The Carbon Issue
Cover image

A farmer burns rice straw prior to planting wheat, in Sangrur District, Punjab, India. Machine-harvested rice leaves long stalks in the ground that need to be cut down and disposed of before wheat can be planted. With low nutritional value as a livestock feed, and little time between rice harvesting and wheat planting, burning the rice residues is widespread in the region.

Photo credit: Neil Palmer, CIAT International Center for Tropical Agriculture.

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On the importance of a long-term perspective to climate policy.
In October we had a celebration at the Royal Swedish Academy of Sciences – the home of IGBP's Secretariat – to acknowledge our longstanding relationship with Sweden. Many Swedish scientists played a formative role in IGBP's early years and continue to make important contributions to global-change research. Sweden has been a stable and generous funder of our activities. The celebration provided an opportunity to recognise the contributions of individuals and institutions in Sweden, and to reminisce on the accomplishments of the past decades.

We would also like to acknowledge our close collaboration with two of the global-change programmes. The International Human Dimensions Programme on Global Environmental Change (IHDP), which closed in June this year, co-sponsored two of our core projects and encouraged and empowered social scientists to address environmental change. DIVERSITAS, which will formally close at the end of this year, has consistently drawn attention to biodiversity and ecosystem services. Many core projects of both programmes are expected to transition to Future Earth, thus ensuring that the vibrant research in these areas will continue unhindered. We will continue to work closely with those communities as we plan our own transition.

In September this year, the Global Carbon Project released its annual carbon budget in advance of the climate summit in New York. As always, the budget was well received with several articles in high-profile journals and media across the world. In this issue of the magazine we look at not only the carbon budget but also other dimensions of carbon: the greening of Australia, peak greenhouse-gas emissions in China and the mitigation of black carbon. While it is the explicit focus of the Global Carbon Project, carbon is the subject of study, directly or indirectly, of all of our core projects. Some projects explore it in terms of ecosystems, sources and sinks, some in terms of models and past processes, and others in terms of air pollution. When synthesised, this information provides a comprehensive picture of the carbon cycle and its anthropogenic modification.

Speaking about synthesis, we continue to work on our landmark synthesis that is expected to be complete by the end of next year. We now have first drafts of papers on the Anthropocene that will form part of a special issue. We also have first drafts of a series of papers that take stock of the achievements and outlook of our core projects. Finally, a commentary on risk is about to be submitted for publication and a paper on Earth-system science is in the making. All of this and more will be presented at IGBP's landmark synthesis event at the American Geophysical Union (AGU) conference in December 2015.

The event will celebrate IGBP's contributions to science, policy and capacity via several transdisciplinary sessions, a young scientists' event, a reception and other activities. Members of our core projects and national committees, past and present, are expected to attend in full force. We are working closely with AGU to make this event a success. We welcome everyone from the IGBP and global-change communities and hope many of you will be able to attend.

In the next and final issue of this magazine we will take a retrospective look at IGBP's scientific and other accomplishments over the years and look ahead to the changing landscape of global-change research and policy. Stay tuned!
New director at World Climate Research Programme

DR DAVID Carlson has been appointed the new director of the World Climate Research Programme (WCRP). He was formerly Director of Atmospheric Technology for the US National Center for Atmospheric Research and is currently serving as Chief Editor for Earth System Science Data. Dr Carlson directed the International Programme Office for the International Polar Year 2007-2008.

IGBP secretariat staff changes

IN SEPTEMBER this year, Office Manager Charlotte Wilson ended her formal association with IGBP to embark on a career as a consultant. Charlotte joined IGBP in 1999 and facilitated several key achievements throughout the years including IGBP’s first synthesis and the Planet Under Pressure conference. She will continue to assist with IGBP tasks from her new office in Irvine, Scotland. Finance Coordinator Britta Boström left IGBP in October this year to take up a new position. Britta joined IGBP in 2005; her skills and experience were instrumental in meeting reporting requirements and the timely completion of projects. We wish both Charlotte and Britta the very best in their future endeavours. We also welcome Linlin Olsson as the new finance coordinator. Linlin has worked with major businesses and comes with extensive financial experience.

UNFCCC scientific meeting

THE 40TH session of the Subsidiary Body for Scientific and Technological Advice (SBSTA) took place 4-15 June 2014 in Bonn, Germany. IGBP Executive Director Sybil Seitzinger presented the latest findings from the four global environmental change programmes at the meeting, which provides a forum for climate negotiators to discuss the science. The presentations focused on climate extremes and integrated scenarios for biodiversity and climate.

IHDP closes

ON 30 JUNE, the International Human Dimensions Programme on Global Environmental Change (IHDP) closed its doors after 24 successful years. IHDP was a close and valuable partner: it co-sponsored several IGBP core projects and participated in numerous collaborative activities including major conferences and workshops. Most of IHDP’s projects have already initiated the transition to Future Earth.

Dearing wins Murchison Award

JOHN DEARING, a longstanding member of IGBP’s Past Global Changes project, has been awarded the prestigious Murchison Award (2014) by the Royal Geographical Society (UK). Dearing was chosen to receive the award in recognition of his “publications contributing to the understanding of environmental change”.

US, China agree to cut carbon emissions

ON 11 NOVEMBER this year, US President Barack Obama and China’s President Xi Jinping announced a bilateral deal, negotiated in secret, to combat climate change. The deal came only days before the annual G20 summit in Brisbane.

Obama pledged to bring US net greenhouse-gas emissions to 26-28% below 2005 levels by 2025. Jinping said he would steer China on a course for CO₂ emissions to peak around 2030 and increase the non-fossil-fuel share of all energy to around 20 percent by this date.

FIVE GLOBAL HUBS FOR FUTURE EARTH

THE SECRETARIAT for the new, ten-year research initiative Future Earth has been announced. The preferred bidder is an international consortium of lead organisations from Canada, France, Japan, Sweden and the United States. The new secretariat was announced by the International Council for Science on behalf of the members of the Science and Technology Alliance for Global Sustainability (the Alliance).

Over 20 expressions of interest were received for the secretariat. Following a two-day bidders’ conference hosted in Paris, consolidated final bids were reviewed on the basis of their vision, capability, organisational model and management plan and funding.

Future Earth’s secretariat (http://www.futureearth.org/secretariat) will span three continents with five global hubs. These hubs will be complemented by a number of regional hubs in Latin America, Asia, Europe and the Middle East. Discussions to develop an African hub are under way, with plans in other regions also under consideration.

More information, key contacts, and statements from members of the Alliance are available on the ICSU website (www.icsu.org).
The news, which came as a surprise to most, was met with jubilation at first. But this quickly turned to concern when the numbers were crunched.

The Global Carbon Project’s Corinne Le Quéré said, “The best these commitments may be able to do is move the world away from the extremely high levels of climate change that we are currently on track for.”

Most commentators agree the deal is a signal to the markets and other nations about the possibility of an ambitious deal at COP 21 in Paris next year.

Changes ahead for the core projects

THE IPO of the Integrated Land Ecosystem - Atmosphere Processes Study (iLEAPS) will move from Finland to China in 2015 to be hosted by Nanjing University and the Jiangsu Provincial Collaborative Innovation for Climate Change (CIC3). Tanja Suni, who has helped to develop the project over the past few years, will stand down as executive officer. IGBP welcomes Sebastien Boillat and Fabiano Scarpa as the Global Land Project’s (GLP) executive officer and project officer respectively. GLP is currently hosted by the National Institute of Space Research (INPE), Brazil, and will remain there until the end of the year. The project is entering its second phase as a Future Earth initiative and has received a number of bids to host its international project office beginning January 2015. The proposals are currently under review.

In September this year, Eric Saltzman stepped down as Chair of the Surface Ocean - Lower Atmosphere Study (SOLAS) project to take up an appointment with the US National Science Foundation. The project has initiated a search for a new chair. Paul Monks, co-chair of the International Global Atmospheric Chemistry (IGAC) project, rotates off at the end of 2014. Mark Lawrence will join Alan Goldstein as the new co-chair. We thank both Eric and Paul for their leadership and service to the IGBP community.

Jean Ometto, researcher and Future Earth Chair was supporting the transition between IGBP and Future Earth”, Syvitski noted. He was confident that the five hubs of the global secretariat would facilitate region-specific discussions between government leaders, development agencies and scientists. He also hoped that the regional hubs would facilitate engagement with a broader range of stakeholders and “dialogue outside the research community”. Syvitski felt that closer ties with government and industry would directly influence environmental messaging and policy change in a regional context. He noted that Future Earth would need to interact with a much wider range of stakeholders than what the global-change programmes have traditionally engaged with.

He emphasised the need for new funding models to support a “long-lasting Future Earth programme”.

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Future Earth is about creating networks so individuals can draw on the knowledge and skills of others,” Syvitski said. The successful Rivers in Anthropocene conference, for example, attracted natural and social scientists and “even included the fine arts”. “It was exciting to see what each community brought to the table, to learn from one another and get over our reluctance to have this conversation.” In response to a query on water security and management, Syvitski bemoaned the paucity of collaborative efforts like the multi-country Mekong River Commission. Solving problems related to water requires looking beyond not only national boundaries but also disciplinary boundaries: in this context Future Earth could draw on IGBP’s recognition of the importance of interconnections among regions and different parts of the Earth system, he said.

FUTURE EARTH: FORGING NEW CONNECTIONS

FUTURE EARTH should work “beyond the natural sciences to forge new research interactions with the social sciences, business and law”, according to IGBP Chair James Syvitski in an interview published in the October issue of Nature Climate Change. Syvitski noted that the five hubs of the global secretariat would facilitate region-specific discussions between government leaders, development agencies and scientists. He also hoped that the regional hubs would facilitate engagement with a broader range of stakeholders and “dialogue outside the research community”.

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EMISSIONS from fossil fuels and deforestation in 2014 are set to reach a new 40-billion-tonne record high, 2.5% above 2013 levels, according to the latest carbon budget released by IGBP’s Global Carbon Project. China, the world’s largest emitter of carbon dioxide since 2006, accounts for 28% of the emissions, followed by the US (14%) and Europe (10%). For the first time, China’s per capita fossil-fuel emissions exceed those of Europe.

The budget was published in the open-access journal Earth System Science Data Discussions. It was accompanied by three analyses relating to the climate target that seeks to prevent global average surface temperature from rising more than two degrees Celsius above pre-industrial temperatures – the so-called two-degree target agreed at the Copenhagen conference in 2009.

The analysis concluded that total future CO$_2$ emissions cannot exceed 1200 billion tonnes for a likely (66%) chance of meeting the two-degree target. Nations have agreed that going beyond this limit risks “dangerous” climate change. At the current rate of CO$_2$ emissions, this 1200-billion-tonne CO$_2$ “quota” will be used up in around 30 years – or one generation.

Unless new technologies to keep carbon out of Earth’s atmosphere are developed and deployed on a large scale, global emissions will need to reduce by more than 5% each year over several decades for a reasonable chance of keeping climate change below 2°C.

“China’s emissions now exceed the US and Europe’s emissions combined. This is an interesting trend and shows the important role China will play in addressing the climate challenge,” said Professor Sybil Seitzinger, Executive Director of the International Geosphere-Biosphere Programme (IGBP).

The world’s second largest emitter, the United States, saw emissions grow 2.9%. This bucks a trend of declining emissions since 2008. While improvements have been made to reduce energy consumption and carbon intensity, economic and population growth coupled with a reversion to coal consumption are driving emissions upwards.

Emissions in the European Union, which ranks third among the biggest emitters, fell 1.8% on the back of a weak economy. Deep emission cuts in some countries offset a return to coal led by Poland, Germany and Finland. Whereas national emissions are falling, Europe exports about one third of its emissions, largely to the emerging economies. When these “consumption” emissions are accounted for, EU emissions can be seen to have only stabilised.

India’s emissions are growing fastest of the big four, and account for 7% of total emissions. Emissions are on course to surpass Europe’s by 2019.

The carbon budget was timed to inform the UN Climate Summit in New York, which took place on 23 September. The summit, billed as the largest gathering of world leaders to discuss climate since the 2009 UN Climate Summit, was not intended to lead to legally binding outcomes. Rather it was an effort by UN Secretary-General Ban Ki-moon to create momentum for an ambitious international agreement at the COP 21 negotiations in Paris in 2015.
Lead author Professor Corinne Le Quéré, Director of the Tyndall Centre for Climate Change Research in the UK, said: “We are nowhere near the commitments necessary to stay below 2°C of climate change, a level that will be already challenging to manage for most countries around the world, even for rich nations.”

The launch of the carbon budget coincided with the start of a large climate march in New York that attracted over 310,000 people according to its organisers. The budget received widespread international media coverage, including articles on the BBC, Bloomberg, Financial Times, Newsweek, The Guardian, Der Spiegel, The Japan Times, China Daily, China Dialogue and three articles or blogs in the New York Times. The FT Chinese published a commentary by two of the authors, Corinne Le Quéré and Dabo Guan.

MORE INFORMATION

www.globalcarbonproject.org/carbonbudget/
www.globalcarbonatlas.org

Friedlingstein P et al. (2014) Nature Geoscience, doi: 10.1038/NGEO2248
Raupach M R et al. (2014) Nature Climate Change, doi:10.1038/NCLIMATE2384

Consumption-based emissions (carbon footprint). This provides an alternative perspective on emission drivers.

Celebrating three decades in Sweden

FOR almost three decades, the home of IGBP’s secretariat has been in Stockholm at the Royal Swedish Academy of Sciences.

On 20 October, we held an event at the academy to celebrate this anniversary. The event coincided with the annual meeting of IGBP’s Officers (our executive committee).

The IGBP community and supporters from funding agencies and government joined us for an evening where we discussed IGBP’s achievements and legacy as it prepares to transition to the new Future Earth initiative.

Indeed, representatives from the new Future Earth global hubs also attended the event. They were meeting in Stockholm to finalise plans for the transition to the permanent secretariat.

IGBP’s first director Thomas Rosswall described the early workings of the secretariat. Effective international communication was one of the first challenges. Back in 1986 email was a strange curiosity to be treated with scepticism and suspicion.

Current Executive Director Sybil Seitzinger opened the event. She spoke of her first interactions with IGBP and how its global perspective helped shape her career.

Current chair James Syvitski from the University of Colorado, Boulder, took to the floor and discussed how IGBP’s syntheses helped shape concepts such as the Anthropocene and planetary stewardship.

Anders Granlund, lead policy specialist for climate and environment for the Swedish International Development Cooperation Agency (Sida), has been a long-time supporter of IGBP. He challenged Future Earth to do more to engage the global south. This is where international capacity must be built and retained. Anders Turesson, senior advisor to the Swedish Government, spoke of the value to policymakers of the Intergovernmental Panel on Climate Change (IPCC), which has close ties to IGBP.

Swedish meteorologist Bert Bolin was instrumental in creating both organisations. IGBP’s Deputy Director Wendy Broadgate invited guests to speak about their own experiences with IGBP. Secretariat staff and scientists past and present offered personal reflections on their time with IGBP including atmospheric physicist Henning Rodhe, former chief climate negotiator to Sweden Bo Kjellen and Dennis Ojima from Colorado State University. Ojima is now part of the Colorado hub of Future Earth but began his career as a scientist in the first IGBP secretariat back in 1986.

In December 2015, IGBP will host a legacy event at the American Geophysical Union meeting, San Francisco, to officially mark the end of IGBP. IGBP’s projects will transition fully to Future Earth at that time.

Wendy Broadgate

Thomas Rosswall and Henning Rodhe
Once the combine harvester became popular, residue burning increased.

Once the combine harvester became popular, residue burning increased.
intensive and hence expensive. Would financial incentives encourage farmers not to burn their fields? How much do farmers save when they burn? To find out, Krishna Prasad Pant, of Kathmandu University in Nepal, recruited farmers from the country’s southern lowland Terai region (Figure 1). He invited them to submit sealed bids for compensation for refraining from burning for a season. He found that the median value of the bids was around 78 US dollars (USD) per hectare; farmers were willing to accept this amount to stop burning rice straw in their fields. Some 170 farmers bid for this amount or less and were selected for a follow-up experiment in which a majority complied with the agreement reached to not burn and accepted payment.

Pant’s team trained the farmers either to plough the stalks back into the soil (which necessitated hiring a bigger, more costly tractor) or to cut them by hand and compost them in a corner of the field (for which they needed to hire more labour). About 85% stuck to their agreement and did not burn that season: many, in a follow-up survey, requested a repeat of the intervention. Based on these results Pant thinks the government should pay farmers not to burn, alongside educating them on soil fertility and composting of residue. “Once we know the cost of non-burning, the government can do something for an alternative,” he says. He is not convinced that other options, such as an outright ban on burning, are feasible. “Putting a legal ban is very difficult to do because it is their traditional right.”

Shyamsundar isn’t convinced, though: “I don’t think we want to take away from this that we want to pay farmers not to burn. This strategy may be un-implementable. But these numbers give us an idea of how big the problem is, and what needs to be done.”

Exploring technologies

Shyamsundar thinks subsidised new technologies might be a better option: “New technologies don’t need to be monitored across the board so it’s an easier solution. Regulations such as bans don’t always work well but technology does, if adopted.”

One possibility is to subsidise access to the Happy Seeder – a miraculous machine that cuts and lifts rice straw, sows the wheat seed, and deposits the straw on top of it as mulch. Ridhima Gupta, from the Indian Statistical Institute in Delhi, considered its potential in Punjab, the only state in India to be using it at the time of the research. She found that the machine allows the earlier sowing of wheat as the rice residue can be removed while still green. The rice mulch reduces the need for herbicides and fertilisers. Overall, the costs and benefits balanced each other and using the Happy Seeder made no tangible difference to profits.

A detailed assessment by the Australian Centre for International Agricultural Research (ACIAR) found long-term economic and environmental benefits of using this technology. Yet, Gupta’s farmers haven’t adopted this technology wholeheartedly. Start-up costs and conservatism are undoubtedly among the reasons. But, the ACIAR study suggests, subsidies for electricity and herbicides may also play a part: they nullify the benefits of long-term reductions in electricity and herbicide use that would result from adopting the Happy Seeder. Gupta is urging the Indian government to subsidise the machine, a process the ACIAR study says is already under way.

Regional perspectives

South Asia is a vast region characterised by different landscapes, agricultural practices, technologies and levels of awareness. Mitigation measures need to be flexible enough to accommodate this diversity. Two studies from opposite ends of the region, Pakistan and Bangladesh, are instructive in that regard.

In Pakistan, researchers looked at 400 farmers in two districts in Punjab who do not have Happy Seeders. Removing the residue by hand pushes the farmer’s costs up by over a third (from just over USD 100 per hectare for burning to just over USD 136 for removal) – and is only worth it if there is a market for the residue, for example to feed livestock. Over 80% of the farmers did not even know that technologies such as the Happy Seeder existed – in contrast, it is used widely across the border in the Indian Punjab. Until the technology penetrates this region, however, “the farmers would need to be subsidised to avoid residue burning practices,” say the study’s authors, Tanvir Ahmed, an economist at Farman Christian College in Lahore, and Bashir Ahmad, president of Innovative Agriculture in Faisalabad. They estimated that the cost of the subsidy need only be USD 20-27 per hectare for incorporating the residue back into the soil; however, this is based on only looking at the costs of the various interventions, rather than the overall profit of the farmer.

A detailed study of 300 farms in southwest Bangladesh by Ziaul Haider of Khulna University did consider farmers’ overall profit rather than just the costs of production. In this area, where the Happy Seeder also has yet to penetrate – researchers found that the farmers’ profit is as much as USD 111 higher per hectare if the residue is burnt rather than
removed. This happens because productivity is higher in fields where burning occurs (although the effects in the longer term are unclear), whereas the costs of rice harvesting are lower. Paying farmers throughout the nation to abstain from burning would cost the government of Bangladesh USD 2.1 million a year – about 4% of current subsidies available to farmers for inputs such as fertilisers.

The breed of rice grown by farmers has an effect too. Long-stalk rice can poke its head above flooding and is thus apt for low-lying fields. But its residue is voluminous and of low quality – not wanted for animal feed – and is thus largely burnt. Haider found that farmers are growing the cheaper, long-stalk rice at higher elevations as well: subsidising and educating farmers to switch to short-stalk varieties at higher elevations might be a promising way forward.

At low elevations farmers should instead be educated, and perhaps subsidised, to incorporate the long-stalk residue into the soil rather than burning it. Haider also thinks there is scope for science to come up with a better variety of rice, for example one with a shorter growth period that would increase the time available after harvest before it is necessary to plant the wheat. That would leave enough time to deal with the residue in ways other than burning.

Whatever the solution, Shyamsundar says, the research shows that the problem is more tractable than dealing with other causes of climate change. This is because it’s a behaviour that is not just contributing to climate change but is also causing local pollution, which can produce local incentives to change. “Planes can’t take off or land because of this really crazy smog that descends during the winter,” she says. “That’s enormously costly.” Perhaps the private sector could be encouraged to get involved in technology subsidies, she suggests.

AISLING IRWIN is a freelance science journalist specialising in developing-world issues.

REFERENCES


We have got to understand the behavioural issues at the local level.
The greening of the Southern Hemisphere

The 2010-2011 La Niña weather event brought lush vegetation to vast semi-arid regions in the Southern Hemisphere and altered the delicate balance of the global carbon sinks. Owen Gaffney explores how La Niña might change in the future and what that might imply.

In Australian Aboriginal mythology a frog called Tiddalik had an unquenchable thirst. He drank every last drop of water leaving a parched and barren landscape. The other animals, concerned for their future, hatched a plan to make Tiddalik laugh hard enough to return the water. Eventually, they made the frog laugh and he spewed out a torrent of water, flooding the land.

Starting in October 2010 through to March 2011, Australia endured an epic deluge straight out of Dreamtime. Queensland in the northeast was declared a disaster zone. An area the size of France, Germany and Italy combined lay under water. Thirty-five people died and 30,000 homes and businesses were damaged.

The average rainfall across Australia is about 453 mm, according to the Australian Bureau of Meteorology. In contrast, the rainfall in 2010 and 2011 measured 703 mm and 708 mm respectively. The excess water was drawn from the oceans and a lot of it was retained by Australia’s large, continental interior basin. As a result, between the beginning of 2010 and mid-2011 global mean sea level fell 5 mm.

Life sprouted from dry and dusty soils across Australia. In May 2014, scientists associated with the Global Carbon Project reported in Nature that heavy rains across the Southern Hemisphere – from Australia to southern Africa and South America – led to a greening of these semi-arid regions.

Globally, this had a big effect on the carbon sink. In 2011, vegetation soaked up 4.1 billion tonnes of carbon. This is significantly more than usual, and around 40% of the annual emissions from burning fossil fuels. Models run by lead author Benjamin Poulter from Montana State University and CNRS in France showed that about 60% of the anomaly from the Southern Hemisphere was due to the greening in Australia alone.

“That’s quite remarkable,” said Pep Canadell, the Executive Director of the Global Carbon Project and an author on the paper. “particularly, when you think that Australia is a very small player in global net primary production because it is such a dry place.”

Blame it on La Niña

La Niña is a periodic global phenomenon that brings wetter weather to Australia, India, Indonesia, the Philippines, southern Africa and South America. North America feels it too, with drier conditions likely in the Southwest, Rockies and Great Plains, and more rain in the Pacific Northwest. La Niña is squarely to blame for the unusual greening across the Southern Hemisphere.

La Niña is part of a larger phenomenon, the El Niño Southern Oscillation (ENSO), first noticed by British academic Gilbert Walker in the early 20th century. While analysing weather data around India, Walker observed that the atmospheric pressure between the Indian and Pacific Oceans rocked back and forth like a seesaw. He linked this seesaw to shifts in temperature and rainfall across the region.

ENSO is driven by atmospheric and oceanic conditions in the Pacific. Trade winds blow warm water westwards from high-pressure areas off the coast of South America to the low pressure in

Life sprouted from dry and dusty soils across Australia.
Mount Connor in the Northern Territory, Central Australia, during the 2010-2011 La Niña event. Extreme rainfall led to a greening across many parts of Australia.
the Pacific east off Indonesia and Australia. Warm waters build up along these coasts. Low pressure plus warm waters lead to evaporation and rain clouds, giving the region its tropical climate – this is the neutral phase of ENSO.

During La Niña this neutral phase intensifies. Westerly trade winds strengthen, thus pushing more warm water across the ocean. Water temperatures off the coast of Australia rise dramatically and, coupled with low pressures, this leads to much more water evaporating into the atmosphere. In 2011, scientists analysing data from NASA’s GRACE satellites, which monitor Earth’s gravitational field, noted that the unprecedented scale of ocean evaporation due to La Niña contributed to a drop in ocean mass of 1.8 trillion tonnes.

The Aboriginal tale of Tiddalik indicates that Australians have long memories of extended droughts punctuated by heavy rainfall. But is recent, anthropogenic global warming also to blame? La Niña varies in strength – sometimes it strikes hard, other times it can be weak. Sea-surface temperatures have been rising globally as a result of greenhouse-gas emissions. “The baseline has been elevated,” says Canadell. “When La Niña builds up on top of a warmer ocean, it is likely to release even more moisture to the atmosphere.”

Changing times
Researchers are keenly interested in attribution, but they also want to know more about future climate variability. “Are we going to get more droughts and more floods?” asks Canadell. The recently published Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that, generally, dry areas are set to get drier and wet areas wetter. This will lead to more fire-prone conditions across the semi-arid regions of the Southern Hemisphere, according to the report. But the 2011 La Niña suppressed fires by about 30%.

The scale of change brought by La Niña in semi-arid regions surprised researchers. Not least because such regions make up 40% of the world’s land area, so any alteration in vegetation patterns may have a significant effect on the global land carbon sink.

This is leading to increased efforts to understand future ENSO variability. Could, for example, a tendency for more and stronger La Niña events create a larger store of carbon on land? Not if strong and frequent La Niña events are balanced out in the long term by equally strong and frequent El Niño events, says Canadell. Any additional carbon stored during La Niña may then be released by the next El Niño.

Canadell reports that researchers are beginning to get a better grip on this. One recent paper indicates that the frequency of extreme El Niño events is set to increase in the future if CO₂ emissions continue

Figure 1. The 2010/2011 La Niña affected the global hydrological cycle with significant impacts across the Southern Hemisphere. The global map shows the change in water mass from the beginning of 2010 (January-February-March average) to mid-2011 (March-April-May average). Blue indicates an increase in water mass over the continents. The map is from: Boening C et al. (2012). The 2011 La Niña: So strong, the oceans fell. Geophysical Research Letters 39: L19602, doi:10.1029/2012GL053055.

Inset: For several decades sea level has been rising 3.2 mm per year on average. Global mean sea level dropped 5 mm between the beginning of 2010 and mid-2011. Topex/Poseidon, Jason-1 and Jason-2 satellite altimeter data (CSIRO).
You expose the system to crossing thresholds.

Ongoing analyses will soon provide additional evidence about changes in the frequency of other extreme events related to La Niña. Would things simply balance out in the end?

Not when you add life to the equation, ecologists say. Some evidence from the Long Term Ecological Research Network in the United States suggests that living systems take advantage of conditions during the good times, whereas new vegetation has a built-in resilience and fights for life when times get bad. So even if both El Niño and La Niña were to intensify in the future we could still see an overall carbon accumulation on land, says Canadell.

All this is on top of another trend: satellite data show that Australia has been on a gradual greening trend for the past 30 years. This is because, as predicted by the IPCC, wet areas in the subtropics are expanding to the north and south into some semi-arid regions in response to increasing atmospheric concentrations of greenhouse gases.

Crossing thresholds

All of this adds up to semi-arid systems in Australia and across the Southern Hemisphere experiencing more variability than once supposed. Although there have always been ups and downs, now it seems the upswings may reach higher up and the downs lower down, says Canadell. This has consequences for vulnerability. “You expose the system to crossing thresholds. Fire is one.” IPCC warns fires will become more likely across the Southern Hemisphere, with implications for the vulnerability of the land carbon sink.

This is a new layer of concern. “When we look at atmospheric carbon-dioxide variability we always look at the tropics. It’s always about the Amazon. It’s always about regions where massive amounts of photosynthesis is occurring.”

“We always thought [semi-arid regions] had a minor role in net primary productivity.” The reality is that they are more responsive to rain than previously assumed and, because they are so extensive, their impact on the Earth system is dramatic. “This is what makes them interesting.”

Poulter and colleagues have added a new piece to the jigsaw of the Earth system – the response to change in semi-arid regions. “These places function very differently from rainforests with alternative components and drivers. Fire is a big deal,” says Canadell.

The record-breaking 2011 La Niña event was undoubtedly remarkable. While it opens up new areas of scientific enquiry, one striking conclusion is the extent to which the ENSO controls much of the variability of the global land carbon sink. With half of our annual greenhouse-gas emissions ending up in the land and ocean carbon sinks, any new information on how the land sink may alter in the future is eagerly awaited.

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In November this year Chinese President Xi Jinping announced that his nation would seek to achieve a peak in its greenhouse-gas emissions by 2030 (see page 4 of this issue). The significance of this announcement cannot be overemphasised: China is the world’s leading emitter of carbon dioxide and, as this year’s Global Carbon Budget underscores, its per capita emissions now exceed the European average (see page 6 of this issue). Moreover, the economic engine that drives its emissions also drives domestic environmental degradation, so a peak would have a bearing on quality of life too.

In this context there is growing interest in exploring the timing of peak emissions and energy consumption in China. Integrated Assessment Models (IAMs) provide one way of knowing when emissions might peak – that is, when they will cease to grow further – and at what absolute value. These models simulate emission trajectories by combining various socio-economic pathways and policy options. However, feedbacks and interactions among social, economic and environmental systems introduce uncertainties that limit the persuasiveness of IAM studies.

Here I discuss an alternative, comparative approach that looks at income growth and per capita emissions through time in China and some other representative countries. This approach complements a recent analysis that explored what it would take for China’s emissions to peak by the year 2030. That analysis considered the experience of developed countries as well as factors such as GDP per capita and carbon emissions per unit of energy consumed. My approach can be described as top-down, underpinned by the rationality of pursuing equity: the principle that given a particular income level, one human being should be able to emit as much carbon dioxide as another at the same level. This approach throws up several possible emission trajectories regarding per capita emissions for China. When combined with possible trajectories of the country’s GDP growth and population growth, we can get some handle on the path that its total emissions might take.

**Economies and emissions**

We know that emissions of some substances – sulphur dioxide and particulates, for example – tend to follow what’s called the Environmental Kuznets Curve: emissions increase with economic growth, peak at a certain per capita income level and then decrease. The peak is driven mainly by end-of-the-pipe treatment, industrial transformations and the increasing demand for environmentally friendly goods. We could estimate when greenhouse-gas emissions in China would peak assuming they too follow this curve. As discussed below, that does not seem to be the case.

End-of-the-pipe treatment such as carbon capture and storage is at present too costly to be applied on a large scale. Renewable energy is making inroads but is not yet
competitive in terms of price. Meanwhile, emissions from increased consumption and the expansion of transportation infrastructure are only partly offset by industrial transformation. Finally, because global warming is a complex issue and poses more indirect health risks as compared with common pollutants (such as sulphur dioxide), the public demand for “green” goods can be influenced by several factors including scepticism. Indeed, during the past five decades today’s developed economies have improved their living standards greatly while achieving little reduction in per capita greenhouse-gas emissions (Figure 1).

Generally, there is a positive relationship between energy consumption and greenhouse-gas emissions. Developed countries consume more energy and emit more greenhouse gases than developing ones. But Figure 1 shows that there are distinct differences within these groups too: this suggests countries have taken or are taking different pathways to achieve income growth. The United States, for example, uses energy equivalent to almost 140 kilograms of oil per unit of GDP, whereas Germany uses just over 90. Diverse factors such as the economic and energy structure, efficiency, and transportation infrastructure affect per capita emissions. The energy-consumption behaviour depends on energy pricing and taxation systems. The difference between Germany and United States can be attributed chiefly to differences in energy efficiency and the higher penetration of nuclear and renewable energy in Germany.

Chinese per capita energy use – equivalent to over 200 kilograms of oil per unit of GDP – and per capita emissions are much higher than those of Brazil, for example. The high growth rate of the Chinese economy, its reliance on the export of primary products and the domination of coal lead to mass consumption of energy and thus high emissions.

Germany has decoupled, to an extent, energy consumption from emissions. Such decoupling can be attributed mainly to the fact that renewable energy such as wind and solar forms a significant part of Germany’s energy mix. The Chinese government is taking a series of measures to similarly decouple its economic growth from energy use and greenhouse-gas emissions.

In 2006, China drew up mandatory targets of energy intensity, carbon intensity, the share of non-fossil sources in total energy supply, and pollution by sulphur oxides and nitrogen oxides. China has committed to the following by 2020: a) lower emissions per unit of GDP by 40 to 50% of the 2005 level; b) meet 15% of its primary energy consumption from non-fossil fuels; c) and increase forest coverage by 40 million hectares and forest stock by 1.3 billion cubic metres from the 2005 level. Then there is the recent US-China agreement. These measures may lead to some GDP loss in the short term but stimulate green innovation in the long term.
Glimpsing the peak

Scenarios for peak emissions can be constructed by combining the pathways of peak per capita emissions, economic growth and population growth in China. I first use the relationship between per capita income and per capita emissions of developed economies as a reference to construct three possible pathways for peak per capita emissions in China (Figure 1).

The black pathway allows China’s per capita emissions to peak at a level similar to that of Canada. The growth rate of per capita emissions will decline gradually and stabilise (that is, reach convergence) at an income of around 15,000 US dollars per capita. If China follows the brown pathway its emissions will peak at a level similar to that of Germany. They will converge at an income level of 10,000 US dollars per capita. Finally, the green pathway is relatively inflexible in that it requires China to maintain its current level of per capita emissions. If the country follows this pathway its per capita emissions will be lower than the emissions of the developed economies.

I then factor in the effects of economic growth and population. The former is assumed to follow one of three pathways: high growth, medium growth and low growth. As to the latter, China’s population is ageing and – based on the United Nations forecast – will begin to shrink from 2030.

Figure 2 shows the results of the analysis in the form of several possible trajectories of total emissions until 2100. Assuming the UN population projection holds, the absolute values and timing of peak emissions depend on both the per capita emission pathways as well as the rate of economic growth. If China were to follow the black emission pathway the total emissions would soon exceed 15 billion tonnes irrespective of growth rate, which seems incompatible with the target of restricting the increase in global temperature to two degrees Celsius above its pre-industrial value. In contrast, the green emission pathway coupled with moderate to low growth would lead to total emissions of about 11 billion tonnes, which would peak between 2040 and 2045. Although this timing is not very different from that estimated for the black emission pathways, the significant reduction in total emissions would help to limit the increase in global temperature over its pre-industrial level.

Realistically speaking, however, China will most likely follow the brown emission pathway. For low to moderate growth rates, the peak would appear around 2040 and the absolute level would be between 13 and 14 billion tonnes of carbon dioxide. If the growth rate were high, the peak would appear even later and total emissions would be almost 15 billion tonnes.

Getting there

In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) has put forward “burden sharing” as a new principle for allocating responsibility for mitigating greenhouse-gas emissions. The principle emphasises equity rather than efficiency. The three per capita emission pathways considered here are consistent with this principle: they take the contemporary levels of per capita emissions in developed countries as benchmarks.

The analysis presented here suggests that both the rate of economic growth and the emissions pathways govern the absolute value and timing...
of the emissions peak. Growth patterns depend on how energy is produced and consumed, the evolution of infrastructure, land-use change and ultimately how resources are allocated. China has many similarities with Germany: for example, both countries are richly endowed with natural resources, display an export-oriented growth pattern and have similar roles in regional economic development. If China could follow Germany’s emission pathway its emissions would peak at a level and time that would help to limit the rise in global average temperature over its pre-industrial value.

From the supply side, the transformation of the energy structure is the most urgent challenge. Compared to Germany, China’s energy supply is still highly dependent on coal. China will need to pursue feasible alternatives to coal so as to generate cleaner energy. The German experience with renewable energy and the distributed co-generation of heat and power systems highlights the importance of green fiscal policies. More stringent taxes on fossil fuels and more flexible feed-in-tariff policies can help China to accelerate the timing of the emissions peak.

In today’s globalised world, though, what the world chooses to do might be just as important as what China does. We know that a significant fraction of China’s emissions can be attributed to goods that are made in this country but consumed elsewhere (in Europe and the US, for example). Many of those countries have per capita emissions that are much higher than the world average. So a change in consumption patterns in such countries will only stimulate the transition to a low-carbon economy in China.

The shift in manufacturing to China can be traced, in part, to the “Polluters Pay Principle (PPP)” enshrined at the 1992 Rio Summit. There was no parallel change in consumption patterns, however, leading to many irreversible environmental externalities in China and the rest of the world. It would be important to insure that China’s transformation will not be at the expense of emissions transfers to less developed regions. So although the current focus on China is justified, we should not ignore developing economies such as the Mint countries (Mexico, Indonesia, Nigeria and Turkey), which are also experiencing rapid industrialisation. It is incumbent on the international community to help them get onto a more sustainable path.

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1. The Global Carbon Budget is published by IGBP’s Global Carbon Project. For more information see: http://www.globalcarbonproject.org/carbonbudget/


3. The unit of gross domestic product considered here is 1000 constant international dollars using purchasing power parity rates for 2011. An international dollar has the same purchasing power over GDP as a US dollar has in the United States.
Throughout history human societies have had to confront and adjust to climatic and environmental hazards. A long-term perspective that draws on such experiences must inform today’s climate policies, argue Jago Cooper and Christian Isendahl.

Scenarios, projections, pathways. Understandably, there’s a lot about the future in the assessments of the Intergovernmental Panel on Climate Change (IPCC). We would like to plan for the changes to come, both anticipated and unanticipated, and not leave future generations too much to do. Such planning could benefit immensely from looking at past human experience of climate and environmental change. Strangely, the IPCC does not consider this aspect in any meaningful way. Policymakers are thus deprived of valuable context in which to interpret the assessment; they also miss out on the lessons offered by the interactions between past societies, their environments and climate.

We argue that climate policies aimed at mitigating and adapting to hazards should be informed by our knowledge of past human experience. Archaeologists, environmental historians and others are slowly building a rich archive of cases that consider diverse spatial and temporal contexts. It is apparent from these efforts that the insights into social-ecological relationships provided by archaeological cases transcend their immediate contexts. The archive is particularly suitable for understanding how small but cumulative changes might affect social-ecological systems. It could help us to go beyond simplistic analogies by elucidating those factors that build long-term resilience and those that introduce vulnerabilities. We expand on this by considering some key aspects relevant to mitigation and adaptation.

Civil engineering
It is tempting for societies to counter natural hazards by investing in infrastructure such as, for example, dams and reservoirs to counter rainfall variability, levees to protect against sea-level rise or terraces to avoid erosion. The archive of past human experience shows, however, that engineering solutions to counter hazards have triggered unforeseen and often fatal long-term consequences.

For example, the Hohokam of the Southwest United States invested heavily in infrastructure so as to mitigate the impacts of short-term climate variability; local population densities increased as a result. The network of canals (Photo 1) and dams they built ran to some 700 kilometres in length with over 100,000 acres of irrigated land – the largest known system in the pre-Columbian Americas. However, this water management
system was ill prepared to handle lower-frequency, extreme-weather events (for example, prolonged droughts and flash floods that knocked out the irrigation system), which ultimately proved catastrophic and led to a dramatic decline in the population (Hegmon et al. 2008).

A key lesson from such case studies is that the focus on frequently occurring but low-impact hazards often renders societies vulnerable and at increased risk to events that occur rarely but can deal body blows. This understanding of trade-offs should inform risk assessments of modern infrastructure projects.

**Settlement locations and architecture**

Pre-Columbian settlements in the Caribbean islands occupied the leeward sides of hills. In contrast, subsequent European-influenced settlements are found in river valleys and the mouths of estuaries. As a result the modern inhabitants are left exposed to extreme wind shears, coastal storm surges and post-cyclone flooding – hazards that the earlier settlements were far more resilient to. The cities of Phoenix and Mexico City are built in locations where their Ancestral Puebloan and Aztec ancestors also had large towns and cities and remain vulnerable to similar hazards. A long-term perspective was clearly lacking when these settlements came up, but it should not be ignored in future urban planning.

Although large-scale movement of populations from urban areas is not feasible, planners should guard against the unwitting expansion into vulnerable locations.

The Zimbabwe plateau provides an example of how decisions about future urban settlements could benefit from understanding the drivers of past urbanisation. The pre-colonial settlement system in Zimbabwe had been one of self-organising landscapes with relatively short-lived farming communities, sometimes lasting only a few decades. The colonial towns of Bulawayo and Harare were established by clearing pre-existing farming communities via taxes; the process was aided by the availability of cheap energy to fuel transport systems. Energy is no longer cheap, and the increasing costs associated with securing its supplies call for alternative strategies to post-colonial cities: for example, distributed networks of smaller scale urban settlements. The strategy of “urbanizing the rural areas and ruralizing the urban areas” (UN-Habitat 2009) may help to buffer

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**Photo 1:** Artist Michael Hampshire’s rendition of the Hohokam settlement at Pueblo Grande, Arizona. An elaborate network of irrigation canals can be seen in the background. Photo of painting courtesy of The Pueblo Grande Museum, Phoenix, Arizona.

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Such examples support the adoption of alternative architectural philosophies.
against the stresses on urban dwellers and systems. Instead of increasing investments that conserve the colonial structure and tend to challenge long-term sustainability, planners need to consider fostering diversity by re-enacting a dispersed, less-energy-intensive settlement system.

Current architectural planning seeks to enhance the capacity to withstand impact. One example is the increased use of expensive, imported concrete and steel for building in the Caribbean. Many past societies, however, developed successful long-term strategies that focused on anticipating locally specific hazards and increasing the speed of recovery. For example, pre-Columbian house structures in Cuba have lightweight wall and roof structures built around robust, deeply embedded hardwood house posts. Following a hurricane the wattle wall and thatch roof structures can be rebuilt quickly from locally available and freely accessible materials (Cooper 2012a). Such examples support the adoption of alternative architectural philosophies – as reflected in recent thinking on disaster management (Watson and Destefano 2010, Amaratunga and Haigh 2011) – focused on resilience rather than fortitude in the face of extreme-weather events.

**Food security**

In today’s globalised world our food tends to take a long route from farm to table, relying on international trade routes that pass through several bottlenecks. Sudden disruption of such delivery systems – via climate change or political volatility – can severely affect the food security of particular regions. Case studies from pre-Columbian Cuba, Southwest United States and Central America suggest that the more resilient societies relied on food from diverse sources that were secured via robust social relationships. For example, the food consumed in pre-Columbian settlements in northern Cuba was sourced from offshore reefs and coastal and upland areas spanning ecological niches up to 50 kilometres from the individual settlements. These food supply systems were built around reticulate trade and exchange networks that were underpinned by community cohesion and the sedentary nature of the populations over the long term (Cooper 2012b). This approach meant that there was an inherent capacity to cope with short-term systemic shocks and the disruption of particular supply routes.

The archaeology of urban food systems provides additional insights into the scale and management of urban farming and its importance in increasing food security in cities – both in times of crisis and in energetically inefficient distribution systems. For example, urban farms in the...
An Applied Archaeology for Future Earth

In April 2014 an international group of archaeologists met in Austin, Texas, to discuss case studies covering ten millennia of human experience of climate variability and environmental change. The presentations focused particularly on research linked to the Integrated History and Future of People on Earth (IHOPE) project and the Global Human Ecodynamics Alliance (GHEA). Both IHOPE and GHEA seek to combine insights from human and Earth-system history to inform efforts to achieve global sustainability. In Austin the group also spoke to the interim secretariat of Future Earth to explore ways of communicating insights generated from research to a wider community and highlighting its relevance to policy. Archaeologists integrate the human, social and natural sciences to provide a long-term perspective on human-environment interaction; they are thus well placed to contribute to the evaluation of key aspects of socio-eco-cultural systems.

pre-Columbian Aztecs and Maya highlight the benefits of alternative city planning that successfully bridged the current divide between rural food production and residential urban consumption (Isendahl and Smith 2013). The city dwellers’ knowledge of farming practices not only maintained resilience but also bestowed on the community an autonomous sustenance capacity at times of political turmoil and breakdown.

It is becoming apparent from case studies across the world that agricultural production was an integral part of urban living until increased globalisation kicked in. This suggests that we need to re-imagine the city as a place where food can be grown (Barthel and Isendahl 2013) (Photo 2).

Implications for governance

Addressing the aspects discussed above depends ultimately on effective governance practices. Considerations of scale are particularly important. People experience the impacts of hazards at the highly personal and localised scale. Disaster management and planning, though, are increasingly centralised: many local communities have less leeway in devising their own responses. Large-scale governance is unavoidable in today’s world where hazards are regional and often transcend political boundaries. However, the archaeological record supports empowering local communities to enhance the success of mitigation measures.

A host of case studies of water-management systems, for instance in the Southwest United States and the Maya, demonstrate that infrastructural solutions for sustainability induced by larger-scale governance institutions impose high maintenance costs and generate trade-offs or backlashes: these in turn undermine longer term sustainability.

The power of the past is not just in providing tangible case studies that capture the public’s imagination, demonstrate the impact of climatic and environmental change and communicate the real vulnerability of societies both past and future. It is also the thematic lessons it provides that can help reconceptualise issues of risk, vulnerability and resilience that are so relevant as we look towards disaster risk reduction post-2015. This is why knowledge from the past is crucial to help create a better future Earth.

**Empowering local communities enhances the success of mitigation.**

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This commentary draws on discussions at a recent meeting involving Future Earth and the IHOPE and GHEA projects (see box).

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- Past Global Changes (PAGES)
- Surface Ocean-Lower Atmosphere Study (SOLAS)

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