MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

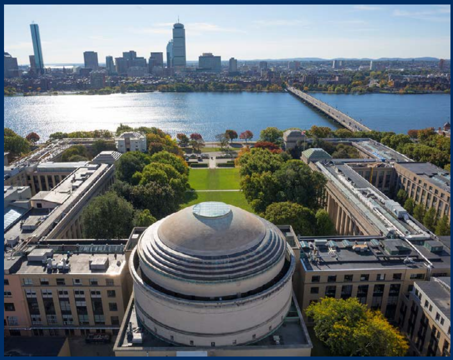
Global Changes

Spring 2015 In this Issue

MISSION AND OBJECTIVES

The Joint Program's integrated team of natural and social scientists studies the interactions between human and Earth systems to provide a sound foundation of scientific knowledge that will aid decision-makers in confronting the coupled challenges of future food, energy, water, climate and air pollution, among others. This mission is accomplished through:

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



IN THIS ISSUE:

Temperature Records, Extreme Weather, and Adapting to a Warmer World

Last year was the hottest year across global land and ocean surfaces since record keeping began in 1880, according to the US National Oceanographic and Atmospheric Administration. And the ten warmest years in the last 135 years have all occurred in the last two decades. At the same time, the ocean has been warming faster since the last great El Niño in 1997–1998 than at any time since measurements began in the 1960s. It is noteworthy that the new record in 2014 was set even without the amplifying effect of an El Niño, during which ocean surface warming accelerates.

The 2014 record refers to global average temperature, but the geographical distribution of temperature anomalies is also revealing. While a large fraction of the world experienced record high or much higher than average temperatures, one spot below South America recorded record lows and Eastern North America and the North Atlantic experienced temperatures much lower than average. These patterns are more associated with weather (e.g., the polar vortex) than climate, and these few unusually cold spots warn us that local climate is not always a proxy for global climate.

"Can we lower the impacts of climate change by adaptation as well as mitigation?"

In recent years we have also witnessed some of the most powerful and damaging storms ever. This trend is related in part to the link between warmer climate and increased global precipitation, since evaporation rates and atmospheric levels of water vapor increase with temperature. Since water vapor is also the basic fuel for convective storms, the potential for megastorms also increases. Thus, warmer tropical ocean temperatures paved the way, at least in part, for the Category 5 Typhoon Pam that hit the Papua New Guinea region in March 2015, the Category 4 Typhoon Rammasun, which struck the Indonesia and Philippines region in November 2014, and the Category 5 Typhoon Haiyan, the most powerful tropical cyclone ever recorded, that bombarded the same area in November 2013.

Weaker events than these megastorms also have the potential to cause catastrophic damage if they strike under the right conditions. Hurricane Sandy in 2012, which at its peak was "only" a Category 3 hurricane, was accompanied by huge storm surges that New York City and surrounding areas were not prepared for. Warmer temperatures are also linked at least in part to the potential for more powerful tornados, such as in May 2013 when a large storm system produced tornados across the Great Plains, including an EF5 tornado that destroyed parts of Moore, Oklahoma. While these individual extreme events are consistent with climate change, I caution that they cannot be definitely attributed to it because changing climate is signaled by trends in the ten or twenty year running average of the weather.

Many other indicators of climate trends have been observed. Measurements show significant increases in global atmospheric water vapor (the major greenhouse gas), and a 50 percent decrease since 1979 in Arctic summer sea ice. Both are driven by and amplify warming. Consistent with warming, observations also show that sea levels have risen steadily over the past century, the power of Atlantic hurricanes has increased, and the mass of the Greenland ice sheet has decreased significantly since 2002.

In the long run, continued substantial and growing evidence for climate change points to the urgent need to step up mitigation efforts. But, given the time needed to affordably transform our energy systems, the role of the oceans in slowing surface warming, and the long lifetime of carbon dioxide and other greenhouse gases in the atmosphere, we won't feel the full benefits of cutting emissions for some decades. To address the impacts of climate change here and now, there is a pressing need to quantify the risks associated with weather extremes, and to elucidate how society can best lower those risks. In other words, can we lower the impacts of climate change by adaptation as well as mitigation?

Toward this end, the Joint Program is working hard to quantify how global warming will affect the incidence and severity of extreme weather. Current climate models are unreliable when it comes to understanding exactly how these extremes will change as the planet warms. To address this weakness, we have developed a method of estimating changes in extreme weather that side-steps the idealized approaches for predicting extreme weather in climate models. This analogue method, so-called because it uses climate models only to identify the large-scale atmospheric conditions associated with extreme weather, can be applied to any event in any region, so long as it is associated with the necessary large-scale atmospheric conditions. In a study published last fall in the *Journal of Climate*, we tested the analogue approach across the continental US with quite promising results.

Informing real-world adaptation decisions is another active area of research. A decision-making framework developed at the Joint Program identifies the cost–benefit path that minimizes adaptation costs for coastal facilities vulnerable to flooding from storm surges and hurricanes. A study published in January in *Climate Risk Management* used the framework to evaluate a facility in Galveston Bay, in Texas. Researchers first estimated how climate change might alter the frequency and magnitude of storm surge heights from a large ensemble of future hurricanes, and then considered the capabilities of a range of adaptation measures for lowering risks. The study concluded that a sea wall built in stages over several decades is the optimal adaptation or protection strategy.

The extensive damage caused by hurricanes and other extreme weather over the last decade foreshadows a risk that will continue, and likely increase in the future with changing climate. Fortunately, while we wait for the needed global climate agreement, there are affordable actions that we can take now to counter some of the more damaging effects of climate change. To act effectively, we must understand the risks we're facing, and use that knowledge to make informed decisions about how to protect our cities, farms, infrastructure, and resources.

While adaptation and protection measures won't give us a free pass on reducing greenhouse gas emissions—it will be practically impossible to adapt to the very large global warming expected with no mitigation—they can go a long way toward preventing some of the worst effects of near-term climate change in countries that can afford them. For those without the resources to adapt, however, mitigation remains both urgent and essential.

—Ronald Prinn, Co-Director
Joint Program on the Science and Policy of Global Change

More Information:

Gao et al., 2014: An Analogue Approach to Identify Heavy Precipitation Events: Evaluation and Application to CMIP Climate Models in the United States. *J. Climate*, doi: 10.1175/JCLI-D-13-00598.1.

Lickley et al., 2015: Analysis of coastal protection under rising flood risk. *Climate Risk Management*, Joint Program Reprint 2015-3.

Where Does Bioenergy Fit into a Low-Carbon Future?

Photo: *Miscanthus*, a biofuel feedstock crop

MIT study evaluates the impacts of a large-scale bioenergy ramp-up.

Biofuels like ethanol and other forms of bioenergy are often seen as a key part of a low-carbon future. But large-scale production of these fuels, which are usually made from either food crops like corn and sugarcane, or from woody plants and grasses, would represent a major shift in how the world makes its energy and uses its land—with implications for global food prices and natural resources like forests.

In a new report from the Joint Program on the Science and Policy of Global Change, researchers investigated what a large-scale increase in bioenergy production caused by a global carbon price might look like. The report concludes that changes spurred by the carbon price, including bioenergy production, could cut greenhouse gas emissions by more than half, with a catch—to achieve the cut, the carbon price must cover emissions from changing land use. Without this safeguard, deforestation becomes a major concern as forests are cleared to make way for farmland.

"If you want to study how land can be used to meet our energy needs, you have to think of all the different ways to use that land—including food, feed, and fuel."

If emissions from deforestation are included in a carbon price, bioenergy together with other advances in clean technology can reduce emissions 57 percent by 2050, relative to when there is not a carbon price. In comparison, not counting emissions from changing land use in the carbon price leads to a reduction of only 16 percent.

The study is one of the most in-depth evaluations to date of how bioenergy might fit into a low-carbon future. The research team developed a cutting-edge modeling tool covering a comprehensive range of bioenergy pathways. Researchers then used the new tool to consider interactions among bioenergy, other low-carbon technologies, and the economy in a world where bioenergy fuels about a quarter of global energy needs by 2050.

"Biofuels are only one channel for bioenergy," says Niven Winchester, an Environmental Energy Economist at the MIT Joint Program on the Science and Policy of Global Change.

"If you want to study how land can be used to meet our energy needs, you have to think of all the different ways to use what grows on that land—including food, feed, and fuel."

Currently, ethanol made from corn and sugar supplies the majority of biofuel. But with new technologies, ethanol can be made from other materials; and there are other ways to generate energy from biomass. For example, the woody residues from logging and lumber processing can be turned into biofuels, or burned to produce electricity or heat for industrial processes.

If the technology to create and use it improves, researchers found that lignocellulosic ethanol becomes the dominant type of bioenergy by 2050. Lignocellulosic ethanol, a so-called second-generation biofuel, can be made from tough grasses such as switchgrass and *Miscanthus*. In some of their simulations, researchers assumed that the cost to produce lignocellulosic fuels would fall by about half over the next decade, as predicted by some analysts. They also assumed that technological improvements would eliminate the barrier to using a fuel mix with a high proportion of ethanol to gasoline, known as the "blend wall."

Under these conditions lignocellulosic ethanol provides more than half of all bioenergy by midcentury. First generation fuels mostly disappear from the market; however, there continues to be a role for Brazilian sugarcane through 2050. If lignocellulosic fuels do become the norm, Africa and Brazil become the largest producers of bioenergy.

"Africa can become a key player in supplying global energy, if agricultural expertise can be transferred to this region." Winchester says. "It has the right climate and a large amount of land, but also the potential for deforestation if policy safeguards aren't in place."

Winchester cautions that, while biofuels could be a boon for areas with the right climate conditions, deforestation is a real concern. The researchers found that deforestation was likely to occur in areas with the weakest political constraints to clearing forests, regardless of where biofuels are actually grown. Deforestation was lessened, and in some cases reversed, when emissions from land-use change were included in the carbon price.

A policy like a global carbon price can lead to changes in land use when it increases the price of fossil fuels, making bioenergy more cost-competitive. This leads to changes in how land is used. Instead of growing soybeans, a farmer might decide to grow biofuel feedstock, or cut down a forested area to convert the land into farmland. Clearing forests increases emissions because trees are natural carbon reservoirs.

Because of its land requirements, bioenergy can put stress on other parts of the economy, especially food prices. Researchers found that large-scale bioenergy production would increase food prices by between 1.3 percent and 2.6 percent by 2050.

"Although many studies already exist on the potential of biomass for energy, they are often criticized because they fail to capture linkages between environmental and economic systems, which limits their value in informing sound decision-making," says John Pierce, Chief Bioscientist at BP, which supported the work.

"The work at MIT is advancing the state-of-the-art of bioenergy modeling," Pierce says of the report. "It applies technical rigor to the assessment of the commercial potential of bioenergy, using a framework whereby economics is linked to land, climate, and ecosystems models. This provides an important and needed perspective in the overall discussion of the use of bioenergy in our energy future." ■

Related Publication:

Winchester, N. and J.M. Reilly, 2015: The Contribution of Biomass to Emissions Mitigation under a Global Climate Policy. *Joint Program Report 273*, January, 31 p.

IN THE NEWS: Imposing carbon price would spur bioenergy, slash emissions—MIT study.

Greenwire covered the bioenergy study's release. Read their coverage here:

http://mitsha.re/1ze2VK7

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Protecting Coastal Infrastructure under Rising Flood Risk

3 questions with Joint Program Research Associate Megan Lickley on helping coastal infrastructure adapt.

Photo: LNG Liquefaction Plant

In a recently published study, Joint Program researchers developed a decision-making framework that identifies the cost–benefit path with the lowest adaptation costs for coastal facilities vulnerable to flooding from storm surges and hurricanes. Megan Lickley, a research associate at the Joint Program, is a coauthor of the study, published in January in Climate Risk Management.

Q. What risks does climate change pose to coastal infrastructure?

A. Climate change brings increasing sea surface temperature, which is the engine of tropical storms, allowing them to grow in intensity and destructive power. At the same time, sea levels are predicted to rise. Further adding to the risk, some areas are sinking as the result of natural processes, or because of removal of subsurface water or fossil fuels. (This geological sinking is known as subsidence.) The combination of increased hurricane risk, rising sea levels, and sinking coastal areas greatly increases the risk of significant damages to coastal infrastructure from flooding.

Q. How is your analysis structured?

A. We evaluate the annual risk of inundation for both today's climate and a 2100 climate for a sample site—Galveston Bay. Using results from multiple climate models, we modeled the change in hurricane activity and applied the results to a surge model in order to project the change in frequency and magnitude of storm surge heights. We couple these projections with uncertainty surrounding the magnitude of sea level rise and subsidence and the result is a detailed projection of flood risk in 2100. We then use intermediate decadal flood risk projections to develop a dynamic decision-making framework to help inform adaptation decisions.

Q. How can this framework be used?

A. The extensive damage caused by hurricanes in the last decade foreshadows a risk that will continue, and likely increase, with a changing climate. As the risk of flooding increases, we will need to decide to abandon or adapt high-risk facilities. We've developed a framework to improve decision-making under uncertainy and changing flood risks. As an example of how to apply the framework, we consider a facility in Galveston Bay sitting at 5 feet above sea level. We determine that the optimal long-term adaptation path is to protect the facility through the construction of a sea wall, but that the sea wall should be constructed in phases, i.e. not all at once, since the cost of construction and maintenance increases with sea wall height. Our dynamic decision-making process finds the cost–benefit path that minimizes the costs of adaptation by considering the risks of a range of adaption measures through all time periods in the coming century. This type of analysis informs city, state and regional authorities facing issues of zoning and building standards, as well as efforts to anticipate future investments in protection and adaptation. ■

Related Publication:

Lickley, M.J., N. Lin, and H.D. Jacoby, 2015: Analysis of coastal protection under rising flood risk. *Climate Risk Management*, 6: 18-14, Joint Program Reprint 2015-4.

Report: Climate Change Could Mean Lights Out at Some Plants

MIT study evaluates the effect of warmer water temperatures on plant shutdowns.

Thermoelectric power plants, which use water for cooling, generate about 91 percent of the energy made in the United States. Plants often withdraw water from nearby rivers and lakes and depend on a supply of cold water to operate. Because they rely so heavily on water, droughts and heat waves can lead to plant shutdowns.

Power plant shutdowns related to climate change could disrupt US energy generation at thermoelectric power plants, especially during summer months, according to a new report by researchers at the MIT Joint Program on the Science and Policy of Global Change. As climate change increases the frequency of droughts and heat waves, there will be more days when plants will be forced to shut down because there is not enough water, or the available water is too hot.

Once-through cooling plants, which use water from a nearby source once before flushing it back into the environment, will be hit especially hard by the effects of climate change. The report finds that thermoelectric plants, which are common east of the Mississippi, will produce 0.8–6 percent less power during the summer months by 2050 if there is no check on greenhouse gas emissions.

The researchers studied a variety of different thermoelectric cooling technologies, including once-through plants, and plants that use cooling ponds or towers to cool water for reuse. They also studied how different climate policies might affect thermoelectric power generation, and how using different climate models might change results.

They found that, year-round and country-wide, it's not clear if climate change will decrease or actually increase power generation, but lowering emissions does reduce the risk of the worst impacts on thermoelectric plants. With no changes in greenhouse gas emissions, changes in power generation range between a 3 percent increase and a 4 percent decrease. When greenhouse gas emissions are decreased, changes range between a 3.5 percent increase and a 2 percent decrease. ■

Related Publication:

Strzepek, K., et al., 2015: Climate Change and Thermoelectric Power Production. *Joint Program Report 280*, May, 28 p.

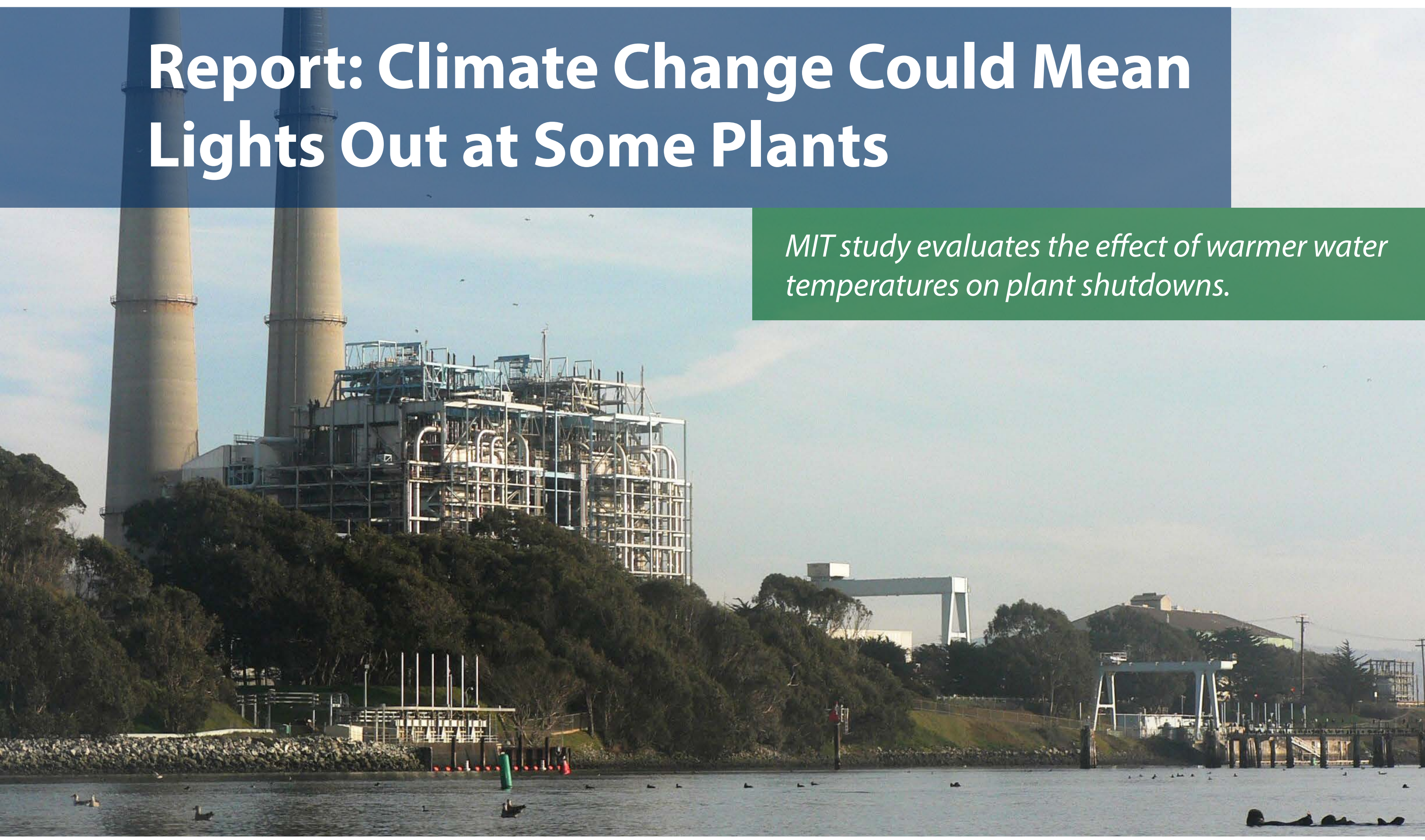

Photo: Moss Landing Power Plant, Moss Landing, CA. Courtesy of David Monniaux

Mapping China's Internal Migration

MIT study finds that migration between China's provinces can have substantial impacts on energy policy implementation.

Photo: Nanjing Road in Shanghai

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China is in the midst of a major internal population shift—100 million people relocated from one province to another in the first decade of the twentieth century, a number about the size of the combined populations of California, Texas, and Florida. Yet the nation's energy and climate policies don't account for how this population shift could affect provincial energy use, productivity, and emissions.

New research from the Tsinghua-MIT China Energy and Climate Project shows that migration does measurably affect the outcome of China's provincial energy policies, and that those policies with built-in ways of accounting for the shift are more effective. The study is the first to evaluate the impact of population flow on China's existing provincial energy policies.

"China is undergoing a big change in terms of where and how people live," says Valerie Karplus, a professor of global economics at MIT and an author of the report. "Building flexibility into China's energy policy will allow it to adapt to uncertainties such as migration across provinces."

The researchers find that China's energy intensity targets, which set flexible limits on energy use based on the size of a province's economy, are better able to respond to the changes in energy use and economic activity that accompany population shifts. In contrast, provincial energy caps, if implemented, would place hard limits on energy use, and are less able to respond to these changes, making them too easy for provinces with declining populations to meet and more burdensome for growing provinces.

"If China continues to set energy targets province-by-province, energy intensity targets are the better choice," Karplus says. "A national energy policy like an emissions trading market would be even more efficient, because energy use cuts would reflect the least expensive options nationwide."

Interprovincial migration will peak before the end of the decade, according to the researchers' population simulations, with approximately 90 million people moving between provinces in the years between 2010 and 2015. Migration rates will continue to remain high over the next five years, with 60 million people moving across provincial lines from 2015–2020. Shanghai and Beijing provinces will grow the most, with the population of each projected to increase by at least a third.

Migration has steadily increased in China since the nation's *hukou*, or household registration, system started to be relaxed. As a result a steady stream of migrants from China's west has poured into the more developed eastern provinces in search of higher wages. As the wage gap between eastern and western provinces begins to close, interprovincial migration will slow down.

The sheer number of people moving between provinces is not the only factor with the potential to affect policy outcomes, researchers found. It also matters where they move. China's eastern provinces lack natural resources, but tend to be more economically developed and are more energy efficient. China's western provinces, on the other hand, have abundant natural resources, but use more energy-intensive methods.

As people move to wealthier eastern Provinces, the GDP of those provinces increases. In Beijing and Shanghai, GDP is more than 17 percent higher when migration is factored in than when it is not. This is the result of a larger workforce leading to increased economic activity.

"Building flexibility into China's energy policy will allow it to adapt to uncertainties such as migration across provinces."

Policies that do not account for these changes have the potential to have unintended effects. "Energy policies run the risk of worsening regional disparities, if they don't take interprovincial migration into account" says Karplus. "Rigid provincial limits encourage growing provinces to outsource manufacturing and production to shrinking provinces to meet their own targets."

Industrial processes in the western provinces are often more energy-intensive, so the relocation of economic activity under rigid targets would make the overall national energy intensity target harder to meet.

The researchers point out that moving from provincial targets to a national policy, like an emissions trading system, would largely resolve the issue of unequal distribution of policy costs. ■

Related Publication:
Luo, X., D. Zhang, J. Caron, X. Zhang, and V.J. Karplus, 2014: Interprovincial Migration and the Stringency of Energy Policy in China. *Joint Program Report 270*, November, 27 p.

Double Impact: Why China Needs Coordinated Air Quality and Climate Strategies.

Paulson Papers on Energy and Environment, Joint Program Reprint 2015-1

In February, the Paulson Institute published a paper by Prof. Valerie Karplus, the Director of the Tsinghua-MIT China Energy and Climate Project, examining China's current approach to tackling air pollution and carbon mitigation. The paper examines the issues nationally and argues that more incentives are needed if China hopes to meet its "peak carbon" goal by 2030.

The urgency with which Beijing is tackling air pollution is certainly positive, and such actions will lead to concomitant benefits in curtailing carbon dioxide (CO_2) emissions, to a certain extent. But Karplus argues that it would be a mistake to view the current initiatives on air pollution, which are primarily aimed at scrubbing coal-related pollutants or reducing coal use, as perfectly aligned with carbon reduction.

This is not the case, according to Karplus. Air pollution reduction is only partly aligned with CO_2 reduction, and vice versa. In addition to air pollution efforts, effective co-control requires a more significant step: a meaningful price on carbon. This is especially so if Beijing is to realize its 2030 pledge. Put another way, air pollution control efforts, while essential, will only take China part of the way toward its stated carbon reduction goals.

One major reason is because while low-cost solutions for air pollution and carbon reduction can overlap, the reality is that co-benefits run out after low-cost opportunities to reduce or displace the fuels responsible for both carbon and air pollution emissions—mostly coal in China's case—are exhausted. In other words, co-benefits diminish over time as greater reductions are needed, according to Karplus.

Read the analysis here:
http://mitsha.re/1zhAzlu

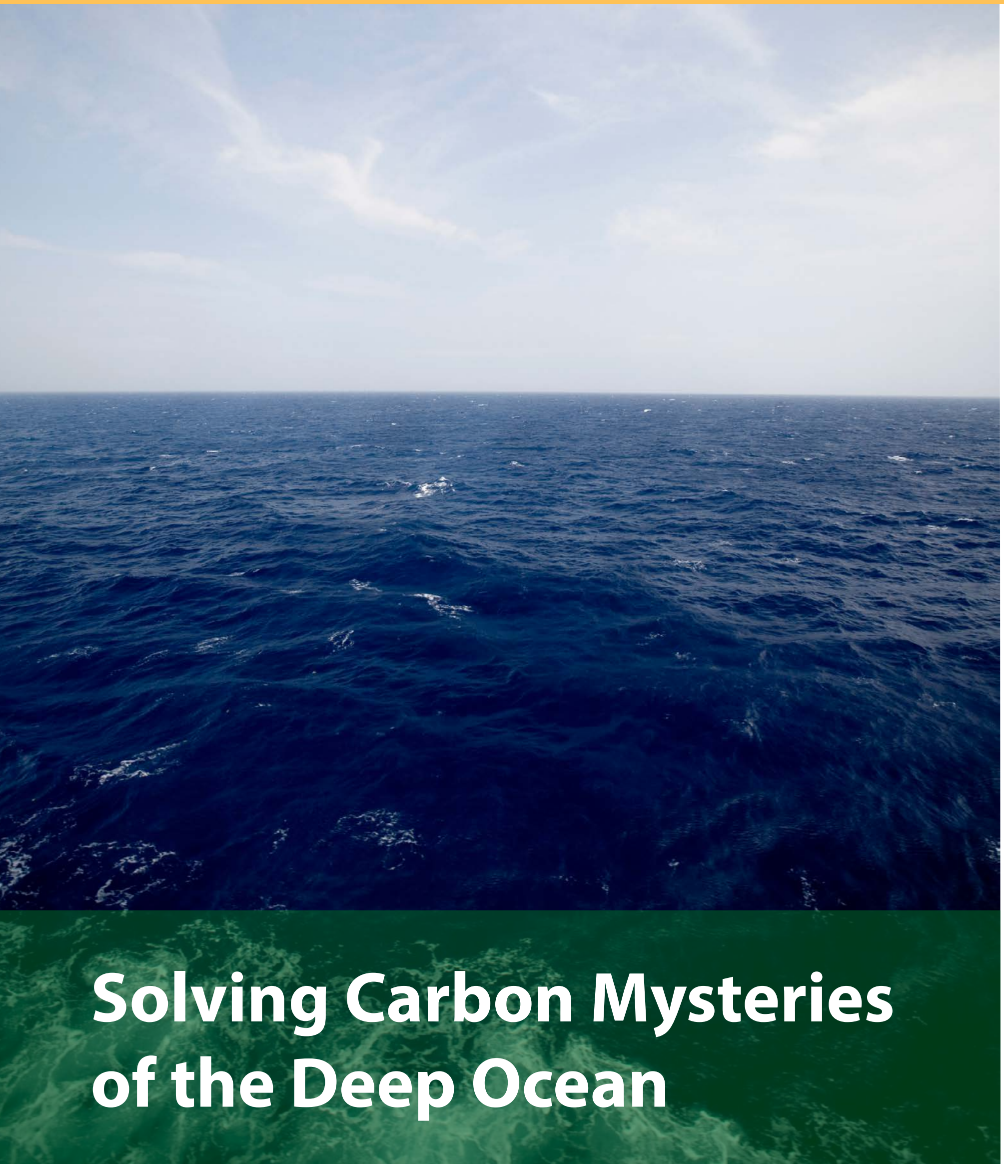

Photo: Atlantic Ocean

Solving Carbon Mysteries of the Deep Ocean

New research from collaborators at MIT

By Cassie Martin, Oceans at MIT

Understanding how oceans absorb and cycle carbon is crucial to understanding its role in climate change. For approximately 50 years, scientists have known there exists a large pool of dissolved carbon in the deep ocean, but they didn't know much about it—such as the carbon's age (how long it's been in organic form), where it came from, how it got there and how long it's been there, or how these factors influence its role in the carbon cycle.

Now, new research from scientists at MIT and Woods Hole Oceanographic Institute (WHOI) provides deeper insights into this reservoir and reveals a dynamic deep ocean carbon cycle mediated by the microbes that call this dark, cold environment home. The work, published in *Proceedings of the National Academy of Sciences*, suggests the deep ocean plays a significant role in the global carbon cycle and has implications for our understanding of climate change, microbial ecology, and carbon sequestration.

For years, scientists thought that carbon of varying ages made up the deep ocean reservoir and fueled the carbon cycle, but nobody could prove it. "I've been trying for over 20 years," said Daniel Repeta, a senior scientist in marine chemistry and geochemistry at WHOI and co-author of the study. "Back then we didn't have a good way to go in and pull that carbon apart to see the pieces individually. We would get half-answers that suggested this was happening, but the answer wasn't clear enough," he said. With the help of Daniel Rothman, a professor of geophysics in MIT's Department of Earth, Atmospheric, and Planetary Sciences (EAPS), and Chris Follett, a postdoctoral associate in Mick Follows' group and formerly of Rothman's group, Repeta would soon find the answers he was looking for.

Follett thought a next-generation method called a step-wise oxidation test might be able to reveal the age distribution of the carbon pool. The team exposed water samples taken from the Pacific Ocean to ultraviolet radiation, which converts organic carbon to carbon dioxide. The gas was then collected and measured for radiocarbon, which Follett used to estimate the carbon isotopes' ages and cycling rate. "At a minimum there are two widely separated components—one extremely young and one extremely old, and this young component is fueling the larger flux through the dissolved carbon pool," he said.

In other words, the youngest source of dissolved organic carbon in the deep ocean originates from the surface, where phytoplankton and other marine life fix carbon from the atmosphere. Eventually these organisms die and sink down the water column, where they dissolve and are consumed by microbes. Because it takes 1,000 years for the ocean's surface waters to replace bottom waters, scientists thought the few centuries-old carbon, some of which is anthropogenic, couldn't possibly contribute to the deep ocean pool. That's no longer the case.

Photo: Chris Follett and Chiara Sanitelli, a visiting scientist from the Institute of Biophysics in Pisa, Italy, process deep ocean samples for radiocarbon measurements. Credit: Dan Repeta, WHOI.

The researchers found that as particulate organic carbon sinks through the water column and dissolves, some of it is sequestered in the reservoir and respired by microbes. The results suggest a more active carbon cycle in the deep ocean bolstered by bacteria that utilize the reservoir as a food source. "We previously thought of the deep ocean as a lifeless and very slow system," Repeta said. "But those processes are happening much faster than we thought." If this microbial pump is in fact more robust, then it gives more credence to the idea of using the mechanism to sequester carbon in the deep ocean—a concept some scientists have been working on in recent years.

Based on mathematical modeling of dissolved organic carbon, researchers are beginning to see the outlines of a new deep sea carbon cycle—one in which dissolved carbon is continually added and removed by a number of diverse processes.

While some carbon in the reservoir may cycle faster, older carbon cycles much slower. This is because older sources such as hydrothermal vents, methane seeps, and ocean sediment produce carbon that isn't easily consumed. However, these sources are often disregarded in analyses of the marine carbon cycle because they are considered too small in magnitude to be significant. But when Follett accounted for them in calculating the reservoir's turnover, or the time it takes for carbon to completely cycle, what he found was astounding. The turnover time of the older portion of the reservoir is 30,000 years—thirty times longer than it takes for the ocean itself to cycle—which indicates these sources may be relevant. "To find something that is more consistent with the biochemical story was fun and surprising," said Follett. "A lot of people have proposed these ideas over the years, but they haven't had the evidence to back them up. It was nice to come in and give them the evidence they needed to support these ideas."

So what do these findings mean for the climate system? In the short term, not much. But on a longer time-scale, one that spans thousands of years, it could affect projections of the amount of atmospheric and sequestered carbon. "It potentially has a very important influence on climate through its role in sequestration of carbon away from the atmosphere," said Mick Follows, an EAPS associate professor in the Program of Atmospheres, Oceans, and Climate, who was not involved in the study. "If some radical change occurred that changed the nature of that pool, then it could have an effect on climate through greenhouse gas' influence on the atmosphere." Such changes might include, for example, deep ocean temperature fluctuations affecting microbial activity, or a shifting surface ocean environment that could affect plankton and other organisms from which dissolved organic carbon originates.

"One of the things I've taken away from the work is that in a way, they've transformed a view of how people are thinking that pool is turning over in the deep ocean and what the sources of that are," said Follows. "It seems like a very profound change in our understanding of how the system works relative to ingrained perspectives." ■

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Archived Webinar: The Role of Oceans and Climate: Ocean dynamics and the biosphere

The ocean plays a critical yet often underappreciated role in the climate system through storage and transport of heat and carbon. In this archived webinar, Joint Program Researchers Jeffery Scott and Stephanie Dutkiewicz present an overview of the ocean's role and describe some of our recent research to better understand the relevant dynamical and biological processes and their related uncertainties. They focus on their work to understand how the three dimensional dynamical movements within the ocean have played a major role in setting regional patterns of warming as well as the overall rate of heat uptake.

Watch the webinar: **http://globalchange.mit.edu/sponsors-only/webinar**

Oil Will Flow Like Milk and Honey. Here's Why.

Worldwide, people are learning to live with less gas, but that's a hard habit to keep.

Joint Program Co-Director John Reilly writes for USA Today about falling oil prices, and what we can expect for the next decade.

By John M. Reilly

The price of oil has fallen nearly 60 percent since peaking in June, and lately there's been a lot of ink and pixels devoted to the question of whether oil prices will plunge even further or whether they will shoot right back up. An even bigger issue is whether prices will stay at these very low levels.

While I doubt oil prices will fall much more—how much further could they reasonably tumble? Perhaps another $20 or so?—history suggests we can expect prices to remain low for the foreseeable future. What's playing out right now in the oil market is likely the same supply-demand dynamic we've seen over and over: several years of extremely high oil prices followed by decades of low prices. The twin oil shocks of the 1970s, for instance, resulted in 20 to 25 years of low prices.

Of course, things are different today—but not that much different. Over the past six or seven years, oil has been relatively expensive, often trading at over $100 a barrel. During that time, both the supply and demand sides of the equation have responded.

On the supply side, high prices have spurred investment in oil and gas exploration. Even as OPEC (Organization of the Petroleum Exporting Countries) has maintained steady production, the U.S. is experiencing a drilling revival and the shale industry is booming. Oil production is up in other countries, too. Canada has boosted its crude oil production, as have Russia and Libya. With more oil on the market, prices predictably have fallen.

On the demand side, many developed countries—including the US—are using less oil. Policies such as CAFE (Corporate Average Fuel Economy) have helped improve the fuel economy of cars and light trucks. Consumers, meanwhile, have recently demanded higher-mileage cars.

There are sociological forces driving oil prices down, as well. For instance, people are more likely to live in cities (rather than car-critical suburbs) and choosing to walk or bike more.

The upshot is that unless the world changes dramatically, we should expect oil prices to remain low for at least the next 10 years. On the supply side, investments in production will continue to bear fruit; and history suggests the forces on the demand side will play out for another decade or two—or at least until people forget about high prices.

For argument's sake, though, let's dwell for a moment on this notion of the "world changing dramatically." Some might say that the world has indeed already changed. Historically, the U.S., Europe, and Japan have accounted for the greatest oil demand. But as countries like China, India, Brazil, South Korea, and Indonesia continue to expand and grow, the demand center is shifting. This has already had a big impact on prices and it will continue to do so. After all, one of the key reasons for the current slump in oil prices is that while the US has, for the most part, recovered from the global recession, many other countries are still not yet back on track.

China is becoming the new gorilla in the oil market. Over the past three decades, China has built modern cities, roads and pulled hundreds of millions of its people out of poverty. If its rapid growth continues, it will be the source of major demand growth for petroleum as it already has for many resources. But even China knows its limits. Its population is increasingly concerned about traffic congestion and domestic air pollution. And with its population density, it is hard to see that China could follow in the footsteps of the US's car-ownership model.

When it comes to predicting oil prices, the "fools rush in where angels fear to tread" quote comes to mind. Major turmoil in oil producing regions, short memories of high prices and suddenly robust global economy could prove me wrong. But I look for oil prices to stay in the range of $50–$100 a barrel for a decade or more, and probably more likely towards the lower end. ■

ON TWITTER

See below for selected tweets about John Reilly's column in *USA Today.*

@MITenergy: A decade of $50-100 #oil? @MITGlobalChange's John Reilly on how "oil will flow like milk and honey": http://usat.ly/1CFJ8yM via @USATODAY

@mitsloanexperts: .@MITSloan's John Reilly explains the factors influencing the changing price of #oil and predicts future oil prices: http://bit.ly/1zOfNjw

@DIc6David: Oil will flow like milk and honey--and so does that leave us with geo-engineering climate change? | @scoopit http://sco.lt/4hy4gr

@MITSloan: Oil prices should stay down for at least a decade, MIT Sloan's John Reilly writes in @USATODAY: http://ow.ly/JcHZ7

XXXVIII MIT GLOBAL CHANGE FORUM

Environmental Change and Economic Development in Sub-Saharan Africa

October 7–9, 2015, Muldersdrift, South Africa

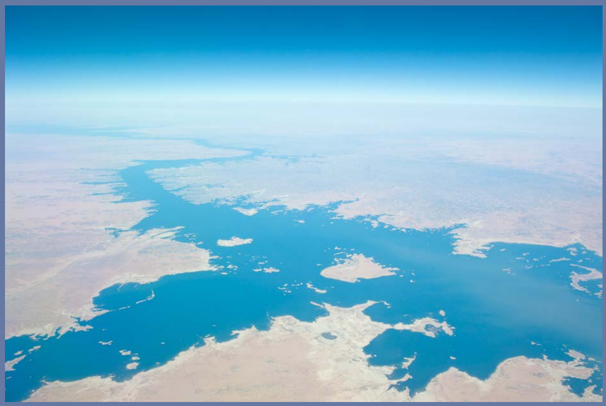


Photo: Aerial view of the Nile River

IN THE NEWS

International Experts Analyze Impacts of Ethiopian Dam

According to present plans, the Grand Ethiopian Renaissance Dam (GERD)—now under construction across the Blue Nile River in Ethiopia—will be the largest hydroelectric dam in Africa, and one of the 12 largest in the world. But controversy has surrounded the project ever since it was announced in 2011—especially concerning its possible effects on Sudan and Egypt, downstream nations that rely heavily on the waters of the Nile for agriculture, industry, and drinking water.

To help address the ongoing dispute, the Joint Program and MIT's Abdul Latif Jameel World Water and Food Security Laboratory (J-WAFS) convened a small, invitation-only workshop of international experts last November to discuss the technical issues involved in the construction and operation of the dam, in hopes of providing an independent, impartial evaluation to aid in decision-making. The group's final report, which was shared with the three concerned governments in early February, was released publicly in April.

Kenneth Strzepek, a research scientist at the Joint Program, was a co-chairman of the November Workshop.

Learn More: http://mitsha.re/1P7FTGL

Helping a Better Future Arrive

MIT researcher Sergey Paltsev studies how to supply the world's growing need for energy—without harming the climate.

Photo: Sergey Paltsev

Currently, there's no silver bullet for fossil fuels—no one energy technology that can provide a cheap and reliable alternative capable of supporting the world's growing energy needs. Instead, decision-makers looking to lower greenhouse gas emissions must choose from an expansive menu of technology and policy options.

MIT economist Sergey Paltsev studies this array of technology and policy options, with the goal of easing any economic growing pains that might result from the world's energy transition. Though his research spans a wide range of topics and regions, it is tied together by a common thread: understanding the economic and climate impacts of energy decisions.

"The world's energy appetite is growing—the question is how do different technologies and policies fit into the picture?" says Paltsev, the deputy director of the MIT Joint Program on the Science and Policy of Global Change. "More importantly, what is the best way to add those technologies to our energy systems so that the economy continues to grow?"

As one example, Sergey points to ongoing research on CO_2 emissions from vehicles in the EU. The European Commission currently sets CO_2 standards for cars, which limit emissions from vehicles. Paltsev and colleagues at the Joint Program found that an alternate policy, where emissions from cars are covered by emissions trading, could achieve the same reduction at a much lower cost, saving the EU €25–60 billion.

"The goal of these policies is so important—to protect the climate. That goal has to be implemented somehow." Paltsev says. "As people say, the devil is in the details. We want to make sure that any policy prescriptions being offered are realistic, and that there aren't any hidden details or unintended consequences."

Paltsev has accumulated a diverse research portfolio during his efforts to understand the economic impacts of policy implementation. Among other topics, he has studied the deployment of advanced energy technologies, air pollution health impacts, the economic costs of vehicle and power plant emissions standards, emissions from fracking, the liquefied natural gas (LNG) market, biofuels and their impacts on land use change, and design of emission mitigation pathways. Paltsev is also a lead author of the chapter on transforming energy pathways in the UN Intergovernmental Panel on Climate Change's (IPCC) most recent climate assessment report.

Road to economics

Paltsev started his career as a computer engineer and designer. While he was pursuing a graduate degree in radiophysics and electronics in Belarus, he heard about a US program offering economics training for scientists in the former Soviet Union. Paltsev applied to the highly competitive program, and was selected to study for a year at The Economics Institute in Boulder, Colorado.

He then returned to his *alma mater*, Belarusian State University, where he founded a business school with the help of Charles Becker, the president of The Economics Institute and support from the US Agency for International Development (USAID). The first western-style business school in Belarus, it has since grown into the university's School of Business and Management of Technology.

After two years of managing the program and teaching economics, Paltsev decided that he needed to learn more in order to pursue his own economic research agenda. He returned to the US to study with Thomas Rutherford at the University of Colorado at Boulder. Rutherford is the creator of MSPGE (Mathematical Programing System for General Equilibrium Analysis), a computer modeling program. MSPGE now serves as the foundation of the EPPA Model, which is the Joint Program's primary economics research tool.

Armed with the skills to do his own research, Paltsev turned his attention to a variety of projects. In one project he evaluated Russia's tax system with the World Bank; in another, social security reform in Kyrgyzstan; in a third, he looked at how the Kyoto Protocol could inadvertently increase emissions in non-participating countries.

In 2002, Paltsev came to the Joint Program, which has allowed him to delve into new research areas. "A great strength of the Joint Program is that you directly interact with scientists from so many different fields," he says. "I work with atmospheric modelers, ocean modelers, land and water modelers. It's really a unique place."

Always one-step ahead

Helping decision-makers make informed energy choices means always being one step ahead of the latest developments in the energy world, Paltsev says. "One of the reasons I enjoy being at the Joint Program is that we have constant interaction with government officials and industry representatives," he says. "It's a reality check. We aren't just working with theoretical structures."

His current work focuses on providing solutions to a number of emerging energy issues. One area of research is assessing nuclear power as a replacement for China's coal-fired power plants. China is a heavily coal-dependent country, and if it is to achieve its goals of improving local air quality and reducing its carbon footprint, it will have to move away from coal.

"The world's energy appetite is growing—the question is how do different technologies and policies fit into the picture?"

Another area of ongoing research focuses on natural gas development. "A lot of people say that natural gas is a bridge energy," Paltsev says. "Well, how long is that bridge, or is it a bridge to nowhere?" Natural gas is often identified as another replacement for coal, since it is a relatively low-carbon fuel. Paltsev and colleagues are studying the natural gas development and how recent low oil prices might affect global natural gas markets.

A third area of research involves figuring out ways to increase the use of renewable technologies like wind and solar power. Paltsev is studying how to counter the intermittency of these power sources, the major obstacle blocking wider use of these technologies.

In the search for efficient low carbon energy sources, solutions always need to be realistic, Paltsev says. "Economics matters. The energy conversation starts with fossil fuels, which are a very efficient source of energy," he says. "Whatever you create as an alternative has to beat fossil fuels economically, and that is going to be a tough job. I am optimistic that we will find a way for a better future. This is exactly what we are working on at the MIT Joint Program." ■

SPONSORS-ONLY WEBINAR

Emissions Trading versus Government Regulations: The example of reducing CO_2 from cars in the EU
Thursday, June 4, 2015, 10:30 EDT

While economic analyses generally indicate that a broader market-based approach to greenhouse gas reduction would be less costly and more effective, regulatory approaches have found greater political success. The example of the EU CO_2 regulations on cars is considered. Emission trading is demonstrated to save the EU economy € 25–60 billion a year compared to emissions standards that achieve the same mitigation levels. The reasons for the EU adoption of the costlier approach are discussed.

More information: http://globalchange.mit.edu/sponsors-only/webinar

Using Storage to Build Cleaner Energy Systems

MIT graduate student Claudia Octaviano studies how energy storage technologies could transform the economics of renewable energy.

Photo: Claudia Octaviano

When she was a little girl growing up in Mexico City, MIT graduate student Claudia Octaviano's school held regular pollution drills. During the drills, it was her job to crawl to the windows and seal them with paper towels. The procedure was in place for a good reason—in 1992 the UN described Mexico City's air as the most polluted on the planet. The city's air quality has improved since then, but the experience left a lasting impression on Octaviano.

"We had drills for earthquakes and also drills for air pollution. It's funny—it left me with the idea that pollution is a really serious problem, on the same level as earthquakes," says Octaviano, who will receive a Ph.D. from MIT's Engineering Systems Division this spring.

As she grew older, Octaviano, also a research assistant at the Joint Program on the Science and Policy of Global Change, began to think about how economies develop. She became especially interested in how countries can grow their energy systems in ways to avoid issues like the poor air quality that plagued Mexico City during her childhood.

Saving energy for a rainy day

Octaviano is now studying how energy storage technologies could transform the economics of renewable energy. Storage technologies, like batteries or pumped hydroelectric storage, could be used to counter the intermittency issues inherent in low-carbon power sources like wind and solar, if it were economically feasible to do so.

For example, Mexico has strong wind and solar resources, but as in any location, the times when the wind is blowing and the sun is shining don't necessarily match up with when people use the most electricity. To counter this, renewables must be supported by some sort of backup generation that can quickly come online, often natural gas.

"If storage developers can lower the cost of the technology to where it becomes economical, then it could change how the energy system operates," says Octaviano. "We wouldn't only be thinking about natural gas as the backup for renewables. They could be assisted by storage instead."

In theory, any energy storage technology could provide this service, but at present most technologies are too expensive to play a large role in the energy market. Octaviano's doctoral thesis estimates the value of energy storage in Mexico's energy market, or in other words how much electricity providers would be willing to pay for it. She does this by modeling how much storage would be needed to support large-scale use of wind and solar power.

"If storage developers can lower the cost of the technology to where it becomes economical, then it could change how the energy system operates."

She is also evaluating the emissions effects of energy storage technologies in Mexico. The benefits are potentially twofold—in addition to enabling more widespread use of renewables, if energy storage becomes a viable backup generation technology, it can eliminate some of the emissions from natural gas.

Creating better future systems

Octaviano's interest in building better energy systems is the result of firsthand experience. Prior to coming to MIT, she developed air pollution regulations for oil and electricity facilities as the Deputy Director of Electricity and Oil Refining at Mexico's Ministry of Environment and Natural Resources.

Part of Octaviano's job was to analyze the costs and benefits of potential regulations based on input from Mexico's state-owned electricity and oil companies, Comisión Federal de Electricidad (CFE) and Petróleos Mexicanos (Pemex), as well as NGOs and academics. During the process, she was struck by the costs resulting from air pollution's effects on human health and infrastructure.

"I spend a lot of time thinking about how to convince people that these technologies are important and worth investing in," she says. "And they are, based on the benefits of cleaner air, and how much we spend fixing these problems."

"Decisions made in the past continue to influence in the present. [I want to] try and make energy systems better so that we don't have these problems in the future."

Working with the parties who would be affected by new regulations, Octaviano saw that many of the problems that now required regulation were created by decisions made decades in the past. The experience made her realize that utility companies—especially state owned ones—didn't want to pollute. They were keenly aware that new regulations would make things very difficult for them, but they were limited by the resources and infrastructure that were available.

"Decisions made in the past continue to influence us in the present, and the repercussions can be very difficult to deal with," Octaviano says. "What I want to do with my research is try to make energy systems better so that people don't have these problems in the future."

After completing her studies at MIT, Octaviano hopes to return to Mexico to work toward developing and incorporating new technologies into the country's energy system.

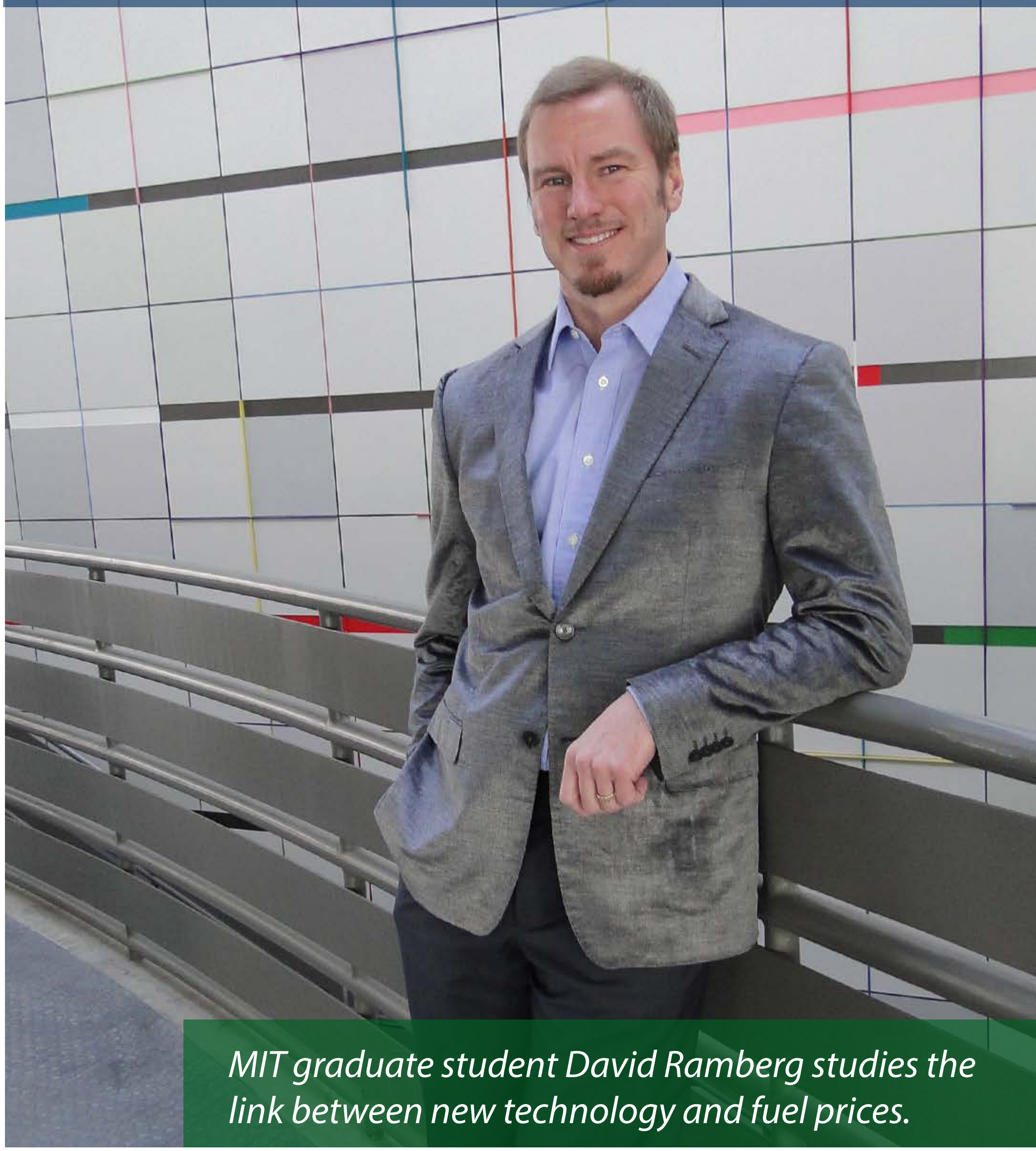
Claudia Octaviano will receive a Ph.D. from MIT's Engineering Systems Division in Spring 2015. She is also a research assistant at the Joint Program on the Science and Policy of Global Change. ■

IN THE NEWS
How global warming can worsen snowfalls

The Boston Globe interviewed Joint Program collaborator Paul O'Gorman, a professor of atmospheric science at MIT, about Boston's historic 2015 snowfall. Gorman is the lead author of a paper published last year in the journal *Nature* that finds that climate change can actually lead to more snowfall in cold regions. Gorman explains that this is due to the increases in the amount of water vapor in the atmosphere, which in cold regions translates into heavier snowfall.

Read the interview: http://mitsha.re/1Q3WDRF

Understanding the Forces Driving Oil and Natural Gas Prices



MIT graduate student David Ramberg studies the link between new technology and fuel prices.

Photo: David Ramberg

Predicting fuel prices is tricky business, since prices regularly fluctuate in response to changes in supply and demand, regulations, political crises, natural disasters, and even changing seasons. MIT graduate student David Ramberg's research adds yet another item to the mix—new technology.

Ramberg studies how new technologies, like Gas-to-Liquids (GTL) plants, affect the prices of oil and natural gas. Although the GTL process itself is not a new technology, GTL plants have been slow to enter the energy market, with the first commercial-scale plants coming online less than a decade ago. As part of his doctoral research, Ramberg integrated GTL refineries into the MIT EPPA Model, the flagship economic research model used at the Joint Program on the Science and Policy of Global Change.

Technology is key to understanding shifts in fuel prices, says Ramberg, whose master's thesis focused on the relationship between oil and natural gas prices. The prices of the two fuels are linked in a pattern based on overlapping infrastructure and production technologies. For years, economists thought this pattern was more or less stable, but Ramberg found evidence that the relationship actually evolves over time.

"Since technology links oil and natural gas prices, I asked myself 'well what happens when you add new technology to the mix?" says Ramberg, who will receive a Ph.D from MIT's Engineering Systems Division this spring. "How does that change the infrastructure, and how does that change how people use fuels? How do these changes affect the prices?"

Wanted: Economist–writer

Ramberg's career as an energy economist began with a help wanted ad. Having just returned to Oregon after a several-year stint backpacking across Latin America, he noticed the ad from a local energy economics consulting firm in the newspaper. It seemed like a natural fit for Ramberg, who had studied economics as an undergraduate. So he answered it.

"The ad was maybe 10 words long, and they were looking for an economist–writer," he says. "I thought, 'I've always wanted to be a writer and I want to be an economist.' So I went in and interviewed."

"I asked myself 'well, what happens when you add new technology to the mix? How does that change the infrastructure, and how does that change how people use fuels?'"

Ramberg got the job and spent seven years at the consulting firm, Economic Insight, Inc., where he wrote a monthly statistical publication on oil data for the West Coast of the U.S. and the Pacific Rim countries. He also wrote and reported as the editor of a daily energy market digest called *The Energy Market Report*.

He continues to work with the firm in his free time. Recently, he consulted on a case before the Federal Energy Regulation Commission (FERC) about a dispute over the pricing of crude oil streams from the Alaska North Slope pipeline. This sort of work informs his research efforts at MIT, he says, in that it gives him a firsthand look at the sorts of decisions facing energy providers.

Practical application

Eventually, Ramberg became interested in understanding the forces at work behind the processes he reported on as a consultant. "I wanted to understand what was driving the markets," Ramberg says. "Why does one commodity cost what it does, while another has a different price?"

He decided to pursue graduate school, first as a masters student in MIT's Technology and Policy Program, and then as a doctoral student, working with the Joint Program. Much of his work as a student is motivated by practical application of economic principles—he chose to study how new technology affects fuel prices because of its immediate relevance for decision-makers.

"Companies want to know, is it going to be worth it to build a new plant?" he says. "The problem is that these plants may run for 30 or 40 years, and companies don't know what fuel prices will be going forward because they're volatile, they're difficult to predict. And the influence that an entire industry of those plants has on prices is difficult to fathom before the industry even exists."

Ramberg cautions though, that focusing exclusively on practical applications is not always the best approach.

"Whenever I learn a new methodology I immediately think about how it could be applied in a practical matter. At the same time, that mindset can blind you to delving into why something works the way it does," he says. "Which is why I'm glad that I'm forced to do that as a student—in the future I'll be able to understand why things work how they do."

After graduation, Ramberg hopes to resume work as an energy consultant, though now with a deeper understanding of the economics behind the energy market.

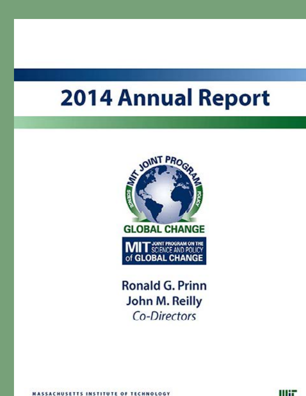
David Ramberg will receive a Ph.D. from MIT's Engineering Systems Division in Spring 2015. He is also a research assistant at the Joint Program on the Science and Policy of Global Change. ■

2014 ANNUAL REPORT: FUTURE DIRECTIONS

In our 2014 Annual Report, released in January, we outlined 7 major research areas for 2015. The list reflects a wide set of diverse capabilities and ongoing efforts.

1. Development of the Integrated Global System Modeling (IGSM) Framework
2. Uncertainty in the Integrated System and risk implications
3. Mitigation policy studies, cost analysis, and policy design
4. Technology, technical change, and issues of the scale of new energy systems
5. Impacts among environmental change, mitigation, and adaptation
6. Links of air pollution to climate, environmental impacts, and mitigation
7. Improved estimation of earth system responses

Read the complete 2014 Annual Report: **http://mitsha.re/1P7D7Bj**



ZEW and MIT Present Joint Project Results in Brussels

By the Centre for European Economic Research (ZEW)

On February 26, 2015, the Centre for European Economic Research (ZEW) and the Massachusetts Institute of Technology (MIT) presented results from an ongoing project, focusing on the topic "CO_2 Regulation of Cars—Truly a Success Story?" during a workshop organised by Adam Opel AG and the Representation of the State of Hessen to the EU. The workshop's main theme was the cost of existing CO_2 standards versus an expansion of the EU Emissions Trading Scheme (ETS) to cover road transportation in the place of a future tightening of existing CO_2 emission standards in the EU for new cars. Over 100 registered participants from the automobile industry, the European Parliament, environmental NGOs, the international research community and regional as well as national representatives took part in the workshop.

Joachim Koschnicke, Vice President of Government Relations and Public Policy Europe from Opel Group, opened the workshop. In the first session, researchers Joshua Hodge and Dr. Sergey Paltsev from MIT presented their research on regulating CO_2 emissions from cars and the economic impacts of CO_2 mandates for new cars in Europe. In a modeling exercise, they found large cost savings from including the transportation sector in the EU ETS instead of regulating new cars by increasingly stringent emission standards. These savings derive from the use of cheaper abatement options in other sectors of the economy under the ETS, but achieve the same overall CO_2 reductions.

Photo: Sergey Paltsev, deputy director, Joint Program on the Science and Policy of Global Change

The second session of the workshop was led by Professor Andreas Löschel, ZEW Research Associate and Professor at the University of Münster. He discussed the practical feasibility of incorporating road transport in the ETS to realise the potential efficiency gains for the European economy. A fully integrated ETS would cover 60 percent of European CO_2 emissions. He argued that in practice, it would be most cost efficient to include road transport by requiring fuel suppliers to hold emission allowances corresponding to the emissions from the fuel sold. The impact on the price of emission allowances would likely be relatively small in the short term, but rise steeply in the longer term, when the more expensive abatement measures found in transportation are required to achieve long term emission reduction goals.

The workshop finished with a lively panel debate and Q&A session with the audience, discussing innovation incentives for the automobile industry, technological potential, and effects on the EU's global competitiveness. The panel consisted of Dr. Richard Smokers (The Netherlands Organisation for Applied Scientific Research, TNO), Philip Owen (European Commission), Dr. John Reilly and Prof. John Heywood, PhD (MIT), Prof. Dr. Andreas Löschel (ZEW and University of Münster) and Jens Gieseke (Member of the European Parliament). ■

Photo: Holger Krahmer, member of the European Parliament, 2004–2014 (left) and John Reilly, co-director, Joint Program on the Science and Policy of Global Change (right).

Land and Water Resources: Looking into the Future

On Wednesday, April 29 and Thursday, April 30 the Joint Program on the Science and Policy of Global Change hosted a workshop on land and water issues. The two-day event featured sessions on a range of topics related to future resources. See below for the full agenda.

Wednesday April 29

Scientific Overview

9:00–9:45 A.M. Climate science and the importance of land/water impacts (Ronald Prinn)

9:45–10:30 A.M. Land and water in socioeconomics (John Reilly)

Setting the Stage: Bridging the Key Science and Socioeconomic Elements

11:00–11:45 A.M. Earth-system components (Adam Schlosser)

Overview of existing capabilities and recent developments

11:45–12:30 P.M. Economic components (Sergey Paltsev)

The session will focus on an overview of the existing capabilities of the MIT Joint Program's energy-economic model (MIT EPPA) with a particular focus on energy, land, and water issues. A structure of the model, major applications, and recent developments will be presented.

Water Resource System (WRS)

2:00–3:30 P.M. Introduction to the IGSM-WRS: Global & US assessments of water stress (Ken Strzepek)

This session will describe the history and scope of the WRS component of the IGSM and how it fits within the IGSM framework, and its key performance indicators as the foundation of published analyses of the impact of global change on water stress at the global and continental US scale. Recent enhancements in municipal and industrial water use, thermal cooling and water quality components for the US will be presented. Ongoing developments on energy water use (hydropower, thermal and fuel extractions) and incorporation of more economics of water management decisions will be presented as well as the major new effort of using IGSM-WRS in the Africa Energy Futures Project.

4:00–5:30 P.M. Future water-risk and risk-reduction options: Case studies in Asia & Africa (Adam Schlosser)

The IGSM-WRS framework has been designed to provide quantitative assessments of risks in future water resources due to climate and socioeconomic changes. A synthesis of recent research results will be presented to demonstrate the IGSM-WRS framework's ability to perform large ensembles that cover a range of future policy scenarios as well as the uncertainty in the climate and economic drivers on both the supply and demand sectors of large, managed river basins. Additional remarks and results will provide further insights toward adaptation strategies.

Thursday April 30

Land-Energy Resources

9:00–9:45 A.M. Agricultural markets and biofuels (Niven Winchester)

This session examines what large-scale global bioenergy might look like. This is accomplished by representing multiple bioenergy feedstocks and conversion technologies in an economy-wide model and imposing a global carbon price.

9:45–10:30 A.M. Environmental impacts of land-use change (Qudsia Ejaz)

This session will discuss the land use changes and the resultant carbon emissions for two different scenarios for biofuel consumption targets in the US using EPPA and the Terrestrial Ecosystem Model (TEM). We use this exercise to illustrate the current and potential linkages between the economic and terrestrial ecosystem models.

Land-Agricultural Resources

11:00–11:45 A.M. Crop modeling (Erwan Monier)

This session will introduce the crop model development that is underway at the Joint Program and place it within our agriculture modeling framework. Concrete examples of how the crop model will be used for climate impact assessment under climate change uncertainty and for the study of the Food-Water-Energy nexus will be presented.

11:45–12:30 P.M. Irrigation demand and food production (Élodie Blanc)

This session considers the effect of climate change (under two greenhouse gas emission scenarios and two climate change patterns) on water and its consequences on irrigation of the three most important crops for the US: maize, soybean, and spring wheat.

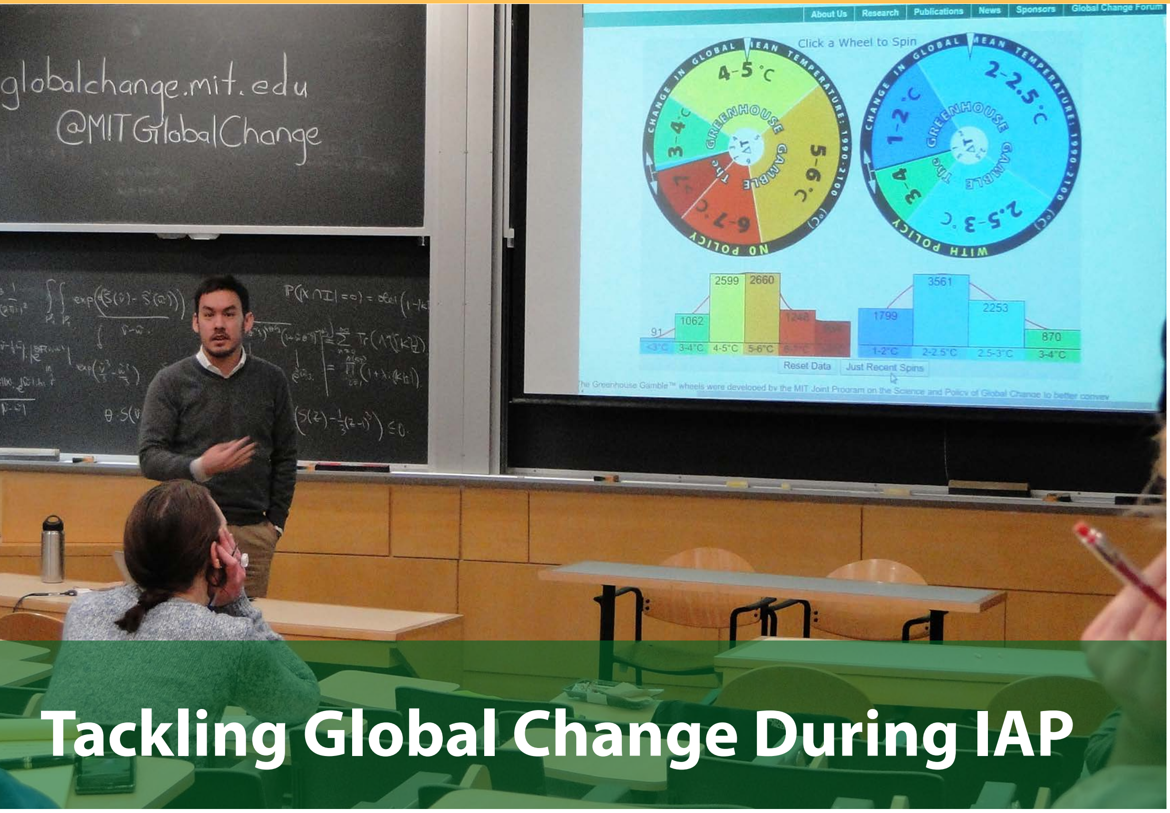
Extreme Events

2:00–2:45 P.M. Tropical storms and the risks of landfall (Sai Ravela)

2:45–3:30 P.M. Extratropical systems and the use of extreme analogues (Xiang Gao)

This session describes our recently developed analogue method which is based on the resolved large-scale atmospheric conditions to detect the occurrence of extreme precipitation events. The method is then evaluated for its performance against the model-simulated precipitation over the US and further employed to assess the potential future shifts in the probability of extreme precipitation under two scenarios.

4:00–5:00 P.M. Wrap up/Going Forward (John Reilly)



Tackling Global Change During IAP

Photo: Paul Kishimito

Graduate students from the Joint Program on the Science and Policy of Global Change taught a series of classes in January as part of MIT's annual Independent Activities Period (IAP) that were designed to bring students and community members up to speed on basic climate science, climate policy, and the state of international climate negotiations.

International climate action

Amanda Giang, a graduate student in the Engineering Systems Division, led a session on January 30 on recent climate negotiations. Climate change is a vexing international problem in part because it is a commons problem—a type of problem which many graduate students may already be familiar with, she said.

A dirty kitchen is an example of a commons problem, said Giang, who has roommates. "We all share the kitchen, so it's in no one's best interest to clean the kitchen alone. If I clean the kitchen myself, I have to do all the work while everyone gets the benefit. But if no one cleans the kitchen we all suffer. What we really need is some sort of coordinated collective action, where I take out the trash and my roommate does the dishes."

Because of this, an international agreement is the best route for action. Giang reviewed the recent history of global climate negotiations, including the UN's efforts leading up to the next round of talks in Paris this winter, where countries are expected to come to an agreement on post-2020 climate action. Giang also discussed existing greenhouse gas mitigation efforts in the US and China, and the recent emissions deal between the two countries.

Economic measurements

Paul Kishimoto, a graduate student in the Engineering Systems Division, led sessions on January 29 and January 30 on the economics of climate change and climate policy.

Economists measure the effects of climate change as costs, both direct and indirect. As an example, Kishimoto asked the class to consider how statistically warmer weather might affect a runner who goes jogging on the Charles. If the runner goes jogging when it's too hot and gets heat stroke and has to go to the hospital, it is a cost directly related to climate change. If the runner avoids running and misses out on an activity that they would otherwise do, it's counted as an indirect, or counterfactual, cost of climate change. Calculating both the costs of climate change and the costs of policies allows researchers to evaluate the effectiveness of policies addressing climate change, he said.

Kishimoto also discussed how different types of policies aimed at reducing greenhouse gas emissions work, including measures like carbon taxes and trading plans, regulations, and policies encouraging research and development of new technology.

Climate science measurements

Daniel Gilford and Jareth Holt, graduate students in the Department of Earth, Atmospheric and Planetary Sciences, led a session on January 29 on how climate scientists measure climate change.

Gilford started the class out by explaining the concept of radiative forcing, which is a measure of the net difference between the energy the Earth and atmosphere absorb from sunlight, and the energy released back into space after a change in the atmospheric composition (such as increasing CO_2). A change that traps more heat in the Earth system is a positive radiative forcing and contributes to warming. The primary gas causing increased radiative forcing is CO_2, but other gases like methane, nitrous oxide, and ozone also play a role.

Holt discussed how climate models account for factors that affect radiative forcing. To do this, models have become more complex, he said. For example, in the 1990s, climate models underestimated the importance of aerosols in calculating radiative forcing, and had simple representations. Models now have more detailed representations of how aerosols behave in the atmosphere.

On the other hand, there are reasons why researchers might want to simplify models. Modern climate models use supercomputers, Holt explained, and can take weeks or even months to make one simulation. Simpler models run more quickly, and allow researchers to complete a larger number of simulations, helping to understand the uncertainty in the climate system. As a result, climate modeling requires constant balancing between complexity and computational efficiency.

Climate fundamentals

Gilford and Holt led a session on January 26 covering basic climate science, and the history of the discipline. Climate science, Holt said, is the study of variability, patterns, and statistics over time.

The field can trace its roots back to the 1820s, when Joseph Fourier discovered that the Earth's atmosphere traps heat. The modern study of climate change got its start in the 1890s when Svante Arrhenius built the first simple model balancing energy in the Earth system. He determined that adding CO_2 to the atmosphere traps energy, causing warming, which is a principle still used by climate scientists today.

Gilford and Holt also explained what makes a gas a greenhouse gas. The Earth's atmosphere is made of mostly nitrogen and oxygen, but those gases absorb almost none of the energy given off by the Earth's surface. Instead, small amounts of other gases, like water vapor and CO_2, trap the most energy. Other gases like methane and nitrous oxide are present in even smaller amounts, but because they strongly absorb energy at different wavelengths than CO_2 and water vapor, they can also contribute dramatically to warming. ■

Indian Environment Minister Visits the Joint Program

Prakash Javadekar, the Indian Minister of Environment, Forests and Climate Change, visited MIT on April 16 to meet with the Joint Program on the Science and Policy of Global Change. Discussions focused on issues in ongoing international climate negotiations, with a particular interest in rising coastal risk related to climate change. Discussions on environmental data gathering technology were also held.

The visit was hosted by Sai Ravela, a principal research scientist in the Department of Earth, Atmospheric and Planetary Sciences. Ravela's work with the Joint Program focuses on quantifying the risk to coastal infrastructure from hurricanes, storm surge and flooding. Additionally, his work includes developing low-cost autonomous instruments for atmospheric investigations.

"It was a pleasure to host Mr. Javadekar," says Ravela. "Our discussion with the minister delved into the facts of the UN climate meeting in Paris this fall and several other issues related to the environment. It was a very lively, insightful discussion."

Among the topics of discussion was India's electricity generation mix.

"Of particular interest was the minister's discussion of India's commitment to build 185,000 megawatts of renewable and other low carbon electricity capacity over the next five years as part of its contribution to mitigating climate change," says John Reilly, co-director of the Joint Program.

The meeting was also attended by faculty and students from departments and centers across MIT, including Earth Atmospheric and Planetary Sciences, Civil and Environmental Engineering, Mechanical Engineering, Economics, and the Tata Center for Technology and Design. ■

Campus Events

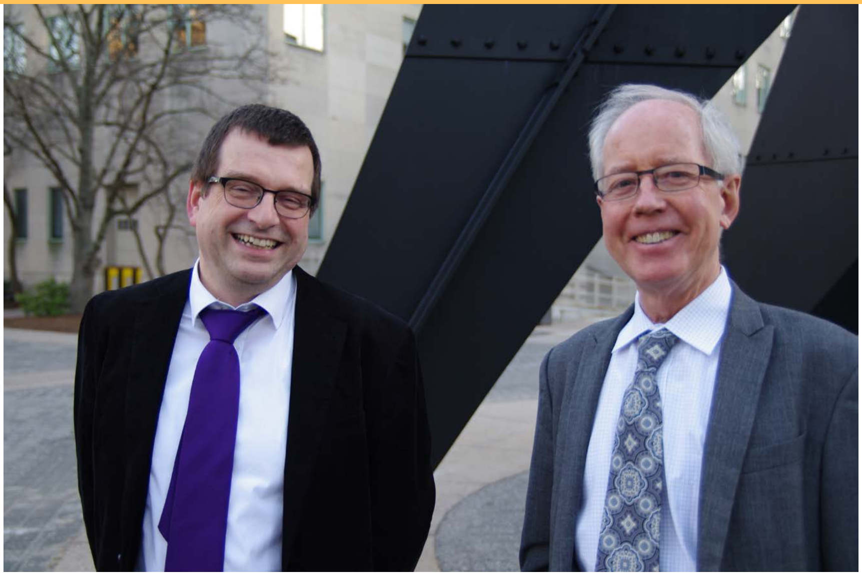


Photo: Jochem Marotzke and Ronald Prinn after the 15th Annual Henry W. Kendall Memorial Lecture; courtesy of Helen Hill

15th Annual Henry W. Kendall Memorial Lecture—Recent Global Temperature Trends: What do they tell us about anthropogenic climate change?, April 15, 2015

Jochem Marotzke, director of the Max Planck Institute for Meteorology in Hamburg, Germany, presented the 2015 Henry W. Kendall Memorial Lecture on Wednesday, April 15. Marotzke's talk was titled "Recent Global Temperature Trends: What do they tell us about anthropogenic climate change?" He discussed the implications of the recently-observed slowdown in global warming, often referred to as a warming "hiatus." The Henry W. Kendall Memorial Lecture Series introduces the MIT community to leading researchers in the field of global-change science. The Kendall Lecture is sponsored by the Joint Program partner program the Center for Global Change Science and the Department of Earth, Atmospheric and Planetary Sciences.

Pricing Carbon to Combat Climate Change: What Can We Learn from British Columbia?, April 13, 2015

Mary Polak, British Columbia's minister of environment, presented remarks followed by panel discussion with perspectives from government, industry, advocacy, and academia. Panelists included: Christopher Knittel, MIT professor and director of the MIT Center for Energy and Environmental Policy Research; Robert C. Armstrong, director of the MIT Energy Initiative; Susanna Laaksanen-Craig of the British Columnian Climate Action Secretariat; Massachusetts State Senator Michael Barret; Ross Beaty of the PanAmerican Silver and Alterra Power Corp. and Merran Smith of Clean Energy Canada. The event was hosted by the MIT Energy Initiative.

Photo: (Left to right) Anthony Janetos, director of the Frederick S. Pardee Center for the Study of the Longer-Range Future ; John Reilly, co-director of the MIT Joint Program on the Science and Policy of Global Change; and Boston University President Robert Brown attend a forum on fossil fuel divestment.

The Economic and Social Impact of Climate Change, April 2, 2015

John Reilly spoke at a forum on the impacts of climate change hosted by the Boston University Board of Trustees' Advisory Committee on Socially Responsible Investing. The committee explored the issues surrounding climate change and divesting from fossil fuels. Reilly's presentation focused on the effects of global climate change and possible solutions.

Reconciling Energy Security, Climate Policy and Prosperity? An Assessment of the German Energy Transition, March 31, 2015

R. Andreas Kraemer, senior fellow with the Institute for Advanced Sustainability Studies (IASS) and a well-known expert on German energy and climate policy, spoke about German's Energiewende, or energy transition.. A. Denny Ellerman, formerly of the the MIT Sloan School of Management, served as a discussant. The debate was hosted by the MIT Center for Energy and Environmental Policy Research, a Joint Program partner program.

MIT Climate Change Conversation

Photo: An aerial view of MIT. Courtesy of MIT Communication Production Services.

MIT's Climate Change Conversation, launched in Fall 2014, aims to foster open, campus-wide conversation about how MIT can lead in confronting climate change. The initiative is hosted by the MIT Climate Change Conversation Committee, which draws its membership from all categories of the MIT community. Both Henry "Jake" Jacoby, Joint Program co-director emeritus, and Anne Slinn, Joint Program executive director for research, serve on the committee. The group hosted a series of events during the spring semester as part of its mission to establish campus-wide conversation.

Should MIT Divest? A Debate on Fossil Fuel Investment, April 9, 2015

The debate, held in Kresge Auditorium before hundreds of attendees from MIT and elsewhere, featured two teams of experts in a classical debate format who addressed the contentious issue of whether MIT should shed its investments in fossil-fuel companies. Participants discussed a proposed elimination of oil, gas, and coal companies from the endowment portfolio.

Photo: Henry "Jake" Jacoby spoke at the MIT Climate Change Conversation's March 12 event focused on MIT's carbon footprint.

Getting Through on Global Warming: How to Rewire Climate Change Conversation, March 31, 2015

This panel discussion identified and examined communication strategies that MIT and others can employ to shift the global climate debate and inspire action. Panelists included: John Durant, director of the MIT Museum; Kerry Emanuel, a professor of atmospheric science at MIT; Susan Hassol, the director of Climate Communication, a non-profit science and outreach project; Judith Layzer, a professor of environmental policy at MIT; Chris Mooney, an environmental writer at *The Washington Post*; and Drazen Prelec, a professor of management and neuroscience at MIT.

Creating the Roadmap: Envisioning/Reducing MIT's Carbon Foodprint, March 12, 2015

This event invited all members of the MIT community to envision and shape the roadmap to a lower-carbon institute. Attendees took part in a series of talks, polling questions, and brainstorming sessions aimed at spurring the MIT community to engage in the process of making the institute a world leader for how campuses can work to reduce their carbon footprint.

One Man's Journey to Climate Activism: A Talk with Larry Linden, January 21, 2015

Larry Linden, former White House advisor in the Carter Administration and a partner at Goldman Sachs, spoke on campus in the opening event of the MIT Climate Change Conversation. He urged his audience to join him in making the issue a top priority—and in pushing elected leaders to take concrete action now, before changes to the world's atmosphere and oceans become irreversibly damaging. The most effective approach, he emphasized, is putting a price on carbon emissions from fossil fuels.

New Projects

Impact of Energy and Water Policy on Sustainable African Economic Development

Project Leader: John Reilly

This project will evaluate the economic and technical potential of renewable-based power systems in Africa under a trading regime. Linking hydropower generated in river basins across the continent has the potential to smooth annual and seasonal fluctuations in hydropower output and enable larger penetrations of intermittent renewable energy technologies. With this in mind, the study seeks to address how different levels of power systems integration may affect development of the generation mix by midcentury and deployment of low-carbon technologies, in particular, electricity prices, and the reliability of electricity supply. It will also address what critical projects can enable greater power system integration; the types of institutional and market mechanisms that must be in place to enable cross-border trading; how vulnerable the African Power Grid is to climate change and variability; and finally, if there is an optimal regional scale for power pool integration.

Source: UNU-Wider (United Nations University World Institute for Development Economics Research)

Will New Limits on Coal Use in China Reduce Toxic Air Pollutants across Asia?

Project Leaders: Valerie Karplus, Noelle Selin

This project quantifies the contribution of newly-enacted Chinese domestic policies to control coal use , and estimates changes in mercury deposition and ambient air quality in China and the greater Asian region. Switching from coal to cleaner sources of energy has the potential to reduce precursors to ozone and particulate matter as well as mercury emissions, but leaves emissions of other precursors unaddressed. To study these dynamics, this project undertakes a combination of empirical analysis and application of advanced modeling techniques. It uses a combination of econometric estimation and modeling approaches to quantify the early impact of China's Air Pollution Action Plan and related policies, and project impact on the energy system, emissions, and air quality through 2020. Researchers will further focus on changes in coal demand across Asia as Chinese domestic demand and prices fall, and the resulting regional impacts on mercury deposition and air quality. Outputs from this project will include new analysis of the impacts of recent air quality policies in China as well as reports that summarize findings for policymakers. Through direct researcher interaction with stakeholders involved in air pollution policy in mainland China and globally, results will inform the policy process by demonstrating how decisions link to environmental outcomes.

Source: MIT Environmental Solutions Initiative Seed Grant

Concrete Sustainability Hub

Project Leader: Adam Schlosser

The environmental impact of pavements and the economic challenge of building and maintaining them have led to a growing need to better quantify performance and cost over pavements' entire life cycle. To meet that need, the MIT Concrete Sustainability Hub (CSHub) is developing tools and data for decision-makers to evaluate pavement designs and make choices that are both cost-effective and environmentally responsible. The project aims to reduce the environmental impact of concrete, both in its manufacturing and use.

Source: MIT Concrete Sustainability Hub

Coming and Going

Vincent Chang joined as a visiting researcher from Peking University.

Chas Fant left for an appointment with United Nations University in Cape Town, South Africa. He continues to work part time with the Joint Program.

Paul Kishimoto is remaining on and will be pursuing a doctoral degree in MIT's Engineering Systems Division.

Claudia Octaviano received a doctoral degree from MIT's Engineering Systems Division.

David Ramberg received a doctoral degree from MIT's Engineering Systems Division.

Rebecca Saari received a doctoral degree from MIT's Engineering Systems Division.

Summer Zhao received a master's degree from MIT's Technology and Policy Program.

Newly-Released Joint Program Reprints

2015-4: Benefits of greenhouse gas mitigation on the supply, management, and use of water resources in the United States, *Climatic Change*

2015-3: Analysis of coastal protection under rising flood risk, *Climate Risk Management*

2015-2: Behavior of the aggregate wind resource in the ISO regions in the United States, *Applied Energy*

2015-1: Double Impact: Why China Needs Coordinated Air Quality and Climate Strategies, *Paulson Papers on Energy and Environment*

2014-27: Coupling the high-complexity land surface model ACASA to the mesoscale model WRF, *Geoscientific Model Development*

2014-26: Understanding predicted shifts in diazotroph biogeography using resource competition theory, *Biogeosciences*

2014-25: Antarctic ice sheet fertilises the Southern Ocean, *Biogeosciences*

Newly-Released Joint Program Reports

Report 279: Emulating maize yields from global gridded crop models using statistical estimates

Report 278: The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption

Report 277: Renewables Intermittency: Operational Limits and Implications for Long-Term Energy System Models

Report 276: Specifying Parameters in Computable General Equilibrium Models using Optimal Fingerprint Detection Methods

Report 275: The Impact of Advanced Biofuels on Aviation Emissions and Operations in the U.S.

Report 274: Modeling Regional Transportation Demand in China and the Impacts of a National Carbon Constraint

Report 273: The Contribution of Biomass to Emissions Mitigation under a Global Climate Policy

Report 272: Advanced Technologies in Energy-Economy Models for Climate Change Assessment

Report 271: International Trade in Natural Gas: Golden Age of LNG?

Peer-Reviewed Studies/Pending Reprints

Firm-level determinants of energy and carbon intensity in China*, Energy Policy*

An Analogue Approach to Identify Heavy Precipitation Events: Evaluation and Application to CMIP5 Climate Models in the United States*, Journal of Climate*

Costs of reducing GHG emissions in Brazil*, Climate Policy*

A self-consistent method to assess air quality co-benefits from U.S. climate policies*, Journal of the Air & Waste Management Association*

Joint Program In the News

http://globalchange.mit.edu/news-events/news

May 7, *CBS News*, Why solar is critical to confronting climate change

April 28, *The Christian Science Monitor*, In 2014, economies grew, emissions did not

April 24, *BloombergBusiness*, Ethiopian Nile Dam Study Warns on Safety, Urges Cooperation

April 22, *The New Republic*, Fear in a Handful of Dust

April 6, *The Japan Times*, On the right path, China must cut coal reliance

April 4, *Financial Review*, Why China should make cutting coal power its No. 1 goal

March 18, *The Washington Post*, Top hurricane expert: Climate change influenced Tropical Cyclone Pam

March 4, *Foreign Policy*, Don't Get Caught Up in the Air Pollution Hype

March 2, *Scientific American*, China's War on Air Pollution May Cause More Global Warming

February 16, *USA Today*, Oil will flow like milk and honey. Here's why.

February 4, *The Boston Globe*, How global warming can worsen snowfalls

January 15, *Greenwire*, Imposing a carbon price would spur bioenergy, slash emissions—MIT study

January 31, *The New York Times*, Climate Change's Bottom Line

January 31, *Reuters*, Rocket blasts off with NASA satellite to track climate change

January 29, *Christian Science Monitor*, New satellite to help NASA predict floods and droughts

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Cover image: Celery field in Salinas, California

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