GLOBAL CHANGES

MIT Joint Program on the
Science and Policy of Global Change

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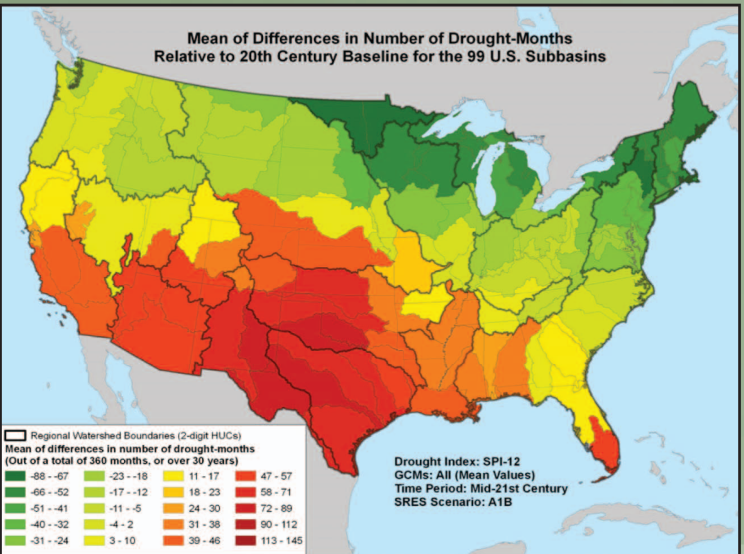


Mean changes in the number of drought months relative to the 20th century baseline for 2036-2065 along the A1B (moderate emissions) scenario.

Spring 2011 Newsletter

Contents

Around the Joint Program...

A team of Joint Program students, including Tim Cronin pictured here, created a winning proposal for the Climate CoLab Contest. As a winning team, student representatives briefed the United Nations and US Congress in December.

In January, students Paul Kishimoto and C.W. Gillespie, along with eight of their fellow students, led four Independent Activities Period sessions on climate change science and policy.

Valerie Karplus defended her doctoral thesis "Climate and Energy Policy for US Passenger Vehicles: A Technology-Rich Economic Modeling and Policy Analysis" on February 23, 2011.

GLOBAL CHANGES

The Joint Program integrates natural and social science to produce analyses relevant to climate and energy policy debates

April 21 Panel Discussion

Rethinking Climate Change: The Past 150 Years and The Next 100...

4:00p–6:00pm, Wong Auditorium, MIT E51-115

A panel discussion looking back at the last 150 years of climate research and rethinking the way forward. In celebration of the 150th anniversary of MIT, the 20th anniversary of the establishment of the MIT Joint Program on the Science and Policy of Global Change, and the 40th anniversary of Earth Day.

Moderated by: **Dr. John Reilly**, Senior Lecturer, Sloan School of Management; Co-Director of the MIT Joint Program on the Science and Policy of Global Change

Panelists:
Professor Kerry Emanuel, Breene M. Kerr Professor of Atmospheric Science, Department of Earth, Atmosphere and Planetary Science; Director of the Program on Atmosphere, Oceans, and Climate
Professor Ronald Prinn, TEPCO Professor of Atmospheric Science; Director of Center for Global Change Science; Co-director of the MIT Joint Program on the Science and Policy of Global Change
Professor Christopher R. Knittel, William Barton Rogers Professor of Energy Economics, MIT Sloan School of Management
Professor Ernest Moniz, Cecil and Ida Green Professor of Physics and Engineering Systems; Director of the MIT Energy Initiative
Professor Sarah Slaughter, Associate Director for Buildings & Infrastructure, MIT Energy Initiative

April 30 MIT 150 Open House

Confronting the Climate Change Challenge

11:00am- 4:00pm, MIT Campus, Between buildings 54 and 56 (http://whereis.mit.edu)

This year, MIT recognizes its 150th anniversary with 150 days of celebration. The centerpiece of the MIT 150 celebration is a formal academic event on April 10, 2011 to recall the 1949 Mid-Century Convocation and to celebrate the scholarly accomplishments of MIT faculty and students.

In conjunction with the Cambridge Science Festival, a campus-wide Open House on April 30th will highlight work being done in MIT's departments, labs, and centers through small-format lectures, tours, demonstrations, and other interactive programs. Particular emphasis will be on showcasing the work of MIT students and sharing the excitement of discovery.

The MIT Joint Program, in collaboration with several other energy and environmental groups around campus, will have special exhibits located just outside building 56, rain or shine. Hands-on activities and demonstrations will help to visualize the current state of climate knowledge and what Earth will look like when MIT is 300 years old. Students and researchers from a wide range of expertise will be on hand to answer questions and discuss global change issues.

June 22–24 XXXII MIT Global Change Forum

Rethinking Global Change

Cambridge, MA

Session Topics include:

- The Scientific Evidence for Environmental Change
- Energy Security
- Managing Agricultural Resources
- Managing the Threats to Ecosystems
- Environmental Change and the Future of Cities
- The Road from Cancun

Forum attendance is by invitation only.

News and Events

New students

Justin Caron (Doctoral, Visiting Student from ETH Zurich, Reilly) Environmental and energy economics; CGE modeling; international trade

Arthur Gueneau (Masters, Schlosser) Impact of climate change on agriculture

Devin Helfrich (Masters, Parsons)

Paul Kishimoto (Masters, Webster) Designing a smart electrical grid

Robin Locatelli (Visiting Student from National School of Meteorology Toulouse, Rigby & Prinn) Chemical transport models and 'inverse' estimates of trace gas emissions

Tanvir Madan (Masters, Reilly) Electrification in end-use sectors

New employees

Ignacio Perez Arriaga, Visiting Professor to ESD from Upcomillas University

Carlos Batlle, Visiting Scholar to CEEPR from Upcomillas University

Ho-Jeong Shin (Post-Doc, Wang) Anthropogenic aerosol-cloud-climate interactions

Tammy Thompson (Post-Doc, Selin) Atmospheric pollution and human health

Niven Winchester, Environmental Energy Economist

New positions/ promotions

Loren Cox was promoted to Deputy Executive Director for Resource Development

Frances Goldstein was promoted to the Assistant to the Co-Directors for Sponsor Relations

Tony Smith-Grieco was promoted to Assistant to the Co-Directors for Project Management

Erwan Monier was promoted from Post-Doc to Research Scientist

Graduated and Departing Personnel

Elodie Blanc, former visiting student, returned to New Zealand in February

Henry Chen, former Post-Doc working on modeling the poly-generation of fuels in the MIT EPPA model, took a new position with the World Bank in December

Claire Gavard, former visiting Doctoral student from Ecole Polytechnique (Palaiseau, France), returned to Electricité de France in December and will continue work with Denny Ellerman

Joaquim Giulhoto, former visiting professor, returned to the University of São Paulo, Brazil in January

Valerie Karplus defended her PhD thesis "Climate and Energy Policy for U.S. Passenger Vehicles: A Technology-Rich Economic Modeling and Policy Analysis" on February 23, 2011

Special Announcement

EPPA (version 4) is now available for public download

The Joint Program has made available to the public a version of the economic component of its Integrated Global System Model, the Emissions Prediction and Policy Analysis (EPPA) model. This will make transparent the model's structure and assumptions, and allows other researchers and organizations the opportunity to build upon the model's methods and approaches. The model code is available for free, for non-commercial and academic use only.

EPPA is a sophisticated multi-sector, multi-region computable general equilibrium (CGE) model of the world economy. EPPA projects economic variables (GDP, energy use, sectoral output, consumption, etc.) and emissions of greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) and other air pollutants (CO, VOC, NOx, SO_2, NH_3, black carbon, and organic carbon) from combustion of carbon-based fuels, industrial processes, waste handling, and agricultural and other land use activities.

For more information, please visit:
http://globalchange.mit.edu/igsm/eppadl.html

Report 189: Modeling the Global Water Resource System in an Integrated Assessment Modeling Framework: IGSM-WRS

Researchers enhance the IGSM's capability to model the effects of climate change on water resource systems, improving our ability to explore adaptation strategies

Through linking the Water Resource System (WRS) and the Integrated Global System Model (IGSM), researchers from the Joint Program and the International Food Policy Research Institute have enhanced the ability to model the effects of climate change and related hydrological shifts on water resource systems. WRS is a global river basin scale model of water resource management, agriculture, and aquatic environmental systems.

Linking the WRS to the IGSM will provide the capability to explore allocation of water among irrigation, hydropower, urban/industrial, and in-stream uses—thereby allowing for more comprehensive analysis of the impacts of climate change on managed water resource systems. Importantly, this modeling advancement will improve our ability to explore possible adaptation responses to climate change and its effects on water resource systems.

by Danya Rumore

Report 190: Climatology and Trends in the Forcing of the Stratospheric Zonal-Mean Flow; and Report 191: Climatology and Trends in the Forcing of the Stratospheric Ozone Transport

Stratospheric circulation is an important component of climate models

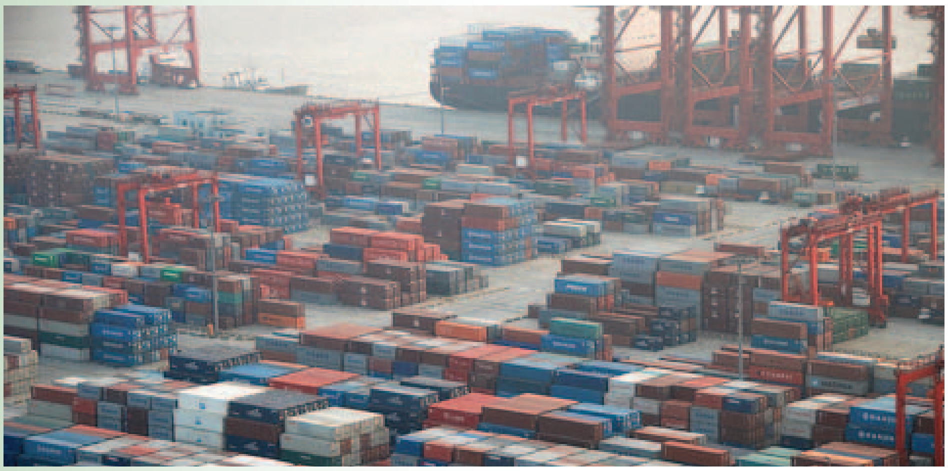
Understanding the dynamics and variability of the stratosphere (the layer of Earth's atmosphere just above the troposphere, between 10 and 50km in altitude) is becoming increasingly important to climate modelers. Few climate models simulate stratospheric processes accurately— partly because its complexity makes it hard to model and partly because stratospheric impacts on the troposphere (the part of Earth's atmosphere closest to the surface) were once thought to be minimal. But recent studies have shown that the stratosphere can affect the troposphere. Therefore, understanding stratospheric dynamics and variability is necessary to fully appreciate the potential impact of the stratosphere on climate change, and the impact of climate change on the stratosphere.

In Report 190, researchers Erwan Monier (MIT Joint Program) and Bryan Weare (UC Davis) calculate a budget of the many different forces that drive stratospheric circulation. They found that one of the terms in their calculations, which described multiple small-scale processes, was dominated by gravity waves. Gravity waves are waves that are formed when two masses of air with different densities collide— like when cool air over the ocean hits warm air over land or when the movement of an air mass is impeded by a mountain. These gravity waves transfer momentum from the troposphere to the stratosphere and have not historically been well represented in climate models. However, this study suggests that they are important to understanding stratospheric dynamics. A second finding of this study was that ozone depletion has a significant impact on stratospheric winds, and this impact can drive a positive feedback cycle that causes further changes in wind strength.

In Report 191, the researchers explored changes in stratospheric ozone transport between 1980 and 2001. They found that the amount of ozone in the stratosphere is determined not just by the amount of ozone-destroying chemicals present, but by the balance between this chemical destruction and the transport of ozone. Ozone transport is determined by both stratospheric circulation (mean transport) and stratospheric waves (eddy transport). Eddy transport acts as the eggbeaters of the stratosphere, mixing chemicals in all directions. The report found that without the increase in eddy transport that occurred between 1980 and 2001, the ozone hole over Antarctica would have been drastically more severe. Both these reports highlight the need to improve stratospheric modeling efforts to better gauge impacts on climate change.

Report 192: The Impact of Border Carbon Adjustments under Alternative Producer Responses

How effective are border carbon adjustments at addressing leakage and competitiveness concerns?



When one country decides to unilaterally implement climate legislation, there is concern that the emissions reduced locally will result in an increase in emissions elsewhere, with no net reduction in greenhouse gases. This phenomenon, known as leakage, can happen in two ways. First, if climate policies in one country or a group of countries reduce the global price of fossil fuels, countries without restrictions may increase their energy consumption. Second, some energy-intensive production could relocate to areas without restrictions, highlighting the sort of competitiveness issues that arise when only a subset of nations restricts emissions.

One of the methods of addressing the leakage and competitiveness issues that arise in these situations is through border carbon adjustments. Border carbon adjustments are tariffs that one or more nations with climate policies place on the emissions embodied in imports from nations without climate policies.

Border carbon adjustments have been proposed in climate legislation, such as the 2009 Waxman-Markey Bill. This bill proposed border carbon adjustment provisions on energy-intensive imports from countries that do not have an economy-wide climate policy at least as stringent as in the US.

But just how effective are these policies at addressing leakage and competitiveness concerns? "Border carbon adjustments are a controversial issue in international climate negotiations," says Dr. Niven Winchester, author of a recent report by the MIT Joint Program on the Science and Policy of Global Change that examines the impacts of border carbon adjustments. "This study evaluates producer responses to border carbon adjustments that have not been considered previously, and provides important information for policymakers", Winchester explains.

The report calculated the emissions embodied in a traded good by adding the direct emissions from fossil fuel use and the indirect emissions from electricity used in production. Dr. Winchester then modeled different scenarios in which a "coalition" of countries established a cap-and-trade policy that restricted their emissions, but a "non-coalition" of countries did not. Finally, the analysis considered several different producer responses to border carbon adjustments.

The report found that if the producers of goods in non-coalition countries viewed the border carbon adjustments as an emissions tax and operated a separate production line for each market, leakage was reduced by about one-third. When non-coalition firms operated a single production line for all markets, firms reduce the emissions content of all energy-intensive production and leakage decreased by 80%.

However, though this last scenario had the highest reduction in leakage, it also resulted in the lowest level of production of energy-intensive goods in coalition countries. This means that policymakers may face a trade-off between leakage and competitiveness concerns.

The study also considered a scenario in which non-coalition countries implemented a cap-and-trade policy. The model results showed that leakage could be completely eliminated with only a modest emissions cap in non-coalition countries. Though this is very unlikely in the near future, it does suggest that border carbon adjustments could serve as a coercion devise in global climate policy negotiations.

Report 193: What to Expect from Sectoral Trading: A US – China Example

The impacts on emissions and welfare of including sectoral trading in international climate policies

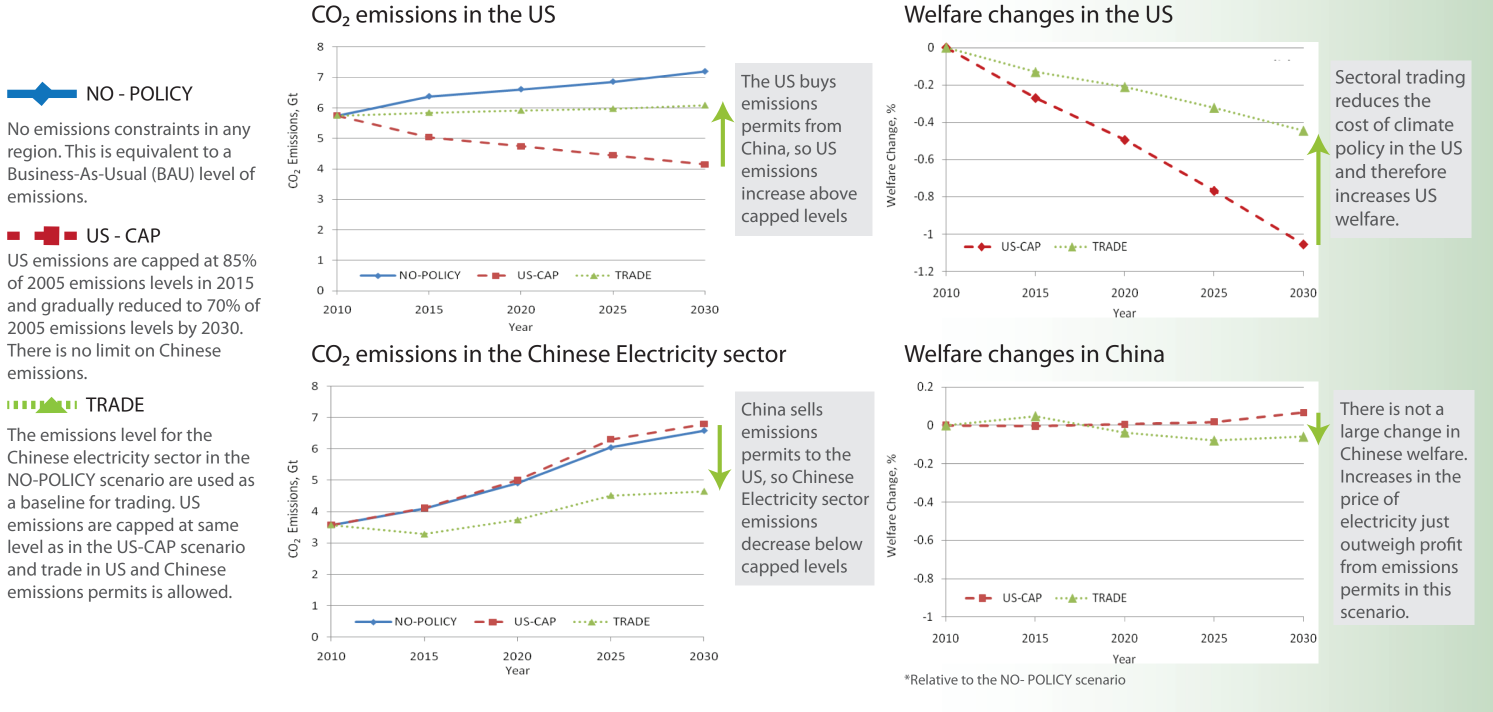
Including developing countries in an international climate agreement is vital to the success of mitigation efforts. One method of promoting early action and wider participation by developing countries is through sectoral trading. Sectoral trading involves including a specific sector, the electricity sector for example, of a nation without emissions constraints into the cap-and-trade program of another nation or group of nations. Though this measure would be less efficient than a global cap-and-trade system, it would encourage nations to participate in international climate agreements without making their own nation-wide commitments.

Using an economic model called the Emission Prediction and Policy Analysis model (EPPA), researchers at the MIT Joint Program on the Science and Policy of Global Change analyzed the potential impacts of sectoral trading. "Sectoral measures have been widely discussed in policy circles, but very few studies have investigated the outcomes from sectoral trading. This study addresses this shortcoming and provides important information for policymakers," explains Dr. Niven Winchester, lead author of the study. Specifically, the researchers observed the results of allowing emissions permits to be traded between an economy-wide US cap-and-trade system and a sector specific cap on Chinese electricity emissions.

Sectoral trading would allow the US to buy carbon permits from the Chinese electricity sector, creating a common carbon price in the two countries. Without trade, the carbon price in the US would be \$105 per ton of CO_2 in 2030. But by allowing trade, the common price would be \$21/tCO_2 in 2030—an 84% decrease in price for the US. US prices decrease as high-cost domestic abatement measures are replaced with low-cost options in the Chinese electricity sector.

As the US buys emissions permits from China, US emissions increase above their capped levels and Chinese electricity emissions decrease below their capped levels. The financial transfer from the US to China for the purchase of the permits is valued at \$42 billion in 2030 (for perspective, the total value of exports from the US to China in 2009 was \$69 billion).

Sectoral trading reduces the cost of the climate policy in the US by more than half in 2030 and increases US welfare. However, though China benefits from



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the financial transfers from the US, the constraint on emissions in the electricity sector also decreases Chinese welfare, since a rise in electricity prices would increase production costs. In the scenario analyzed in the MIT report, welfare losses in China were not outweighed by the financial transfer from the purchase of permits. This means that, to entice China to participate in sectoral trading, the US may have to make financial transfers to China greater than the value of the permits purchased.

These results are specific to the US and China. Considering a different combination of countries, especially one with smaller markets than the Chinese electricity sector, would likely yield very different results. The researchers at the MIT Joint Program also looked at sectoral trading scenarios between the European Union Emissions Trading Scheme (EU-ETS) and electricity sectors in China, India, Brazil, and Mexico. The results showed a high level of trade between the EU and China and India, with purchased permits making up more than 50% of the reductions in EU emissions in 2030. In contrast, the EU purchased permits from Brazil and Mexico for less than 4% of 2030 emissions.

The results of this study indicate that outcomes from sectoral trading depend on the nations involved. Policymakers must also consider the implications of the fact that, though sectoral trading reduces the sector-specific carbon content of the nation without emissions constraints, it also causes emissions to increase in those nations with cap-and-trade systems.

Reprint 2010-10: Competition for Water for the Food System

Researchers model the effects of competition for global water resources on agriculture.

As the globe's population increases and people become wealthier, agricultural production will need to likewise increase. But food systems may become more stressed because of a competition for water, according to a new study on various threats to agricultural water supply released by the MIT Joint Program on the Science and Policy of Global Change.

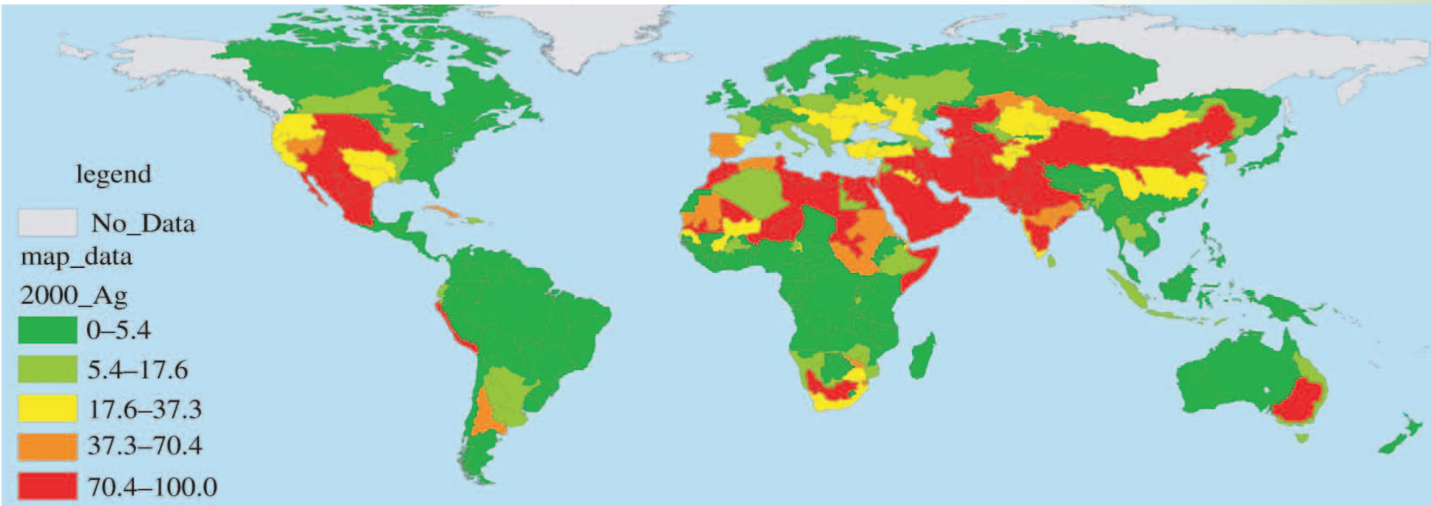
The study found that the biggest threat to future water availability for agriculture comes from environmental flow requirements. These requirements ensure that the appropriate water levels needed for a healthy aquatic ecosystem are maintained. But environmental flow requirements, especially when combined with other competition for water resources, can create geographic hotspots of severe water scarcity.

Already, competition for water comes from demands for energy generation and growing urban populations. As water scarcity increases and river-basin supplies are put to full use, more and more water will be diverted from agricultural use. Added to this is the expected growth in population, which will tax water availability and food supply. Furthermore, the growing population is also getting wealthier, meaning more people will demand services that use more water and will shift to diets that consist of water-intensive products. All of this will lead to greater water demand on a per-capita basis, particularly in developing nations.

The MIT study examines three specific factors that may threaten agricultural water availability in the future. The first factor is increased demand for water in municipal and industrial uses, including for domestic and commercial purposes and for use in manufacturing, energy generation or other industrial

Surface irrigation system using siphon tubes. Photo: Dan Ogle/USDA

Although the global agricultural system will need to provide more food for a growing and wealthier population in decades to come, increasing demands for water and potential impacts of climate change pose threats to food systems.



This figure shows the percentage of surface water run-off that was withdrawn for agriculture in 2000. Areas where water is used most intensively for agriculture (e.g. the Middle East, central Asia, western US) are most vulnerable to changes in water supply and competing demands.

activities. The increase in water use in these sectors is driven by rising populations and increasing per capita income, but will vary widely across different countries. The exact relationship between per-capita water use and per-capita GDP often depends on the development path of a particular nation.

For example, developing nations such as India and China will likely experience dramatic increases in water use. As per-capita income rises, the way in which people access water will evolve from traditional methods, such as rainwater catchments and public standpipes, to modern services, such as individual household plumbing. Developed countries, on the other hand, may experience a flattening of water consumption with respect to income. As nations like the U.S. and Switzerland introduce water-efficiency measures, per-capita water use may actually decline.

The second factor the MIT study modeled was environmental flow requirements, which regulate a minimum flow of water to allow for the maintenance of aquatic ecosystem services, including considerations for floodplain maintenance, fish migration and water quality. Imposing water flow minimums, while crucial for some ecosystem demands, may cause the demand for water to exceed supply in river basins within the Middle East, central Asia and southern Europe.

The third factor modeled by the study is the impact of climate change on water availability. Climate change can affect the water available for agricultural use through changes in temperature, precipitation and the magnitude and frequency of extreme events. The combination of these climatic impacts will affect the supply of water — in the form of run-off — in different ways around the world. For example, models predict that run-off will increase in eastern equatorial Africa under a warmer climate, while in southern Africa run-off would decline. Rising temperatures will also increase water demands for domestic uses, including garden and lawn watering, thermoelectric cooling in power plants, and electricity generation to meet increased use of air conditioning.

Researchers modeled the effects these three factors would have on agricultural water availability, assuming increased demands were met by the transfer of water currently used for agriculture. The study found that meeting environmental flow requirements presents the biggest threat to agricultural water availability, with the second-largest threat coming from increased municipal and industrial demands.

> In areas with growing populations and income, water demands are projected to increase by more than 200 percent by 2050. When combined, increases in demand for water from municipal and industrial uses and environmental flow requirements cause an 18-percent reduction in the water available for agriculture globally.

Climate change alters the distribution of water supply. Therefore, climate change can increase the threat to agriculture in some areas, such as Africa, Latin America and the Caribbean, and decrease the threat in others, such as North America and Asia.

The effect of competition for water creates dramatic geographical hotspots where water resources available for agricultural purposes are threatened. Such hotspots include northern Africa, India, China, parts of Europe, the western U.S., and eastern Australia — areas that already tend to experience water scarcity. Competition for water may pose significant threats to future food systems in these regions.

Reprint 2010-11: Costs of Mitigating Climate Change in the United States

What's the price of environmental policies? Why do proposals for climate change legislation often have varying and wildly different cost estimates?

A key element in the evaluation of recent climate legislation is an understanding of how much a policy will cost if implemented. Multiple studies have been conducted to determine the costs of proposed emissions reductions in the US. But different studies have resulted in a wide range of estimated costs, even for similar climate policy targets. For example, nine independent cost estimates for the 2009 Waxman-Markey Bill, which would reduce emissions in the US primarily through a cap-and-trade system, ranged from $69 to $808 per household in 2020— a staggering 12-fold difference in the price of the policy. This example highlights the puzzling disparities that arise when evaluating the costs of climate change mitigation.

A recent report from researchers at the MIT Joint Program on the Science and Policy of Global Change sheds some light on the reasons behind such wide variations in cost estimates.

The report focuses on two causes for disparate model outcomes: 1) the use of different cost measures and 2) different assumptions used to determine the amount of emissions reductions required to meet a policy target.

First, some of the differences in cost estimates can be attributed to modelers using different measures to quantify costs. In other words, there is no consistent or conventional way to measure the costs of climate policies.

Table 1 outlines several commonly reported cost measures, which have specific uses but also limitations. In principle, this source of disparity could be eliminated, but economists, policymakers, and analysts will likely continue to use the measures they favor. Regardless, cost estimate studies should clarify that different cost measures, such as changes in welfare, consumption, GDP, or personal income, are not comparable—even though they can be put in a common unit, such as dollars per household.

Table 1. Cost measures used in policy cost calculations

Measure	Description	Uses	Issues
Emissions Price	A price on GHG emissions in units of $ per metric ton of CO2 or CO2-e, established through a market or with a tax	Measures the marginal cost of each additional unit of emissions reductions	Misleading when other policies considered; not a measure of total economic cost; does not convey volume of emissions reductions
Welfare Change	Total economic cost measured in dollars or units of percent change	Considers GHG price, volume of emissions reductions, effect of other policies; includes changes in labor and leisure time	Though often preferred among economists, potentially less understood by non-economists
Consumption Change	The change in macroeconomic consumption measured in dollars or units of percent change	A measure of cost similar to welfare change but does not include leisure time	Similar to welfare change; excluding the value of leisure time will result in higher cost values than welfare change
GDP Change	Economic activity [consumption + investment + government + (exports - imports)] measured in $ or units of percent change	Most familiar metric to general audiences; a measure of output	Output not necessarily a measure of consumption; metrics are not comparable to consumption and are less relevant; can lead to double-counting of costs
Per-capita or per-family costs	Consumption or GDP change in absolute dollars divided by population or number of households, measured in units of $ per capita or $ per household	A compelling metric to the average person or family; can be compared with GDP per capita	Similar issues to consumption change and GDP change
Discounted costs	Future costs measured in units of present day dollars, calculated with a discount rate	Often used to evaluate aggregate cost over the lifetime of a policy in current dollars units	The value of the discount rate used will greatly affect results and the appropriate rate is highly contentious
Marginal Abatement Cost Curve (MAC)	The relationship between the number of tons of emissions abated and the CO2-e price	The area under the MAC curve provides an estimate of total cost of abatement	Does not capture distortion costs or terms-of-trade effects; "negative" marginal costs can be a misleading to economy-wide policies

Second, when projecting the costs of legislation, assumptions have to be made on how much emissions will need to be reduced in the future to reach a climate policy target. Because policies that address climate change are necessarily long-term endeavors, small assumptions made from the beginning of legislation implementation can be magnified over the time span of the cost estimate study. This means that small initial differences in assumptions can result in large differences between end results.

In particular, assumptions are made that reflect fundamental economic uncertainties, undetermined policy implementation details, and the complex effect of other complementary policies. The MIT Joint Program study, using the Emissions Predictions and Policy Analysis (EPPA) model, established a consistent framework to test the influence of different assumptions on policy cost calculations. Six areas of uncertainty, upon which assumptions have to be made to calculate policy costs, are illustrated to the right.

The broad range of cost estimates of meeting proposed climate legislation in the US contributes to confusion in policy discussions. Even if the disparities that arise from using different cost measures were eliminated, much of this range in cost estimates would still exist. Some uncertainties may be reduced, by for example defining policy implementation details. But others, like projecting economic activity or the availability of alternative technologies over long time horizons, are irreducible. Regardless, greater care and transparency is needed when comparing cost estimate results.

Table 2. Assumptions considered in policy cost calculations

1. How does the cost estimate model economic growth?

Emissions are highly correlated with economic output, but future economic growth is uncertain. A smaller economic growth rate would mean fewer emissions, and an easier path to reaching a climate target. A higher economic growth rate would mean more emissions, thus a more difficult, and costly, path to reaching a climate target.

2. What will the availability and cost of alternative technologies be in the future?

In many cases it is assumed that technologies like carbon capture and sequestration, renewable wind or solar energy, or advanced nuclear fuel will not be cost effective until carbon prices are high. However, assuming that any one of these options becomes very inexpensive in the future, or conversely, that none of these options become cost effective, greatly varies policy cost estimates.

3. How many offsets will be allowed in the policy?

Some climate policies allow producers to offset a portion of their emissions by investing in projects that reduce emissions outside the jurisdiction of the legislation. Allowing offsets often lowers the cost of reaching a climate target. Though uncertainties in the actual amount of credits allowed would eventually be defined by the policy, the effectiveness of the credit program remains uncertain and can affect policy costs.

4. What is the policy time horizon and how will it treat banking of allowances?

If entities are allowed to cut emissions more than required in the short term and bank those extra cuts for use towards compliance in later periods, when costs may be higher, then the near-term costs of the policy would appear more expensive. However, if entities predict the emergence of cheap alternative energy technologies or think the long-term goal is too lofty to be achieved, they may not bank allowances, making near-term costs appear less expensive.

5. Does the legislation contain complementary policies?

Renewable portfolio standards and other regulations subsidiary to a cap-and-trade system drive costs up. The effect of building codes and appliance standards that address market failures is ambiguous, though these options are not likely to be free. Finally, policies that invest in infrastructure that will be in higher demand as energy prices rise, such as public transportation, can bring down climate policy costs. The combination of the effects of these policies on the cost of climate legislation is complex.

6. Are other policies considered in the cost estimate?

In general, accounting for other non cap-and-trade policies that reduce emissions lowers policy cost estimates because fewer emissions need to be reduced to meet the climate target. In the US, accounting for emissions reduced through the Energy Independence and Security Act of 2007 or the American Recovery and Reinvestment Act of 2009 reduces the estimated costs of the Waxman-Markey Bill.

Reprint 2010-12 and 2010-13: Adaptation Costs and the Future Price of Water

How much will it cost to adapt to climate-induced changes in water supply and demand?

Two related articles, recently released from the MIT Joint Program on the Science and Policy of Global Change, use new approaches to explore the costs incurred on the water sector by climate change.

Despite growing recognition of the importance of climate change adaptation, few global cost estimates separate the costs attributed to climate change from the expected future investment in water supply infrastructure. The MIT studies identify the total costs of regulating water infrastructure to meet future water demands without climate change, and then observe how those costs change under different climate change scenarios—thereby realizing the additional climate change adaptation costs to the water sector.

The two studies found that, though climate change will cause the availability of water to increase in some parts of the world and decrease in others, the costs on water infrastructure attributed to climate change is small in comparison to the baseline costs needed to meet non-climate related demand.

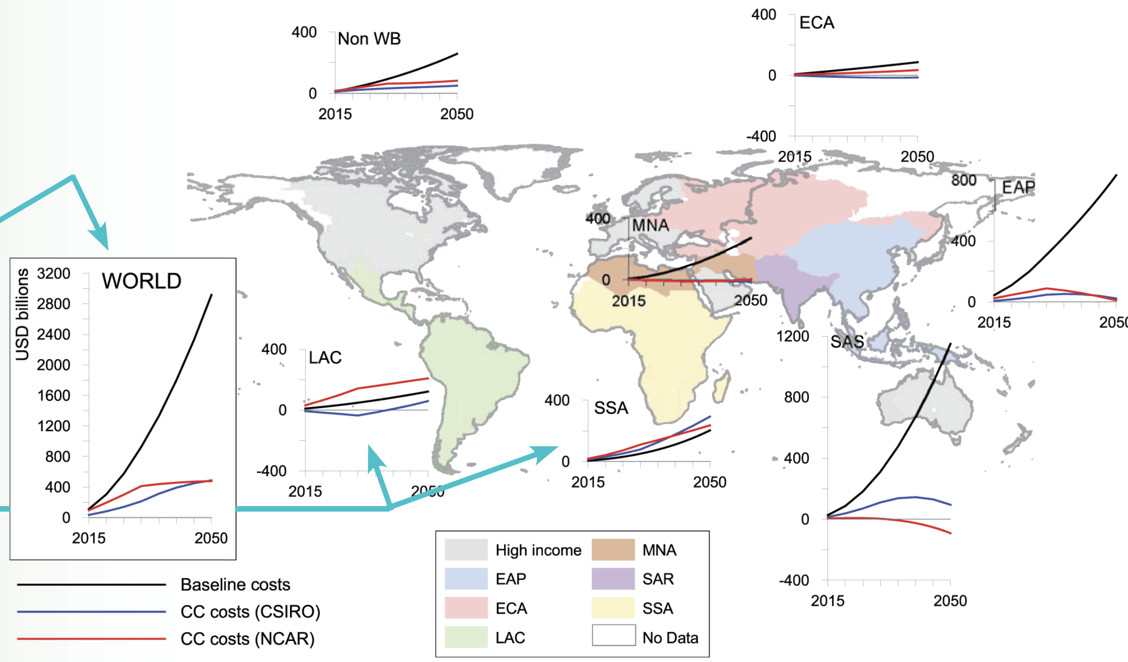
In the first article, the authors focus on OECD countries, where the costs of adapting the water sector to climate change are believed to be substantial. However, researchers found that the total cost of adaptation to climate change in 2050 is less than 2% of the total cost of regulating water service infrastructure in OECD countries, though there are regional differences. The majority of adaptation costs are due to increases in total water demand, particularly for municipal uses.

This cost estimate is based on an engineering solution that would increase supply to meet the increased demand. But the problem could also be addressed with an economic solution. A market-based approach that ensures water use does not increase with future climate change would convert the overall costs of adaptation from an average of $5 billion a year to a net saving of more than $7 billion a year for all OECD countries.

The second article models global adaptation costs with a primary focus on the World Bank's six development regions, which are areas that are particularly vulnerable to the impacts of climate change. The study looked at the costs of meeting increased municipal and industrial water demands by

Global baseline costs are high compared to the climate change adaptation costs.

There are two regions in which adaptation costs are greater than baseline costs, namely Sub-Saharan Africa (SSA) and Latin America (LAC).



increasing the storage capacity of surface reservoirs or by using a combination of alternative backstop measures, like recycling, rainwater harvesting, or desalination.

This study estimated average global climate adaptation costs between 2010 and 2050 at approximately $12 billion a year. The majority of these costs would be incurred in developing countries with the largest costs, namely Sub-Saharan Africa and Latin America. However, global baseline costs of maintaining and operating future water supply infrastructure would be approximately $73 billion a year— far exceeding the climate adaptation costs. This supports the notion of mainstreaming climate change adaptation into broader policy aims.

Both studies provide valuable tools for estimating broad costs of adaptation to climate change for the water sector at the global and regional level, which is of key importance for international negotiations.

Cumulative adaptation costs (in $2005 bn) in the industrial and municipal water supply sectors for the period 2010–2050. The results are aggregated and displayed for the World Bank development regions (East Asia and Pacific (EAP); Europe and Central Asia (ECA); Latin America and Caribbean (LAC); Middle East and North Africa (MNA); South Asia (SAS); and Sub-Saharan Africa (SSA)), and for countries not belonging to one of these regions (high income).

Reprint 2010-14: Characterizing changes in drought risk in the US

Increased drought risk suggests substantial benefits for greenhouse gas emissions reductions

Changes in precipitation and temperature caused by increased CO_2 emissions will increase the frequency and severity of droughts throughout much of the contiguous United States, suggests a recent study led by MIT Joint Program on the Science and Policy of Global Change researcher Ken Strzepek.

But defining "drought" can be tricky. Drought can be defined as extreme events produced by decreased rainfall, low reservoir levels, and reductions in soil moisture. In agriculture, it can also be defined as the difference in water supply and crop demand. In years of normal precipitation levels, warm temperatures would increase water demand and crops could still be water stressed. However, those same warmer temperatures may be accompanied by more winter precipitation and thus more snowmelt runoff to fill reservoirs, mitigating a potential drought.

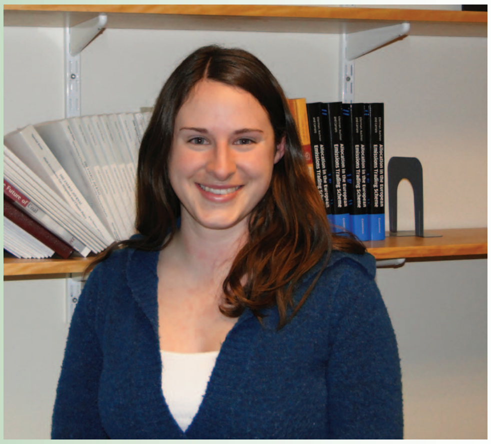
To analyze the impacts of climate change, researchers applied two different methods of measuring drought. The first method is called the Standardized Precipitation Indices, and uses meteorological data to measure how precipitation in a given time and region has changed from past measurements. The second method is called the Palmer Drought Severity Index, and uses hydrological data of both precipitation and temperature to measure changes in soil moisture

Model projections indicate that climate change's impact on drought frequency and severity will vary by region and will depend upon the level of future greenhouse gas emissions. Higher CO_2 concentrations are generally associated with increased drought frequency and severity throughout the United States. This finding supports the hypothesis that climate change mitigation may play a key role in reducing future drought risk.

Model results indicate that the Southwestern U.S. and Rocky Mountain states are likely to experience the largest increases in drought frequency due to climate change. The hydrological method of measuring drought showed that climate change tends to turn events that might currently be mild droughts into long periods of severe or even extreme droughts. This is important for policymakers considering adaptive responses, as current measures to manage droughts may be overwhelmed by large changes in the expected severity of future droughts. While the authors suggest that exploiting existing excess water storage capacity or reservoir yield may be able to ameliorate the negative impacts of increased drought, they caution that greater research is needed in this area to identify basins where such opportunities exist.

The average cost of droughts in the US is estimated to be between $6 billion and $8 billion annually—a number that will only increase as water shortages become more frequent. Advancing our understanding of drought modeling, this study demonstrates that the use of different measures of drought (i.e. meteorological drought vs. hydrological drought) in climate change modeling generates different projections and distributions of drought frequency, pointing to the importance of using multiple indices in future studies of drought risk.

by Danya Rumore



Jennifer Morris tackles uncertainty in climate policy analysis

Joint Program student Jen Morris is interested in climate policy. As she puts it, she likes "the nitty-gritty details of policy design: what are the components in a climate bill and how would they interact?"

Now a doctoral student working with advisor John Reilly, Jen completed her M.S. in the Technology and Policy Program at MIT in 2009, and has been part of the Joint Program for almost four years. Studying climate policy options in the context of the US, she has largely focused on using EPPA—the Emissions Predictions and Policy Analysis model— to gain insight into the likely costs and impacts of developments in renewable energy technology and climate policies.

Currently, Jen's research is taking a new direction: she is now working to better represent uncertainty in policy analysis models such as EPPA. As she explains, "One of the main challenges in the models we use is how we capture all of the important uncertainties, such as: 'How is the economy going to grow?' and 'What is the cost of future technologies going to be?'". According to Jen, her work will "more formally incorporate uncertainty analysis into models such as EPPA, so that we can more fully explore the range of possibilities and possible futures."

Improving how policy and economic models such as EPPA represent uncertainty isn't simply an academic exercise. As Jen explains, EPPA and other such models are used to inform policy and decision-making. For this reason, improving how these models represent the uncertainty involved in real world decision-making will allow them to "do an even better job of helping provide information to policy-makers about what potential policies might do and what kind of impacts they might have. And that is the goal."

As for her experience working with the Joint Program, Jen says "it is such an excellent place to be because it is so well established and so well respected in the realm of climate change and climate change analysis…I've been here for about four years now and I'm loving it!"

by Danya Rumore

Arthur Gueneau models potential impacts on agricultural yield

A Masters student in MIT's Technology and Policy Program, Joint Program research assistant Arthur Gueneau studies the impacts of climate change on agriculture and water resources. Originally from France, Arthur is driven by the question: "How do we feed the world? How do we feed nine billion people in 2050?" This is a particularly important question given changing climatic conditions.

Seeking to improve our understanding of how climate change will impact future agricultural yields and irrigation need, Arthur (with colleague Chas Fant at the University of Colorado) recently finished validating a new model, called CliCrop, which calculates crop yields based upon climatic information. To do this, he plugs historical meteorological data for a given year into CliCrop and then compares the model's projected crop yields with actual crop data that was recorded in that year. By comparing the model's outputs with actual historical crop yield data, Arthur can verify how accurately the model calculates agricultural yield based upon climatic variables, such as precipitation and temperature.

His findings for far? "The model seems to be relevant; it seems to be working."

Now that CliCrop is validated, the next step will be to insert global climate projections into the model to see how future changes in precipitation and temperature may affect regional agricultural yields and irrigation demand. Improving our understanding of how climate change will impact crop production throughout the world will allow us to better prepare for the effects of 'climate stress' on the food system and to develop new policies and adaptation strategies accordingly.

When asked about his work with the Joint Program, Arthur says, "I love what I am doing because it is really interesting

to try to understand the future impacts of our policies." For this reason, he plans to continue studying the potential impacts of climate change on water and agriculture and is particularly interested in exploring possible adaptation strategies for increasing agricultural resilience to climate stress.

by Danya Rumore

Dan Chavas asks how meteorological changes affect hurricane size

A self-described 'weather geek', doctoral candidate Dan Chavas is fascinated by hurricanes. More specifically, he is interested in what factors influence hurricane development and how large a given storm will become. As he describes, "right now, we have no capacity to predict how big or small a hurricane will be. Sometimes they're big; often they're small. I am trying to understand the mechanisms and processes that determine the size of a particular hurricane."

Using weather models, Dan is investigating how specific changes in meteorological conditions impact the final size of an eventual hurricane. By relating initial weather conditions to the final storms that they produce, Dan hopes to improve our ability to predict how large forming storms will eventually become. "If we can predict that," he explains, "it's useful because these storms impact people's lives—they make landfall and destroy things, and a bigger storm affects a bigger area." By allowing us to predict the final size of a forming storm, Dan's work may enable us to better prepare for and respond to emerging hurricanes. As both the frequency and intensity of severe weather events could increase with climate change, this predictive capacity may become increasingly important.

Discussing his work, Dan describes hurricane research as an "open area," saying, "There is a lot of research to be done in the field, which makes it kind of exciting… we still don't really understand how hurricanes form; we are not very good at predicting when they are going to get stronger or weaker. There are a lot of fundamental things that we don't understand still." For this reason, he may continue to study how hurricanes develop after completing his doctorate. However, Dan is also interested in the policy side of things and would like to work at the nexus where science meets decision-making. For now, Dan is enjoying his work with the Joint Program and being involved with "a lot of interesting people doing a lot of interesting work."

by Danya Rumore

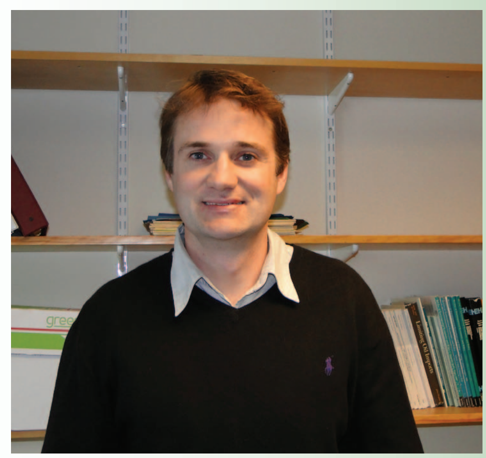
Niven Winchester investigates economic impacts of climate policy

A visiting scientist since June 2009, Niven Winchester has officially joined the Joint Program as an Environmental Energy Economist. A native of New Zealand, Niven broadly focuses his research on evaluating the economic costs and impacts of climate change policies and new technologies. Currently, he is interested in how climate policies affect what is called 'leakage': the shifting of greenhouse gas emissions from nations with stricter climate policies to countries without climate policies.

One proposed policy option for reducing this 'leakage' is to impose border carbon adjustments, such as tariffs on embodied greenhouse gases. For example, nations with climate policies may place a tax on imported goods to adjust for the greenhouse gases that would have been emitted if the products had been produced domestically. Interested in the effectiveness of this type of policy, Niven is exploring how tariffs actually impact leakage, and at what economic costs (See Report Summary 192 on Page 5).

To examine the effects of policies like carbon tariffs, Niven and his colleagues in the Joint Program employ large-scale models of the world's economy, "building up, layer-by-layer, pieces of information about different aspects of the climate story, about different technologies or different policies" in order to understand how policy changes and technological developments will impact both greenhouse gas emissions and the economy.

Niven's work suggests that carbon tariffs can cause significant economic distortions and may not be good for overall economic activity. Based upon these findings, Niven reasons that encouraging nations without climate policies to adopt minor efficiency actions—rather than imposing carbon tariffs on imported goods from these nations—will likely be a more cost-effective way of reducing greenhouse gas emissions, particularly in developing countries.



Given the lack of political progress on federal climate policies, Niven and his colleagues are now shifting their focus toward analyzing alternative policies, such as bio-fuel mandates and state-level programs. According to Niven, the modeling framework can not only be employed to analyze the impacts of particular technological developments or climate policies, but it also "can be used to look at the impact of climate change if we don't do any action."

by Danya Rumore

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