy standards: rebound and leakage. Adoption of more fuel-efficient vehicles, by decreasing fuel demand, also reduces the per-mile price of fuel as supply and demand balance in the market. This price reduction can lead to more driving in the market covered by the policy—known as the rebound effect—as well as in sectors and regions not covered by the policy—known as the leakage effect—because globally interlinked fuel markets cause prices to fall worldwide.

“What makes our study unique is that we used a global model that captures market linkages around the world, rather than within a single nation, region or sector,” says Karplus.

Higher fuel economy standards may enable fewer trips to the gas pump but are not as cost-effective as carbon pricing in reducing carbon dioxide emissions.

Modeling New Technologies and Behaviors

The model simulates not only rebound and leakage effects, but also the gradual adoption of new, more expensive vehicles and retirement of old ones; how vehicle owners navigate the tradeoff between using more fuel and purchasing a more efficient vehicle; the relationship between changes in household income and vehicle usage behavior; and the adoption of off-the-shelf and advanced, low-carbon technologies that increase miles per gallon.

The study also determined that by 2050, currently planned fuel economy standards would reduce CO_2 emissions by about 4% relative to a no-policy scenario. Extending these standards past their deadlines through 2050 would decrease emissions by an additional 6%. These relatively modest reductions would come at a high cost.

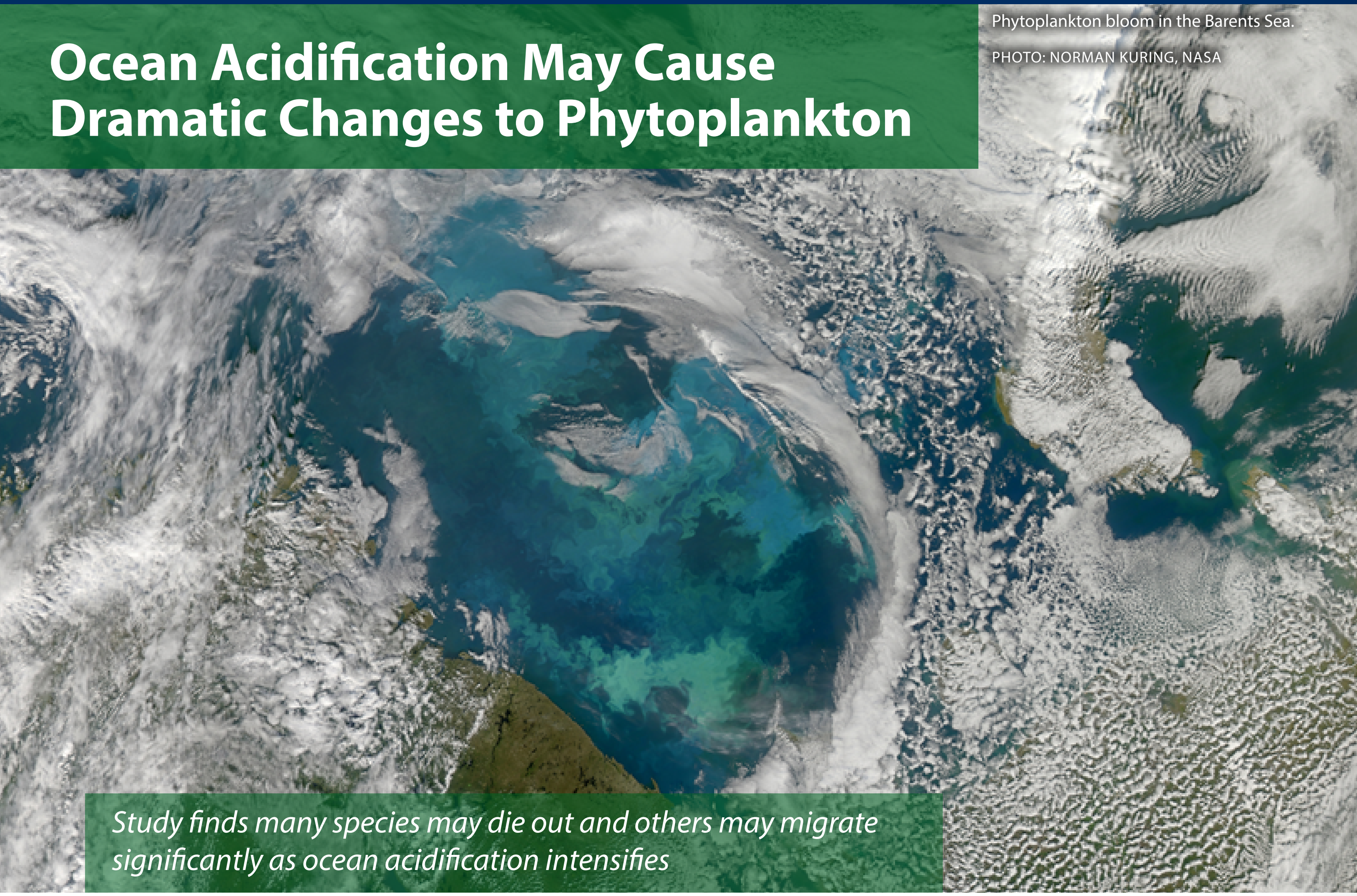
Although it may be politically easier to repurpose or replicate commonly applied fuel economy standards to reduce CO_2 emissions, this analysis suggests that a coordinated approach that includes a price on CO_2 will be far more effective at achieving this goal. ■

The EPPA model used in this study is supported by a consortium of government, industry and foundation sponsors of the MIT Joint Program.

Related Publication:

Valerie J. Karplus, Paul Kishimoto and Sergey Paltsev, 2015: The Global Energy, CO_2 Emissions and Economic Impact of Vehicle Fuel Economy Standards. *Journal of Transport Economics and Policy* 49(4): 517–538.

Ocean Acidification May Cause Dramatic Changes to Phytoplankton



Phytoplankton bloom in the Barents Sea.
PHOTO: NORMAN KURING, NASA

Study finds many species may die out and others may migrate significantly as ocean acidification intensifies

By Jennifer Chu, MIT News Office

Oceans have absorbed up to 30% of human-made carbon dioxide around the world, storing dissolved carbon for hundreds of years. As the uptake of carbon dioxide has increased in the last century, so has the acidity of oceans worldwide. Since pre-industrial times, the pH of the oceans has dropped from an average of 8.2 to 8.1 today. Projections of climate change estimate that by the year 2100, this number will drop further, to around 7.8—significantly lower than any levels seen in open ocean marine communities today.

Now a team of researchers from MIT, the University of Alabama and elsewhere has found that such increased ocean acidification will dramatically affect global populations of phytoplankton—microorganisms on the ocean surface that make up the base of the marine food chain.

In a study published in the journal *Nature Climate Change,* the researchers report that increased ocean acidification by 2100 will spur a range of responses in phytoplankton: some species will die out, while others will flourish, changing the balance of plankton species around the world.

> *"I try not to be an alarmist, because it's not good for anyone... but I was actually quite shocked by the results."*

The researchers also compared phytoplankton's response not only to ocean acidification, but also to other projected drivers of climate change such as warming temperatures and lower nutrient supplies. For instance, the team used a numerical model to see how phytoplankton as a whole will migrate significantly, with most populations shifting toward the poles as the planet warms. Based on global simulations, however, they found the most dramatic effects stemmed from ocean acidification.

Stephanie Dutkiewicz, a principal research scientist in MIT's Center for Global Change Science, says that while scientists have suspected ocean acidification might affect marine populations, the group's results suggest a much larger upheaval of phytoplankton—and therefore probably the species that feed on them—than previously estimated.

"I've always been a total believer in climate change, and I try not to be an alarmist, because it's not good for anyone," says Dutkiewicz, the paper's lead author. "But I was actually quite shocked by the results. The fact that there are so many different possible changes, that different phytoplankton respond differently, means there might be some quite traumatic changes in the communities over the course of the 21st century. A whole rearrangement of the communities means something to both the food web further up, but also for things like cycling of carbon."

> *"You might get whole species just disappearing because responses are slightly different."*

The paper's co-authors include Mick Follows, an associate professor in MIT's Department of Earth, Atmospheric and Planetary Sciences.

Winners and Losers

To get a sense for how individual species of phytoplankton react to a more acidic environment, the team performed a meta-analysis, compiling data from 49 papers in which others have studied how single species grow at lower pH levels. Such experiments typically involve placing organisms in a flask and recording their biomass in solutions of varying acidity.

In all, the papers examined 154 experiments of phytoplankton. The researchers divided the species into six general, functional groups, including diatoms, Prochlorococcus and coccolithophores, then charted the growth rates under more acidic conditions. They found a whole range of responses to increasing acidity, even within functional groups, with some "winners" that grew faster than normal, while other "losers" died out.

The experimental data largely reflected individual species' response in a controlled laboratory environment. The researchers then worked the experimental data into a global ocean circulation model to see how multiple species, competing with each other, responded to rising acidity levels.

The researchers paired MIT's global circulation model—which simulates physical phenomena such as ocean currents, temperatures and salinity—with an ecosystem model that simulates the behavior of 96 species of phytoplankton. As with the experimental data, the researchers grouped the 96 species into six functional groups, then assigned each group a range of responses to ocean acidification, based on the ranges observed in the experiments.

Natural Competition Off Balance

After running the global simulation several times with different combinations of responses for the 96 species, the researchers observed that as ocean acidification prompted some species to grow faster, and others slower, it also changed the natural competition between species.

"Normally, over evolutionary time, things come to a stable point where multiple species can live together," Dutkiewicz says. "But if one of them gets a boost, even though the other might get a boost, but not as big, it might get outcompeted. So you might get whole species just disappearing because responses are slightly different."

Dutkiewicz says shifting competition at the plankton level may have big ramifications further up in the food chain.

"Generally, a polar bear eats things that start feeding on a diatom, and is probably not fed by something that feeds on Prochlorococcus, for example," Dutkiewicz says. "The whole food chain is going to be different."

By 2100, the local composition of the oceans may also look very different due to warming water: The model predicts that many phytoplankton species will move toward the poles. That means that in New England, for instance, marine communities may look very different in the next century.

"If you went to Boston Harbor and pulled up a cup of water and looked under a microscope, you'd see very different species later on," Dutkiewicz says. "By 2100, you'd see ones that were living maybe closer to North Carolina now, up near Boston."

Dutkiewicz says the model gives a broad-brush picture of how ocean acidification may change the marine world. To get a more accurate picture, she says, more experiments are needed, involving multiple species to encourage competition in a natural environment.

"Bottom line is, we need to know how competition is important as oceans become more acidic," she says. ■

This research was funded in part by the National Science Foundation, and the Gordon and Betty Moore Foundation.

Related Publication:

Stephanie Dutkiewicz *et al.*, 2015: Impact of ocean acidification on the structure of future phytoplankton communities. *Nature Climate Change* 5: 1002–1006

Commentary: On the Path to Paris, Obama and Xi Invite Stronger Global Climate Ambition

The latest Obama–Xi announcement sends a strong message: the two nations are acting fast to enable a global, low-carbon transition.

By Valerie Karplus

Delivered on September 25, the joint announcement is an unprecedented step by the world's #1 and #2 emitters to commit, at the highest levels, to a strong set of domestic policies and to reinforce global mechanisms that will help to engage peers ahead of the upcoming landmark climate change negotiations in Paris.

Pricing Carbon

President Xi has committed China to launching a national emissions trading system for CO_2 in 2017. An emissions trading system will directly constrain a large share of China's CO_2 emissions and, by putting a price on emissions, encourage reductions where they cost least. This is impressive in that China is pledging to reduce emissions at a time when its *per capita* income is less than one-fifth of the U.S. and its economy faces headwinds. It recognizes the long-term benefits of action now—for local air quality, global climate and its own long-term leadership—in delivering innovative solutions that all nations will eventually need.

While China is not the first to establish an emissions trading system, China's is likely to be the largest when it comes online in 2017. While the European Union has built an emissions trading system over the past two decades, the U.S. has so far not been successful in adopting a national system for greenhouse gases. In 2009 the Waxman–Markey Bill, which would have established an emissions trading system in the U.S., failed to pass Congress, leaving the U.S. to rely on a piecemeal approach that largely repurposed existing regulations such as vehicle fuel economy standards and power plant emissions limits established under the Clean Air Act, to mandate CO_2 emissions reduction. Indeed, these measures formed the cornerstone of the U.S. domestic action pledged on September 25, and they will have impact. However, an emissions trading system that could deliver the same reductions at lower aggregate cost has so far proven politically unpalatable. China's latest move could prompt a rethink on emissions trading in the U.S.

Linking Global and Local Action

Along with a strong portfolio of coordinated domestic actions, Xi and Obama made progress on defining the architecture of a global climate agreement. The two leaders have agreed on the need for an enhanced system that monitors domestic action through reporting and review of progress, recognizing that some developing nations will still need time to put these capacities into place. Both sides also recognized the need to increase ambition over time. This is essential because even with all present contributions, the global emissions trajectory is not expected to bend down anytime soon. Recognizing that this will likely not be fully resolved in Paris, setting in place a timeline for assessing and revisiting commitments going forward will go a long way towards ensuring that the goal Xi and Obama reaffirmed at the outset of their remarks—deep reductions in GHG emissions that will markedly limit global temperature rise—does not slip off the radar.

Beyond generating momentum ahead of Paris, U.S.–China joint action will have far-reaching consequences at home when it comes to enabling a low carbon transition. Although many insiders anticipated that an emissions trading system in China would be established, efforts to codify this effort in a new Climate Change Law were moving more slowly—this high-level pledge will redouble the pressure. Beyond emissions trading, China has also pledged to promote "green dispatch" in the electricity sector, which will prioritize lower emitting plants. In China, generators are powerful interests entitled to supply a "fair share" of annual generation—now their "fair share" will need to reflect environmental impact more strongly and directly.

Leading on Climate and Development

Perhaps the greatest promise of the latest announcement by China and the U.S. lies in its invitation to all parties to increase ambition, if not before Paris then as soon as possible as part of ongoing negotiations. On the eve of Paris, the world is poised to miss the 2 degree target—by a large margin. Stronger action will be needed by developed and developing countries alike. By committing to limit CO_2 emissions, China has shown that domestic action on climate change does not need to undermine long-term development goals. In recent years, it has developed the domestic capability to assess—through research, modeling and real-world experimentation—the advantages and disadvantages of various instruments for limiting fossil energy use and CO_2 emissions. The results suggest that some opportunities, such as industrial energy efficiency and new energy development, can support cleaner air, better operational performance and—in the case of, say, solar energy—open opportunities as a leading global provider of clean technology. Every developing country will have its unique set of opportunities. The architecture emerging on the road to Paris is shaping up in a way that will accommodate these differences, allowing the countries that are poised to grow the fastest over the next several decades to find ways to power this growth with clean, affordable, low-carbon energy sources. Greater action from the developed world will also be essential. Ideally, the steps Xi and Obama have taken in September will inspire a broad-based, cooperative effort to deliver more than promised that carries both local and global benefits. ■

PHOTO: U.S. EMBASSY THE HAGUE, VIA FLICKR CREATIVE COMMONS LICENSE

Along with a strong portfolio of coordinated domestic actions, Presidents Xi and Obama made progress on defining the architecture of a global climate agreement.

Dr. Valerie Karplus is a ChinaFAQs Expert at the Massachusetts Institute of Technology (MIT). She is an Assistant Professor in the Global Economics and Management Group at the MIT Sloan School of Management and Director of the China Energy and Climate Project (CECP) at the MIT Joint Program.

ChinaFAQs is a project facilitated by the World Resources Institute that provides insight into critical questions about Chinese policy and action on energy and climate change. The ChinaFAQs network is comprised of U.S.-based experts, including researchers at U.S. universities and government laboratories, independent scholars and other professionals.

Related Publication:

Valerie Karplus, 2015: ChinaFAQs: The Network for Climate and Energy Information, http://www.chinafaqs.org/blog-posts/path-paris-obama-and-xi-invite-stronger-global-climate-ambition.

Report: Expected Paris Commitments Insufficient to Stabilize Climate by 2100

2015 Energy and Climate Outlook projects likely impacts of current policies and pledges on global climate, emissions and energy mix

This December's international climate negotiations in Paris are expected to yield reductions in manmade greenhouse gas emissions, but unless deeper cuts follow, the global temperature is likely to rise 3.1–5.2°C above pre-industrial levels by 2100, according to a report released in October by the Joint Program. The projected temperature increase far exceeds 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.

New pledges from countries responsible for the largest global share of greenhouse gas emissions, announced in advance of the UN Climate Change Conference in Paris, promise to make barely a dent in the Earth's warming trend, says Joint Program Co-Director John Reilly, a coauthor of the report, the *2015 Energy and Climate Outlook*.

"Those pledges shave 0.2°C of warming if they're maintained through 2100, compared with what we assessed would have been the case by extending existing measures [due to expire in 2020] based on earlier international agreements in Copenhagen and Cancun," Reilly observes. "We are making progress, but if 2°C stabilization is our goal, it's not nearly enough."

To determine the likely global impacts of extending existing measures beyond 2020 and implementing current pledges (known as intended national determined contributions, or INDCs) from the biggest emitters through the end of the century, Outlook researchers used the Joint Program's Integrated Global System Modeling (IGSM) framework, a linked set of computer models designed to simulate the global environmental changes that arise as a result of human causes. They also used the latest UN estimates of the world's population, which is expected to reach 10.8 billion by 2100.

The report highlights several key findings in the areas of global climate, emissions and energy mix.

By 2100, the *Outlook* projects—relative to pre-industrial levels—increases in global mean surface temperature (3.1–5.2°C), global mean precipitation (7.1–11.4%), sea level (0.30 to 0.48 meters) and ocean acidity. Over the same period, greenhouse gas (GHG) emissions levels are expected to decline in developed countries but rise in some G20 nations and most developing countries, which should account for about 15% of global emissions by 2050.

"As a result of China and some of the other middle-income emerging countries taking on actions, we see emissions stabilizing in developed and many G20 countries," says Reilly. "The looming issue is what happens in the rest of the world, which includes many of the poorer countries. Their emissions remain a relatively small share of global emissions but continue to grow. A challenge is how those countries achieve sustainable growth that doesn't lead to ever greater GHG emissions."

The *Outlook* also projects that carbon dioxide emissions from fossil fuels (about 50% generated by the electricity and transportation sectors) will remain the largest source of GHGs, accounting for about 67% of total GHG emissions by 2100. Despite rapid growth in renewables and nuclear energy, fossil fuels will continue to account for about 75% of the global energy mix in 2050.

"In this *Outlook* we tried to represent the mix of policies and measures that countries will pursue to meet the INDCs they've laid out," says Reilly, noting that most of these favor targets for wind and solar generation, vehicle fuel economy standards and phasing out coal from the power sector. "That leads to a different mix of energy technologies than if we had a broad carbon pricing scenario in these countries."

According to the *Outlook*'s projections, by 2030, the planet will be within about 5 years of reaching a cumulative emissions level deemed by the Intergovernmental Panel on Climate Change as consistent with a 50% chance of exceeding the 2°C threshold (which it would likely pass by the 2050s). But based on significant recent progress in international climate negotiations resulting in major improvements in GHG emissions levels, the report's authors remain optimistic that world leaders will follow the Paris talks with more ambitious climate policies.

"The extension of the forecast beyond 2025 or 2030 is not a prediction of what is most likely," they write. "Rather it is intended to indicate the need for continued effort, and a measure of the magnitude of effort needed." ■

Related Publication:

John Reilly *et al.,* 2015: Energy and Climate Outlook.
http://globalchange.mit.edu/Outlook2015

Website: Background on the UNFCCC.
http://unfccc.int/essential_background/items/6031.php

MIT Announces Five-Year Plan for Climate Change Action

Hundreds of millions sought for low-carbon research; advocacy for carbon pricing; a call to the alumni and beyond

By MIT News Office

MIT is launching a multifaceted five-year plan aimed at fighting climate change, representing a new phase in the Institute's commitment to an issue that, the plan says, "demands society's urgent attention."

Citing "overwhelming" scientific evidence, *A Plan for Action on Climate Change* underscores the "risk of catastrophic outcomes" due to climate change and emphasizes that "the world needs an aggressive but pragmatic transition plan to achieve a zero-carbon global energy system."

To that end, MIT has developed a five-year plan to enhance its efforts in five areas of climate action, whose elements have consensus support within the MIT community: research to further understand climate change and advance solutions to mitigate and adapt to it; the acceleration of low-carbon energy technology via eight new research centers; the development of enhanced educational programs on climate change; new tools to share climate information globally; and measures to reduce carbon use on the MIT campus.

The plan calls for MIT to convene academia, industry and government in pursuit of three overlapping stages of progress.

"The first step," according to the plan, "is to imagine the future as informed by research: e.g., What is the optimal mix of energy sources in 15, 25 and 35 years, in order to meet emissions targets and eventually reach a zero-carbon global energy system? And how can societies across the globe best adapt to damaging climate impacts in the meantime?"

"Next," the plan continues, "it will be vital to establish the policy and economic incentives to achieve that future. Finally, clear technological goals and aligned incentives will focus and accelerate the research and development required to achieve success. All three phases need to be continuously refreshed: Research and development should continuously inform timelines and targets. The success of this strategy depends on the best efforts of all three sectors."

The plan specifically asserts the need for a price on carbon in order to align the incentives of industry with the imperatives of climate science.

The plan also announces that MIT will not divest from the fossil fuel industry. This decision and the overall plan emerged from more than a year of broad consultation with the MIT community, including extensive public discussion led by the Committee on the MIT Climate Change Conversation, and engagement with the student-led group Fossil Free MIT. This group originally petitioned MIT to divest from 200 companies and more recently has asked for "reinvestment in campus sustainability, and a reinvention of the approach that MIT takes toward climate change."

"We believe that divestment—a dramatic public disengagement—is incompatible with the strategy of engagement with industry to solve problems that is at the heart of today's plan. Combatting climate change will require intense collaboration across the research community, industry and government," the plan states.

PHOTO: CHRISTOPHER HARTING/ABOVESUMMIT

"Combatting climate change will require intense collaboration across the research community, industry and government."

The plan commits MIT to several actions, including $5 million in funding for cross-disciplinary projects to advance an improved understanding of climate change, and practical solutions to mitigate and adapt to it; the launch of eight new low-carbon energy centers focused on solar energy, energy storage, materials, carbon capture/use/sequestration, nuclear energy, nuclear fusion, energy bioscience, and the electrical grid; an Environment and Sustainability degree option and online Climate Change and Sustainability credential; and the reduction of campus emissions by at least 32% by 2030, elimination of the use of fuel oil on campus by 2019 and enactment of "carbon shadow pricing," to explore the effects of assigning a self-imposed cost to campus carbon emissions. ■

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

Landsat-7 satellite image of the bend in the Nile River and adjacent farmland.
PHOTO: JESSE ALLEN, NASA

How to Share Water along the Nile

With water becoming precious enough to be the stuff of war, can nations find ways to share it?

Joint Program Research Scientist Kenneth M. Strzepek co-authored the following New York Times Op-Ed column with John H. Lienhard V, a professor at MIT and director of the Abdul Latif Jameel World Water and Food Security Lab.

On the Blue Nile in Ethiopia, construction is underway on a public works project of gigantic physical proportions and exquisite political delicacy. The Grand Ethiopian Renaissance Dam, now about halfway finished, amounts to a test: with water becoming precious enough to be the stuff of war, can nations find ways to share it?

So far, so good. The project is moving toward completion, and a recent joint declaration of principles by the leaders of Egypt, Ethiopia and Sudan pledges cooperation and no "significant" downstream harm. That is critical, given that the dam will control nearly two thirds of the water on which Egypt depends. But for the cooperation to be meaningful, these three countries will need serious technical analysis. Poor assessment of such matters as the variability of annual rainfall or minimum flows required to maintain downstream water quality could undermine a decent agreement, leading to conflict of unpredictable intensity.

That's because the flow of the Nile is climatic roulette. It experiences periods of plentiful water and periods of extended drought, and it always has: remember the story (in both the Bible and the Quran) of seven years of plenty, and then seven lean years? But now the stakes are much higher: Egypt's population is 90 million, and growing. That country's Aswan High Dam, downstream from the Ethiopian dam, helps to moderate these fluctuations, but a second large dam and its reservoir higher upriver are going to complicate things.

"The flow of the Nile is climatic roulette. It experiences periods of plentiful water and periods of extended drought, and it always has."

Egypt now receives virtually all its water from the Nile—about 60 billion cubic meters a year, slightly above the amount provided for in its treaty agreement with Sudan. That amounts to the withdrawal of 700 cubic meters *per capita* per year. Compare that with California, which annually withdraws about 1,400 cubic meters *per capita* from multiple sources, including 30% of the Colorado River's annual flow, and you understand just how scarce and precious the Nile's water is to Egypt's welfare.

California depends heavily on Lake Powell and Lake Mead, the reservoirs behind dams on the Colorado River, which together store slightly more than three years' worth of that river's total flow. The new dam in Ethiopia will have an even larger storage capacity than that of Powell and Mead combined, but still amounts to just 1.5 years of the flow of the Blue Nile alone. Adding in the very large reservoir behind Egypt's Aswan High Dam gives a storage of about 1.75 years of the total flow of the Nile. It's not a wide margin of safety for a long drought—as Californians will attest.

The monsoon rains in Ethiopia that will feed the new dam come mainly during just three months, so by storing that water, the new dam will moderate and smooth out the flow of the Blue Nile, the 900-mile-long headstream of the Nile itself. It will also generate huge amounts of electricity, the sale of which could finance much-needed development in Ethiopia—except that transmission lines to export the power are not yet being built.

Just as California has used stored water to become an agricultural powerhouse, Sudan will benefit by using the more stable flow of water from the new dam to raise its agricultural productivity. This will allow Sudan, which sits between Ethiopia and Egypt, to finally employ its full treaty allotment of river water, which in turn will reduce what is available to Egypt.

It's clear that a cooperative agreement among Ethiopia, Sudan and Egypt is needed to avoid conflict and downstream harm. This includes agreement on what amounts to "significant" harm, given that, in the past, Egypt has been willing to go to war to protect its water.

All three countries stand to benefit if they work together. The dam's huge storage capacity could help both Sudan and Egypt during drought years. And if Egypt were to agree to buy the power that the new dam will generate (and to build the transmission lines to connect to it, perhaps with international help), then Ethiopia will benefit economically from stored water that has to flow downstream eventually.

Here is where the technical issues will be critical. Last November, the Abdul Latif Jameel World Water and Food Security Lab at MIT convened experts on Nile Basin water resources. They pointed out that management of a river system with multiple dams required sophisticated joint management with a shared knowledge base and scientific modeling framework. The hard negotiations ahead to achieve detailed agreements on such things as reservoir operation policy, power trading, dam safety and irrigation practices will require that foreign policy and water experts from each of the three countries have a shared understanding of the technical issues and a willingness to compromise.

In May 2015, the three countries engaged technical consultants to assist with these problems, but that arrangement has since collapsed over disagreements about project management. It behooves the international community to help, through support of regional efforts like the Nile Basin Initiative, to build scientific and engineering coordination and knowledge among the three countries, provide impartial expertise, set up a management system and perhaps offer a process to resolve disputes.

The world needs to get good at sharing water, and right away. The alternative is frequent regional conflicts of unknowable proportions. ■

Related Publication:

John H. Lienhard V and Kenneth M. Strzepek, 2015: How to Share Water along the Nile. *New York Times*, Sept. 28 2015.

Part of the Brain Trust

MIT Research Associate Mustafa Babiker assesses climate scenarios for the IPCC

What is the optimal way to stabilize greenhouse gas emissions and slow down rising global temperatures? What targets should be set, and through what technologies, mitigation policies and international agreements might those targets be reached? And how might actions taken today narrow or widen the choices available in the future?

These are among the questions that MIT Joint Program Research Associate Mustafa Babiker grappled with as a lead author of a chapter on "Assessing Transformation Pathways" in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, the IPCC's latest comprehensive review of the state of climate change, its potential impacts and options for mitigation and adaptation.

Shaping Climate Policy

For more than a decade, Babiker has contributed his climate and economic modeling expertise to three such reviews, which support the United Nations Framework Convention on Climate Change (UNFCCC), the main international treaty on climate change. One of these, the Fourth Assessment Report, propelled the IPCC to share the Nobel Peace Prize with former Vice President Al Gore in 2007.

Compiled by the world's most authoritative brain trust on the global climate and based on thousands of scenarios from climate modeling research groups including the Joint Program, IPCC Assessment Reports do far more than occupy space on bureaucrats' bookshelves. Providing scientific, technical and economic evaluation of the feasibility of capping the average global temperature rise at 2°C; the likely consequences of not meeting that goal; strategies, timelines and costs for achieving greenhouse gas reduction targets; and other pertinent issues; these reports set the tone for climate action around the globe.

"They help shape climate policies at multiple levels, from driving municipal and business investments to guiding national action plans to formulating international agreements among more than 190 countries," says Babiker. "The Fifth Assessment Report, which we completed in 2014, will be influential in the [COP21] negotiations in Paris, especially in determining how large an effort will be needed."

Contributing to IPCC Assessment Reports since 2004 as a review editor and lead author, Babiker has served on IPCC Working Group III, a panel of experts charged to

MIT Joint Program Research Associate Mustafa Babiker.

Babiker's journey began in his native Sudan, where he completed undergraduate studies in econometrics and social statistics at the University of Khartoum.

assess options for mitigating climate change and their socioeconomic implications. He is now participating in the group's efforts to explore new emissions scenarios for the Sixth Assessment Report.

Babiker's journey to his initial appointment on IPCC Working Group III began in his native Sudan, where he completed undergraduate studies in econometrics and social statistics at the University of Khartoum. Offered a Fulbright Scholarship to continue his studies in the U.S., he pursued a doctorate in environmental and natural resources at the University of Colorado, Boulder. Working as a research assistant to Thomas Rutherford, a renowned applied economist specializing in trade, energy and environmental economics (now an MIT Joint Program research collaborator), and focused on computational economics, Babiker developed his expertise in modeling the global climate and economy.

Becoming a Modeler

"My undergraduate training in three disciplines—economics, mathematics and statistics—was essential to my effectiveness as a modeler," he observes. "Graduate studies in public and environmental economics and computation further sharpened those skills."

RESEARCHER FOCUS

Drawing upon that skill set, Babiker completed his PhD thesis, "Climate Change and the International Trading System: A Computable General Equilibrium Perspective," which highlighted the economic impacts of climate change mitigation policies in developing countries, in 1998. One year later, he was invited to present his research at an IPCC expert meeting at The Hague. That presentation, along with subsequent papers and talks on the topic, paved the way to his long-term relationship with the IPCC.

Meanwhile, Babiker worked at the Joint Program from 1998 to 2002 as a developer for the MIT Economic Projection and Policy Analysis (EPPA) model. Since then he has visited periodically to help enhance EPPA with structural improvements and new sub-models of climate policies, technologies and economic sectors. He has also collaborated with Joint Program researchers from his home base in Saudi Arabia, where he serves as an analyst for Saudi Aramco.

Whether informing global climate policymakers through IPCC Assessment Reports or EPPA upgrades, Babiker's motivation is twofold.

"Part of what got me into this work was that I grew up in a country undergoing significant desertification," he says, "but the main reason was the opportunity to develop modeling tools and apply them to environmental and climate issues." ■

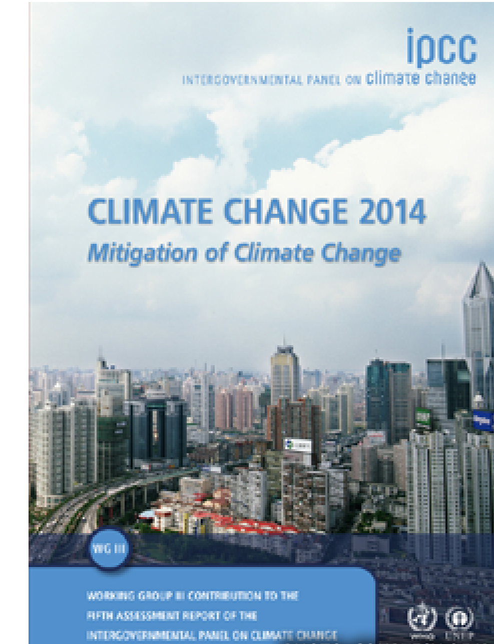


PHOTO: COURTESY OF IPCC

Cover of the Working Group III contribution to the IPCC Fifth Assessment Report

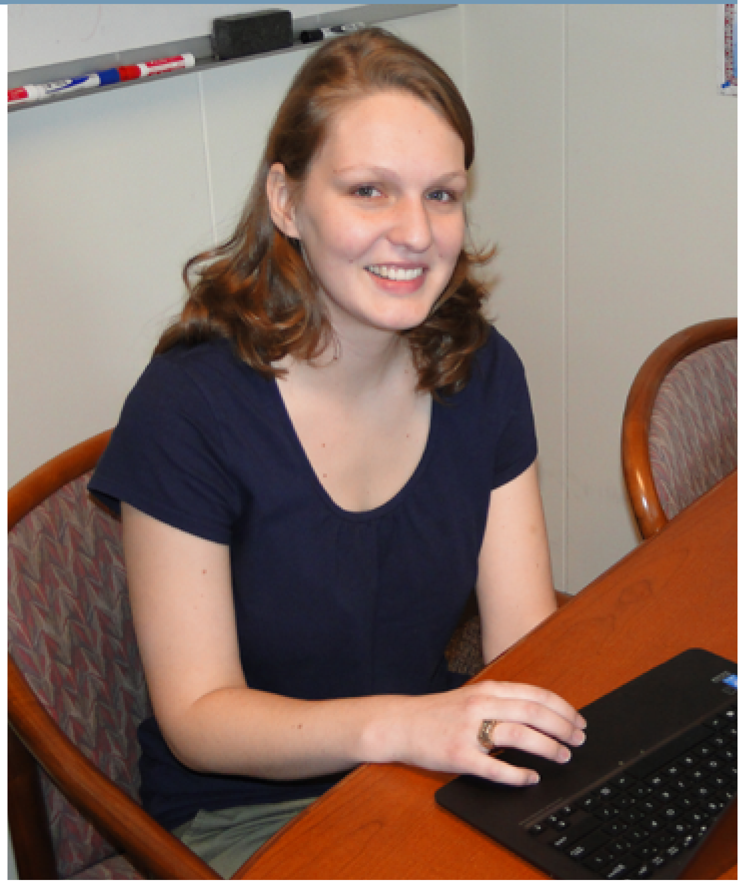
Related Publication:

Mustafa Babiker *et al.*, 2014: Chapter 6: "Assessing Transformation Pathways." *IPCC Fifth Assessment Report*, pp. 413–510.

Joint Program Research Associate Mustafa Babiker and Deputy Director Sergey Paltsev were lead authors on the IPCC Fifth Assessment Report.

Making a Finer-Grain Assessment

UROP student Kirby Ledvina studies effects of carbon pricing and expanded irrigation on biofuel production



MIT Joint Program UROP student Kirby Ledvina

While most kids in her Houston neighborhood were ensconced in classrooms, playgrounds, backyards or other child-centered spaces, seven-year-old Kirby Ledvina could often be found at rallies and planning meetings giving short speeches to community activists. Joined at the hip with her mother, a biochemist turned green building consultant, in a quest for a more livable, sustainable city, she spoke out against the expansion of Interstate 10, diesel exhaust particulates and other threats to the environment. One time she even wore a sandwich board showing how many days a year schoolchildren couldn't go outside to recess due to high ozone levels. Advocating everything from better mass transportation systems to more stringent clean air policies, she would paint a picture of the kind of city she wanted to live in, stressing that the future of her generation was at stake. Her speeches were often followed by standing ovations.

These outings, along with eventual challenges in getting to high school on city buses, put urban design, energy and the environment on Ledvina's radar screen from an early age.

"I became interested in how we can get cities to be smarter in their design and energy use," she recalls. "When I came to MIT, I wanted to study math and economics so I could figure out how to show people the opportunities for cost savings if they adopted more responsible and sustainable technologies and designs."

Ledvina's interest in energy and economics—and a passion for "putting numbers to the environment"—led her to participate in the Joint Program as an Undergraduate Research Opportunities Program (UROP) student. Working full-time in the summers and part-time during the academic year since June 2014, she has collaborated with Joint Program Environmental Energy Economist Niven Winchester and Co-Director John Reilly on a two-phase project sponsored by BP to investigate the impact of a global carbon tax on biofuel production using the MIT Economic Projection and Policy Analysis (EPPA) model.

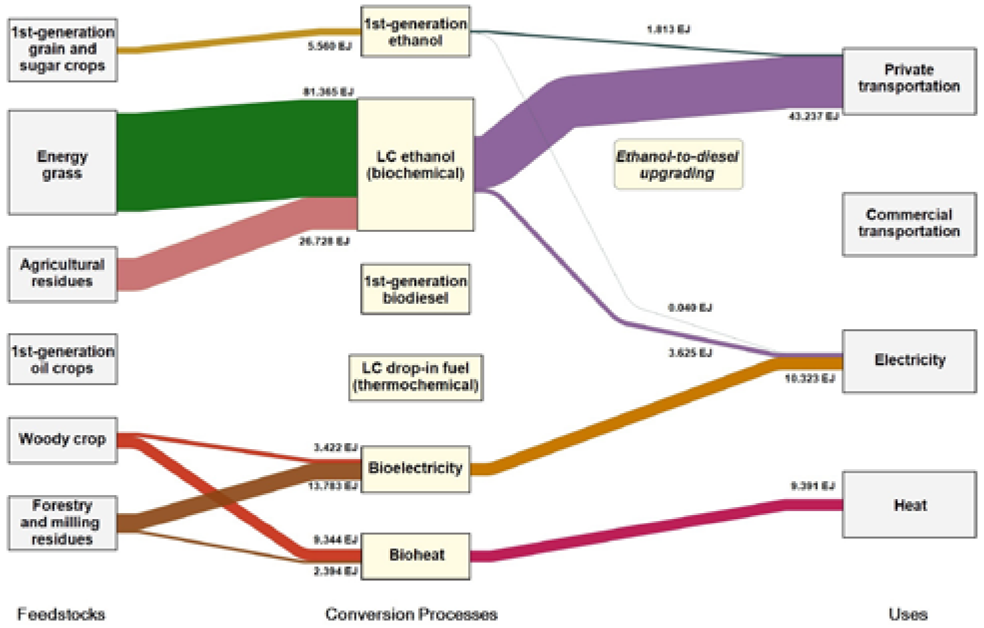
"Kirby has been instrumental in developing a detailed representation of bioenergy in the EPPA model and in the dissemination of results," says Winchester. "Her contributions to the project include managing and analyzing large datasets, developing new methods to augment the EPPA model, and building new tools to collate and communicate results."

Applying a Global Carbon Tax

The project's first phase involved running the EPPA model from 2010 to 2050 to explore six scenarios: a "business as usual" reference policy extending existing climate commitments through 2050; a base policy implementing a global carbon tax set to achieve a production target of 150 exajoules (10^{18} joules) of bioenergy by 2050; and four variations of the base policy, in which selected parameters are constrained.

"The main thrust of Phase 1 was: in a world where bioenergy was actually significant, which fuels in particular would rise up, and where would they be produced?" says Ledvina.

To address those questions, she processed EPPA output with the GAMS programming language and developed a Python program to control software used to produce more than 900 Sankey diagrams (flow charts in which the width of the arrows is proportional to the amount of biofuel energy produced) showing the magnitude of bioenergy being produced, its source and its final use in 16 EPPA regions and the globe from 2010 to 2050 in 5-year increments. Some of these diagrams appeared in a groundbreaking paper published by Winchester and Reilly in *Energy Economics* estimating that under a global carbon price that accounts for deforestation, biofuel and other clean energy technologies could reduce greenhouse gas emissions 52% in 2050 relative to the business-as-usual case.



To illustrate the impact of a global carbon price on biofuel production, Ledvina produced more than 900 diagrams showing the magnitude of bioenergy being produced from different sources and how that energy gets used.

Expanding Irrigation

In Phase 2 the researchers plan to explore where constraints on the expansion of irrigable land may impact the scale of bioenergy production. Toward that end, they're working to enhance the accuracy of the EPPA model's projections by distinguishing between irrigated and rain-fed land. This will enable Ledvina and her collaborators to determine the cost of converting rain-fed land to irrigated land, and how that cost affects land use and economic productivity. They will subsequently run a Phase 1 global carbon tax scenario to see how more accurate land-use modeling affects bioenergy production projections, and how imposing additional constraints on irrigated land further impacts the results.

To support Phase 2, Ledvina developed software to estimate the harvested area of different crops on rain-fed and irrigated land at the country level, and to calculate current crop production values in U.S. dollars. This data was then fed into the EPPA model to enable projections of future crop production values in different subregions of the world, both on irrigated and rain-fed land. Working from data assembled by Joint Program Research Scientist Kenneth Strzepek, she also modelled the costs involved in the regional transformation of rain-fed into irrigated land.

"When we understand at what cost you can transform rain-fed land into irrigated land, we can plug that into EPPA so it will use that cost to project the likely amount of irrigated land in future years, and determine the profitable amount of rain-fed land to convert," Ledvina explains. "By distinguishing between rain-fed and irrigated land, you get a more accurate idea of how much crop production will result, and thus how much biofuel will be produced."

Building a Skillset

Now a junior majoring in management science and economics, Ledvina plans to continue supporting the project for the duration of Phase 2, and possibly beyond. Throughout her time as a Joint Program UROP student, she has cultivated skills not only in programming and modeling but also in communicating the results of her work in periodic conference calls with Winchester, Reilly and James Primrose, BP Biofuels Head of Strategy and Market Analytics.

"In our last call, I presented a research update to BP and enjoyed the process of understanding the technical details and communicating them," says Ledvina. "I like the skills I'm gaining here, and hope to use them in the future."

Her default plan is to work as a management consultant or analyst focused on energy, the environment or public policy. Regardless of the issues she chooses to tackle, Ledvina aims to organize people to pursue action aimed at improving the quality of life. And stand up for future generations, just as she did back in the old days. Even if she's still the youngest one in the crowd. ■

Related Publication:

Niven Winchester and John Reilly, 2015: The feasibility, costs, and environmental implications of large-scale biomass energy. *Energy Economics* 51(September): 188–203.

XXXVIII (38TH) MIT GLOBAL CHANGE FORUM

ENVIRONMENTAL CHANGE AND ECONOMIC DEVELOPMENT IN SUB-SAHARAN AFRICA

By John Reilly

The 38th MIT Global Change Forum was held October 7–9, 2015 in Muldersdrift, Republic of South Africa, in collaboration with United Nations University-WIDER and the Government of the Republic of South Africa (Departments of National Treasury and Environmental Affairs, and National Planning Commission).

The theme for the 38th Forum was chosen to highlight the challenges of economic development in the face of environmental change in sub-Saharan Africa. Talks focused on the effects of environmental change on natural resources across the continent, and on the need to expand access to energy and develop the infrastructure of economies in the region to solve problems of unemployment and low incomes.

Setting the tone for the Forum, the keynote address highlighted the tension between the risks of climate impacts across Africa and the need for structural transformation of economies on the continent toward a productive, high-paying manufacturing sector with an obvious need for expanded energy supplies. While there's an abundance of natural resources in Africa that could provide low-carbon energy, the main challenge is the cost of their development. Who will pay for this higher-cost energy?

Three themes were repeated throughout the Forum: the importance of agricultural development, the need for development of the manufacturing sector, and the question of who would pay for mitigation efforts. One was struck by the delicate task of keeping those countries on track that have turned around their economies, and even accelerating development in these countries and in others that had lagged. Many presentations framed both mitigation and environmental impacts of climate change as risks, indicating that at this point, development needs to be the priority, and that the main burden of mitigating greenhouse gas emissions needs to fall mostly outside Africa, where emissions are much larger and the financial wherewithal to reduce them greater.

The 38th MIT Global Change Forum was held at Misty Hills Country Hotel and Conference Center in Muldersdrift, Gauteng, Republic of South Africa

The final panel, *Developing Countries and the COP*, noted that COP21 represents a significant departure from previous negotiations. For the first time, mitigation efforts include contributions from developing countries; attention on/funding for adaptation has been raised to a comparable basis with mitigation; discussions and interests are shifting from the Developed/Developing divide toward a paradigm that better reflects the diversity of conditions and situations of different countries; and there is a strong signal to non-state actors (private industry, cities, civil society), especially in developing countries, that business as usual going forward is not an option. ■

SAVE THE DATE:
XXXIX GLOBAL CHANGE FORUM

The 39th MIT Global Change Forum will be held June 15–17, 2016 in Cambridge, MA, USA.

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

The MIT Global Change Forum invites representatives of industry, government, NGOs and research groups to discuss the evolving science and policy of the climate issue. The Forum is designed to promote interaction among disparate stakeholders and provides an informal, "off-the-record" setting for independent assessment of studies and policy proposals.

WILL THE PARIS CLIMATE SUMMIT LEAD TO A COOLER PLANET?

LEADING CLIMATE ECONOMISTS DISCUSS PROSPECTS FOR A GLOBAL AGREEMENT

Big hopes are riding on the 2015 United Nations climate change conference planned for November 30–December 11 in Paris, where more than 190 nations will strive to hammer out an international agreement aimed at lowering global temperatures through significant reductions in manmade greenhouse gas (GHG) emissions. As some 40,000 attendees and 80 heads of state prepare to converge on Paris, the stakes are high, said Michael Mehling, Executive Director of the MIT Center for Energy and Environmental Policy Research (CEEPR) as he introduced a panel discussion, "The Paris Climate Summit: Prospects for a Global Agreement," on November 5 at MIT's Tang Center.

"This time around, we really know that we've pretty much run out of time, meaning we do not have the luxury of endless further negotiating rounds," Mehling warned. "So in many ways, the climate summit in Paris is a make-it-or-break-it test for UN-led international climate diplomacy."

In their remarks on the upcoming Paris talks, the panelists—Henry D. Jacoby, the William F. Pounds Professor of Management, Emeritus at the MIT Sloan School of Management, former director of CEEPR and former co-director of the MIT Joint Program; Michael Grubb, Professor of International Energy and Climate Change Policy at University College London; and Valerie Karplus, Assistant Professor of Global Economics and Management at the MIT Sloan School of Management and Director of the Tsinghua–MIT China Energy and Climate Project (CECP)—expressed guarded optimism.

Jacoby called on Paris negotiators to launch "a new climate regime" that he believes could lead to meaningful, long-term cuts in GHG emissions. Noting that expected emissions reduction pledges at the Paris conference will not be sufficient to prevent global temperatures from exceeding the 2°C threshold, Jacoby recommended the establishment of an ongoing, credible, timely process to review pledges; periodic cycles of new, increasingly stringent pledge updates; and sustained, large-scale financial support to enable developing countries to meet their commitments to lower GHG emissions.

Despite his estimate that expected emissions reduction pledges would produce global temperatures in the neighborhood of 3°C, Grubb noted several positive trends, including China's pledges to achieve a GHG emissions peak by 2030 and to establish a national emissions trading scheme by 2017; the hard push for a deal by the U.S. administration; and the increased market penetration of new, low-carbon technologies. While maintaining "90 percent confidence" that Paris will reach a deal, he emphasized that its successful implementation will depend on the ongoing engagement of citizens across the globe.

Karplus outlined several steps China is taking in Paris to move the needle in the right direction, including a commitment to reaching peak carbon dioxide emissions by 2030. She also observed that China's Paris pledge will deliver significant co-benefits in the form of reduced air pollution and associated health effects. She noted, however, that additional measures will be needed to deliver air pollution reductions targeted in the near term. Karplus cited China as a prime example of the challenges that rapidly emerging countries face as they try to balance the global call to reduce emissions with the national imperative to grow their economies and improve the livelihoods of their populations.

The event was cosponsored by CEEPR, the Joint Program and the Harvard University Program on Science, Technology & Society. ■

SEE VIDEO →

PHOTO: DIMONIKA BRAY, MIT JOINT PROGRAM

Michael Grubb, Valerie Karplus and Henry D. Jacoby field questions from a packed audience at the MIT Tang Center.

MIT SOLAR DAY

JACOBY SUGGESTS WAYS TO INCREASE PACE OF DEPLOYMENT

MIT Joint Program former Co-Director Henry "Jake" Jacoby (second from left) with MITEI Director of Research and Analysis Francis O'Sullivan, MIT Institute Professor John Deutch and MIT Energy Initiative Director and Chevron Professor of Chemical Engineering Robert Armstrong.

Through a series of speaker sessions featuring MIT faculty from across the Institute's five schools, MIT Solar Day explored the global potential of solar energy and the challenges involved in realizing a solar-powered future. Among the researchers sharing their expertise at the September 10 conference was Henry "Jake" Jacoby, former co-director of the Joint Program and William F. Pounds Professor of Management, Emeritus, at the MIT Sloan School of Management. Serving on a panel tasked to sum up the key takeaways of the day, Jacoby focused his remarks on how public funding can best advance the deployment of solar energy technologies.

"At the start you want to do something to build a foundation for the industry," he said, "but as you go to scale, you need to rethink this." Toward that end, he explored two questions:

Why did we want solar energy in the first place?

Jacoby's answer: to cut CO_2 emissions in a way that's not too wasteful. He called the Investment Tax Credit (ITC)—a 30% federal tax credit for solar systems on commercial and residential properties set to expire at the end of 2016—a wasteful system that should be gradually replaced by a federal Production Tax Credit (PTC) based on per-kilowatt-hour output that supports the development of renewable energy facilities. The federal PTC expired in 2014.

"We're just at the point where we could fix that and go to a production tax credit," he said. "We need to get out of subsidizing how much you spend rather than how much you produce."

Why did we want residential solar?

Noting residential solar's high cost relative to utility or commercial solar, Jacoby pointed out that state subsidies and net metering have enabled residential users to install photovoltaic systems that have prevented the dispersal of hundreds of tons of CO_2 emissions into the atmosphere. He compared today's residential solar trailblazers to U.S. citizens who, during World War II, collected newspaper and tin cans to support the troops.

"They didn't contribute much to the war effort, but people felt involved in the process," he observed. "Maybe residential solar involves people being more involved in the climate issue in order to get to a much larger scale than we're at now." ■

UNU-WIDER CONFERENCE

SEE VIDEO →

JACOBY RAISES CLIMATE CHANGE CONCERNS

Former Joint Program Co-Director Henry "Jake" Jacoby discussed the impact of climate change policies on both developing and developed countries at the 30th Anniversary Conference of UNU-WIDER, a leading forum for development economics. Held in Helsinki, Finland on September 17–19, the conference drew top experts in the field, including a number of Nobel Prize winners.

Jacoby called expected pledges at the upcoming UN Climate Change Conference (COP21) insufficient to meet global climate targets, but a step in the right direction. Stabilizing the climate over the long term, he said, will require the establishment of an ongoing, credible, timely process to review pledges; periodic cycles of new, more stringent pledges; and sustained financial support to enable developing countries to meet their climate targets, many of which are contingent on such funding.

During his presentation, Jacoby showed how he applied the MIT Economic Projection and Policy Analysis (EPPA) Model to assess emissions outcomes of expected COP21 pledges and national performance in meeting them, and lay out the components of a successful launch of a new climate regime.

Jacoby was just one of two UNU-WIDER Conference presenters to emphasize the strong impact of climate change—and climate change policies—on development economics. The other keynote/closing speaker, Nobel Prize winner Amartya Sen, devoted his entire talk to climate change. ■

EPPA MODEL TRAINING WORKSHOP

ANNUAL TRAINING PROBES MODEL STRUCTURE AND APPLICATIONS

The Joint Program's 7th annual Economic Projection and Policy Analysis (EPPA) model training workshop was held on September 25–26 in Bethel, Maine. The main objective of the workshop was to introduce new Joint Program research assistants to the economic modeling approach and software used in EPPA. About 25 laptop-toting students, staff, sponsor representatives and guests attended the workshop, which featured a series of interactive talks and online exercises on computable general equilibrium (CGE) modeling of the global economy, how EPPA implements that modeling and how to use EPPA to evaluate the potential impacts of climate policy proposals at the national, regional or global levels.

Alicia Robbins (Weyerhaeuser), postdoctoral fellow Claudia Octaviano (MIT Joint Program) and Bo Ava Chen (BP) confer during an EPPA training session.

"The workshop gave me a better understanding of how the model is structured and described, sources for data and assumptions, and the level of details built into the model."

-Bo Ava Chen, BP

Joint Program Co-Director John Reilly kicked off the training session with an overview of the EPPA model, which, in tandem with an earth system model, simulates the response of the global economy over time under different emissions regimes. Reilly showed how the EPPA model accounts for all land, energy resources, capital and labor that factor into energy production, and the economic interrelationships among different geographical regions, markets and industry sectors.

"Because of the strong interconnections across all sectors, any change in one sector can ripple through the economy," he said.

In other sessions, Joint Program researchers introduced participants to EPPA software and new sub-models that have been added in the past year.

Up to Speed on EPPA

Environmental Energy Economist Niven Winchester led a training on the Mathematical Programming System for General Equilibrium Analysis (MPSGE), which simplifies specification of CGE models by freeing modelers from laborious equation writing. Research Assistant Paul Kishimoto followed with a hands-on session on the use of dynamic CGE models to capture the economic impacts of changes in population, energy efficiency, renewable energy technology penetration and other factors.

Henry Chen, EPPA's lead developer, described the structure of EPPA6, the latest version of the model, and walked participants through several exercises to explore the impacts of different climate policies on emissions, energy use and Gross Domestic Product (GDP). He noted some recent changes to the model, including the addition of new settings to improve the model's projections, a standalone "dwelling" sector to better represent household energy consumption for heating and cooling, and two new regions—South Korea and Indonesia.

Research Scientist Jennifer Morris discussed how EPPA simulates the adoption and diffusion of initially expensive new energy technologies into the global economy, and how the costs of these technologies fluctuate over time. Finally, Postdoctoral Associate Claudia Octaviano presented a new EPPA sub-model that estimates the value, under different climate policy scenarios, of augmenting renewable energy generation systems with energy storage technologies.

New Insights

Representatives of BP, the Electrical Power Research Institute (EPRI), the Institute of Nuclear Energy Research (a national laboratory based in Taiwan) and Weyerhaeuser emerged with new insights about CGE models and the evolving EPPA model.

Dr. Bo Ava Chen, BP group technical advisor and BP-MIT relationship manager, came away with a good general overview of the EPPA model.

"The workshop gave me a better understanding of how the model is structured and described, sources for data and assumptions, and the level of details built into the model," said Chen. "As BP-MIT relationship manager, this helps me understand the benefit of the EPPA model for BP businesses, and how BP can use the EPPA model in supporting strategy, policy, economics and technology challenges going forward."

John Bistline, an EPRI technical lead and project manager, enjoyed the opportunity to meet Joint Program researchers and learn more about their work.

"The hands-on walkthroughs of the latest version of the EPPA model helped me to understand and appreciate the model's structure, data and features," he said. "It was impressive to see the range of timely applications for the model and how so many researchers could coordinate to bring their expertise to different components of EPPA. Many of these insights will help our model development moving forward." ■

WATCH EPPA WORKSHOP COURSES

Find videos of workshop sessions and accompanying PowerPoint presentations on the sponsors-only website at **https://globalchange.mit.edu/sponsors-only/eppa2015**

2015 EPPA Workshop participants

MIT SOLVE: FUELING SOLUTIONS

"FUEL" PILLAR AT MIT SOLVE UNDERSCORES ENERGY'S CRUCIAL ROLE IN SOLVING HUMANITY'S BIGGEST CHALLENGES

By Francesca McCaffrey, MIT Energy Initiative

At a kickoff event for the inaugural MIT Solve conference in October, Jeffrey Sachs, director of the Earth Institute at Columbia University, commented on the growing need for the world to apply scientific thinking to the world's toughest problems. In a discussion of how to achieve the United Nations' recently unveiled global sustainable development goals, Sachs said, "It's not a dream, it's an architecture. It's about how and why we act, and how to change it." At Solve, thought leaders from across the nation and the world gathered at MIT to draw up new blueprints for that architecture. They began by planning how they would tackle the world's greatest problems with a mix of critical thinking, imagination and technology.

The issues at hand were organized under four pillars: "Cure" tackled the most pressing challenges in health care today; "Learn," those in the education system; and "Make" those related to infrastructure and the economy. The "Fuel" pillar's objective—"to double energy and food production, halve carbon output by 2050 and set a path to net-zero carbon emissions by 2100"—acknowledged the importance of improving quality of life in developing countries and protecting our environment while feeding a growing global population.

The Fuel pillar was moderated by MIT Energy Initiative (MITEI) Director Robert Armstrong and Angela Belcher, professor of biological engineering and of materials science and engineering at MIT. "The key linkages that Solve seeks to create between like-minded individuals and institutions around the world will enable us to find inclusive solutions to global issues," said Armstrong in introductory remarks. He identified seven elements he considers important to what he called our current "energy revolution": solar, storage, carbon capture and sequestration, nuclear, materials, the grid and bioenergy.

PHOTO: MIT SOLVE

At the kickoff roundtable panel for Fuel, leaders in the conventional energy industry focused on new horizons for energy and the need for sustainable and renewable energy solutions to meet growing energy demand in the developing world. Panelists also stressed the critical ties between energy issues and food and water issues. "Cheap renewable energy and clean water are critical to allowing the world to make, learn and build," one speaker said.

After this opening session, Fuel participants broke off into four parallel sessions on renewable energy, nuclear, climate and food. Capitalizing on new technology was at the forefront of the climate panel. Panelists discussed challenges associated with current carbon capture and sequestration methods, such as cost and reliability, but also identified opportunities related to novel membranes and absorption processes. In addition, researchers highlighted the need for climate resiliency.

As cities plan for climate resiliency, the need to "empower citizens and institutions to prepare" was discussed as a high priority. Kerry Emanuel, the Cecil and Ida Green Professor of Atmospheric Science, who spoke as a panelist, reflected that "the panel brought together key elements at MIT that define the climate problem and address potential solutions to it, which is very much in the spirit of the Solve program." ■

MIT CLIMATE CHANGE CONTEST SELECTS GRAND PRIZE WINNER

SOLAR PANEL SYSTEM WINS $10,000 PRIZE FOR TECHNOLOGY THAT MAKES ENERGY AND WATER MORE ACCESSIBLE IN THE DEVELOPING WORLD

By Vicki Ekstrom, MIT Energy Initiative, and Laur Fisher, MIT Climate CoLab

An MIT initiative is using the global crowd to help solve climate change. And with the United Nations' climate agreement anticipated to fall short of the 2°C carbon emissions target, it's never been a more critical time to take this approach.

MIT's Climate CoLab initiative is a growing community of 50,000 people from around the world who work together online through a series of interrelated contests focused on different aspects of the climate change problem. On October 6, MIT hosted the Crowds and Climate conference, where the Climate CoLab awarded its 2015 contest winners.

PHOTO: MIT CLIMATE COLAB

Eden Full from the non-profit SunSaluter won the $10,000 Grand Prize for its technology that makes energy and water more accessible in the developing world. Their product uses gravity and water to rotate a solar panel throughout the day, generating 30% more electricity than a standard panel and four liters of clean drinking water each 24-hour period. The rotator is cheaper than motorized solar trackers and has already achieved success: there are already 130 SunSaluters in 16 countries.

In addition, two proposals received honorable mention awards:

- A national campaign on energy conservation and renewable energy in Indian schools that is working towards building a network of energy ambassadors. The campaign already has support from the Indian government, and is well on its way to fostering a more environmentally-aware generation of Indians.
- A mechanism for internalizing marine emissions that combines charging a levy on emissions from international maritime shipping, with a fuel levy on fuel consumption by domestic shipping.

These proposals were selected by Robert Armstrong, director of the MIT Energy Initiative; Jason Jay, director of the MIT Sloan Sustainability Initiative; John Reilly, co-director of the Joint Program on the Science and Policy of Global Change, a cosponsor of the Crowds and Climate conference.

The grand prize and honorable mention awards were selected from the 37 winners of the 24 contests run on the Climate CoLab in 2015. The winners are a diverse group of non-profits, entrepreneurs, scholars and climate experts, students, business people and concerned citizens looking to confront the climate challenge, who hail from 11 countries.

Crowds and Climate brought together leaders from businesses, non-profit organizations, governments and communities around the world to advance an online global problem-solving effort to more effectively tackle climate change. This bottom-up approach enables large communities of people to work together to shift business practices, influence policy makers and reshape public attitudes and behavior on climate change. ■

New Research Project Grants

ASSESSMENT OF CCS TECHNOLOGY IN A CLIMATE MITIGATION PORTFOLIO

Project Leaders: Howard Herzog, Sergey Paltsev

This project will assess the future role for carbon capture and storage (CCS) in a portfolio of mitigation options as a basis for strategies to advance the CCS option. Researchers will update/improve the accuracy of models for the deployment of CCS and other competing/complementing options based on recent experience, literature and data (e.g., costs, storage, workforce/knowledge capacity and deployment barriers); use the MIT EPPA model to examine different long-term scenarios to estimate the importance of factors influencing CCS deployment and its role in mitigating carbon emissions; identify developments that may be needed in the near term to improve the competitiveness of CCS options; and assess CCS issues across regions and applications such as gas, coal, bioenergy and industrial.

Sponsor: ExxonMobil (via MITEI membership), 3 years

POWER-GRID RESILIENCY UNDER CLIMATE CHANGE: ASSESSMENT AND OPTIONS

Project Leader: Adam Schlosser

The main objective is to examine the reliability of projections for power-grid resiliency across the United States, while more fully characterizing uncertainty. The focus of this phase is to connect existing science and power-grid resiliency modeling capabilities between MIT Lincoln Laboratory and the MIT Joint Program, so as to inform strategic thinking about adaptation and coping decisions for power-grid resiliency. Using the MIT Integrated Global System Modeling (IGSM) framework, Joint Program investigators will prepare a set of climate/weather and water resource scenarios that include climate change and economic development. Scenario designs will represent a range of mitigation scenarios and climate sensitivities, and plausible regional hydro-climatic changes. Lincoln Laboratory researchers will analyze the expected power generation capacity in each climate change scenario based on the mix of generation systems and corresponding impacts of changes in climate conditions. Combined with demand projections, the analysis will indicate vulnerable regions where substantial shortfalls would be expected. The work is expected to form the basis of a model framework that establishes baselines as well as probabilistic projections of the nation's power-grid resiliency across a range of policy and/or adaptation pathways.

Sponsor: MIT Lincoln Lab, 1 year

PROJECTING AND QUANTIFYING FUTURE CHANGES IN SOCIOECONOMIC DRIVERS OF AIR POLLUTION AND ITS HEALTH-RELATED IMPACTS

Project Leaders: Noelle Selin, Steven Barrett, John Reilly, Susan Solomon

MIT's contribution to this collaborative effort will be to investigate future changes in regional air pollution characteristics due to technological and societal changes. The researchers will quantify the future implications of technologies and efficiency improvements in the energy and transportation sectors on regional differences in air pollution impacts. As a case study, they'll assess the environmental and health benefits of choices in state and regional carbon policy implementation relevant to recently proposed carbon dioxide emission reductions from the energy sector. Finally, they will examine the health-related benefits of reducing concentrations of ozone and particulate matter, as well as changing regional air pollution mixtures including air toxics. To produce their findings, they will use an integrated assessment model framework linking economic models with details on advanced technologies for transportation and energy supply that consistently simulations economic and population growth, air quality and health impacts, including the economic implications of air pollution health impacts. The project will ultimately result in a computationally-efficient analysis tool that can be used to assess the relative importance of global change, technologies and policies to air quality, including their costs and benefits, and taking into account uncertainties.

Sponsor: U.S. EPA, via grant to Harvard School of Public Health to establish an Air, Climate and Energy (ACE) Center, 5 years

JOINT PROGRAM REPORTS

286. Launching a New Climate Regime

285. US Major Crops' Uncertain Climate Change Risks and Greenhouse Gas Mitigation Benefits

284. Capturing Natural Resource Dynamics in Top-Down Energy-Economic Equilibrium Models

283. Global population growth, technology, and Malthusian constraints: A quantitative growth theoretic perspective

282. Natural Gas Pricing Reform in China: Getting Closer to a Market System?

281. Impacts of CO_2 Mandates for New Cars in the European Union

280. Water Body Temperature Model for Assessing Climate Change Impacts on Thermal Cooling

JOINT PROGRAM REPRINTS

2015-17. The feasibility, costs, and environmental implications of large-scale biomass energy (*Energy Economics*)

2015-16. Capturing optically important constituents and properties in a marine biogeochemical and ecosystem model (*Biogeosciences*)

2015-15. Quantifying and monetizing potential climate change policy impacts on terrestrial ecosystem carbon storage and wildfires in the United States (*Climatic Change*)

2015-14. Modeling intermittent renewable electricity technologies in general equilibrium models (*Economic Modelling*)

2015-13. U.S. Air Quality and Health Benefits from Avoided Climate Change under Greenhouse Gas Mitigation (*Environmental Science & Technology*)

2015-12. Carbon taxes, deficits, and energy policy interactions (*National Tax Journal*)

2015-11. Impacts on Resources and Climate of Projected Economic and Population Growth Patterns (*The Bridge*)

2015-10. Climate Change Impacts on U.S. Crops (*Choices*)

2015-9. Natural gas pricing reform in China: Getting closer to a market system? (*Energy Policy*)

2015-8. Changes in Inorganic Fine Particulate Matter Sensitivities to Precursors Due to Large-Scale US Emissions Reductions (*Environmental Science & Technology*)

2015-7. Climate change policy in Brazil and Mexico: Results from the MIT EPPA model (*Energy Economics*)

2015-6. Impacts of the Minamata Convention on Mercury Emissions and Global Deposition from Coal-Fired Power Generation in Asia (*Environmental Science & Technology*)

2015-5. Modeling Regional Transportation Demand in China and the Impacts of a National Carbon Policy (*Transportation Research Record*)

IN THE NEWS

Jun 18, *Wall Street Journal*: Scientists Back Pope Francis on Global Warming

Jun 22, *US News & World Report*: White House Touts Economic Benefits of Climate Action

Jul 10, *BloombergPolitics*: (Some) Republicans Get Religion on Climate

Jul 14, *Boston Magazine*: Meet Two of MIT's New Institute Professors

Aug 3, *The Guardian*: Obama's clean power plan will hit shale gas share of electricity

Aug 5, *Rolling Stone*: The Point of No Return: Climate Change Nightmares Are Already Here

Aug 7, *CBS News*: U.S. carbon pollution from power plants hits 27-year low

Aug 19, *CCTV-America*: Study: China carbon emissions lower than previously thought

Aug 26, *The New Republic*: Is Your City Ready for the Next Katrina?

Aug 31, *Smithsonian*: Tampa and Dubai May Be Due for Extreme "Grey Swan" Hurricanes

Sep 8, *United Press International*: Can fertilized phytoplankton help cool the planet?

Sep 14, *Christian Science Monitor*: From Boston to Beijing, signs of climate momentum

Oct 14, *Washington Post*: Why natural gas is catching up to coal in powering U.S. homes

Oct 14, *Environmental Leader:* Carbon Pricing Beats Vehicle Fuel Economy Standards

Oct 22, *Los Angeles Times*: New Technology Keeping Air We Breathe Under Unprecedented Level Of Scrutiny

Oct 26, *New York Times*: Deadly Heat Is Forecast in Persian Gulf by 2100

PEER-REVIEWED STUDIES & PENDING REPRINTS

Regulatory control of vehicle and power plant emissions: how effective and at what cost? (*Climate Policy*)

Impact of ocean acidification on the structure of future phytoplankton communities (*Nature Climate Change*)

Land carbon sequestration within the conterminous United States: Regional- and state-level analyses (*Journal of Geophysical Research: Biogeosciences*)

Biogeochemical drivers of the fate of riverine mercury discharge to the global and Arctic oceans (*Global Biogeochemical Cycles*)

Enhanced marine sulphur emissions offset global warming and impact rainfall (*Nature Scientific Reports*)

Climate change impacts and greenhouse gas mitigation effects on U.S. water quality (*Journal of Advances in Modeling Earth Systems*)

Quantitative Assessment of Parametric Uncertainty in Northern Hemisphere PAH Concentrations (*Environmental Science & Technology*)

The impact of climate change on wind and solar resources in southern Africa (*Applied Energy*)

Reconciling reported and unreported HFC emissions with atmospheric observations (*PNAS*)

Protected areas' role in climate-change mitigation (*Ambio*)

The Global Energy, CO_2 Emissions, and Economic Impact of Vehicle Fuel Economy Standards (*Journal of Transport Economics and Policy*)

COMINGS & GOINGS

Tochukwu "Tox" Akobi appointed BP Energy and Climate Fellow

Rotem Bar-Or returned to Israel to pursue research opportunities

Jamie Bartholomay promoted to Communications Coordinator

Dimonika Bray appointed as Administrative Assistant

Ben Brown-Steiner appointed as Postdoctoral Associate

Justin Caron departed for faculty position at University of Montreal

Evan Couzo departed for faculty position at University of North Carolina

Mark Dwortzan appointed Communications Officer

Carey Friedman departed for faculty position at Maine Maritime Academy

Fernando Garcia Menendez departed for faculty position at North Carolina State University

Thomas Geissman joined as visiting doctoral student from ETH Zurich

Sae Kwon appointed as Postdoctoral Associate

Robert Morris resigned as Administrative Assistant

Claire Nicolas joined as visiting doctoral student from University of Paris

Claudia Octaviano appointed as Postdoctoral Associate

Audrey Resutek resigned as Communications Coordinator

Rebecca Saari departed for faculty position at University of Waterloo

Giacomo Schwarz returned to ETH Zurich

The work of the Joint Program 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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