ONE planet, FOUR futures

How will our complex societies and economies respond to climate change? So far, future climate scenarios have not adequately included emissions-reductions policies and adaptation. All that is about to change. Owen Gaffney reports.

In February, President Barack Obama announced his intention to build two new nuclear power stations on US soil. If this happens, these will be the first nuclear power stations commissioned in the US since the Three-Mile Island nuclear disaster in Pennsylvania in 1979.

The announcement along with legislation to curb greenhouse-gas emissions could mark a turning point in US policy. Maybe the rest of the world will follow suit, and we will soon be on track to reduce emissions by 80 percent by 2050. By the end of the century, carbon-dioxide emissions may stabilise at what is considered an acceptable level.

Alternatively, public outcry in the US at the mere thought of nuclear will deal it a fatal blow. Other legislation will fail. Emissions will continue unabated or, in the jargon of the climate policy people, the world remains on the "business as usual" track.

These are two possible options for the planet's future greenhouse-gas emissions. There are many more. A new technology may appear eliminating the need for fossil fuels. The story is often recounted of how New Yorkers once complained of the mountain of horse manure building up in the city. Before long, some claimed, manure would reach the first floors of many buildings. Then, Henry Ford's internal combustion engine trundled into town. No similar game-changing technology is in sight, yet.

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Exploring scenarios

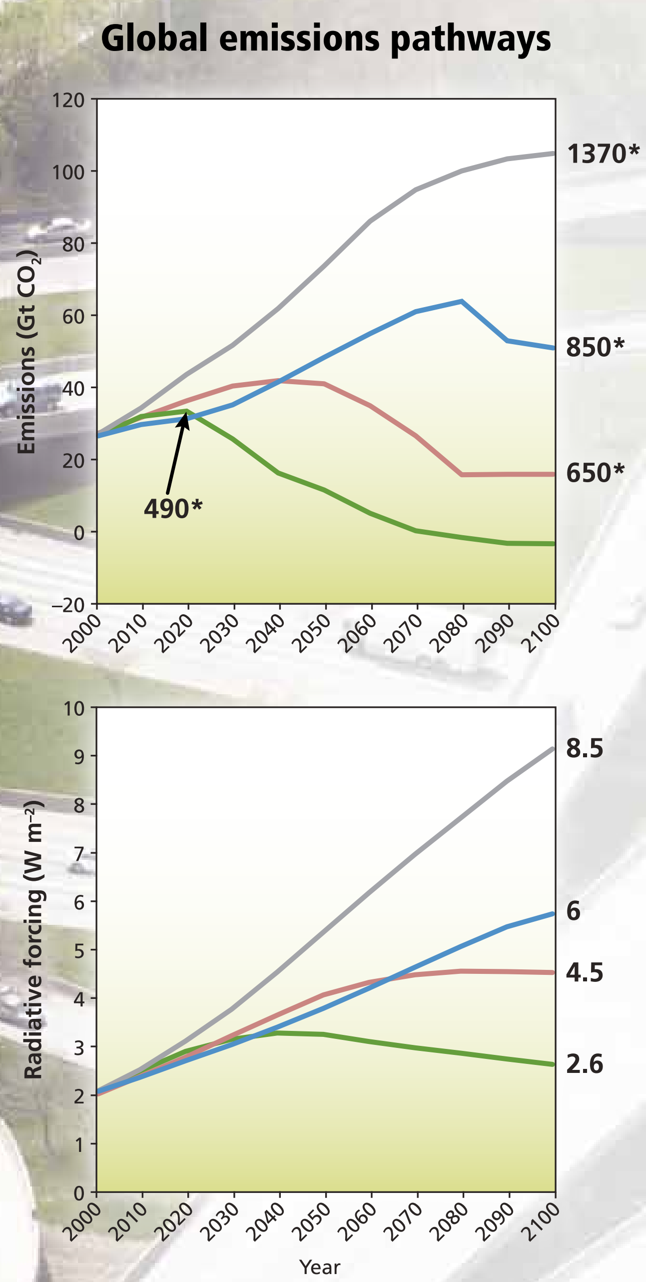
This uncertainty about which direction society will lurch is a massive challenge for climate researchers. It is impossible to pin down a single route, so economists, energy experts and others develop a range of realistic possibilities or scenarios. Climate researchers feed these scenarios into climate models that output likely ranges for global temperature, rain and snowfall and other climate parameters. Specialists in ecosystems, agriculture, water, city planning, economics and other areas take this information and assess impacts and costs.

The importance of these scenarios cannot be overstated. They provide a range of options for the world's governments and other institutions. Some of these options will require the wholesale upheaval of the global energy system, upon which industrialisation has depended. Some options, for example business as usual, require little action.

The pathway society chooses to follow will have profound consequences for developed and developing economies alike. The Global Carbon Project's recent carbon budget shows the business-as-usual option seems to be society's preferred choice for now. This choice has been made despite warnings based on robust and comprehensive scenarios published in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Now, a new way of developing scenarios has been created.

In the past, IPCC had a cumbersome system for turning predictions of energy demands, population growth and political leadership into atmospheric emissions and finally vulnerability assessments.

First, researchers drew up complex future economic scenarios. Second, these families of scenarios – the famous SRES families (Special Report on



The four pathways

Radiative forcing	*Atmospheric CO_2 equivalent (parts per million)	When
8.5	>1370	By 2100, but rising
6	850	Stabilisation after 2100
4.5	650	Stabilisation after 2100
2.6	490	Peak before 2100 then decline

Four plausible global radiative forcing pathways from greenhouse-gas emissions from human activities. The new pathways, known as Representative Concentration Pathways, have been developed for the Intergovernmental Panel on Climate Change Fifth Assessment Report. The numbers associated with each scenario relate to the final radiative forcing (W/m^2) by 2100. The 8.5 scenario equates to little effort to reduce emissions, while 2.6 sees emissions peak early then fall.

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Emissions Scenarios) – fed into climate models. Third, the models informed specialists on impacts, vulnerability and adaptation.

Emissions scenarios emerging in 1997 were used in climate models assessed in the 2001 IPCC Third Assessment Report. Remarkably, scientists from IPCC's Working Group Two (WGII) studying vulnerability, impact and adaptation to climate change had to wait six years, until the 2007 report, to publish assessments of the same scenarios. This complicated how costs and benefits of climate change were calculated because the other two IPCC working groups were already reporting on new scenarios (WGI deals with the physical basis of climate change, WGIII handles mitigation).

IPCC needed something more responsive, and besides, the SRES families had a perceived major drawback: they did not include mitigation. IPCC decided to drop the problem in the laps of the research community. An international group coordinated the work. This was led by IGBP's Earth system modelling project, Analysis, Integration and Modelling of the Earth System (AIMES), the World Climate Research Programme's Working Group on Coupled Modelling (WGCM) and the Integrated Assessment Modelling Consortium. The result was published in the journal *Nature* in February 2010 in a paper entitled "The next generation of scenarios for climate change research and assessment".

The new approach

It all kicked off in summer 2006 with a meeting in Aspen, Colorado. Lead author Richard Moss, from the Joint Global Change Research Institute based at the University of Maryland in the US, explains, "We brought together a range of different modelling communities: climate, chemistry, carbon cycle, terrestrial modellers, land-use specialists, as well as people from the social science side working on emissions, economics, policy, vulnerability and impacts."

The complexity of humanity's future emissions is distilled down to four numbers.

Later, in 2007, more than 150 researchers met in the Netherlands.

The outcome was a rethinking of the entire process. The group came up with the idea of starting with atmospheric concentrations of greenhouse gases rather than detailed socio-economic processes. Climate researcher Nebojsa "Naki" Nakicenovic representing IPCC's WGIII argued that IPCC's old emissions scenarios failed to include mitigation. What happens, he asked, if emissions peak then begin falling? The group concluded that some of the new scenarios should take this into account.

The series of meetings pared down 324 published emissions pathways to just four. The pathways finish in 2100, where the complexity of humanity's future emissions is distilled down to four numbers. These are based on the extra heat, or radiative forcing, the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per metre squared (W/m^2).

The new pathways result in 2.6, 4.5, 6.0 and 8.5 W/m^2 as plausible outcomes by 2100. Earth's radiative forcing is now around 1.6 W/m^2 greater than at the start of the industrial revolution. The four pathways are based on greenhouse-gas emissions that would result in peak atmospheric emissions concentrations equivalent to 490, 650, 850 and over 1370 parts per million CO_2 respectively. The new scenarios were named "representative concentration pathways", or RCPs.

Moss explains, "At the core of the new approach is humans' total radiative forcing on the atmosphere over time."

It was decided four RCPs were enough. AIMES Executive Officer Kathy Hibbard says, "Preliminary results showed that as far as global temperature goes, if radiative-forcing predictions are too close, the span of possible global temperature ranges overlaps too much."

Computer power was another consideration. Earth-system computer models are now so complex that more scenarios would eat up too much computing time.

A significant improvement

The scientists are sure the new approach is a big improvement on its predecessor. While the four pathways allow researchers to develop climate-model scenarios, they do not constrain future work on integrated assessments. These researchers will simultaneously develop a range of completely new socioeconomic and emissions scenarios. They will have complete freedom to develop these new scenarios which will allow them to explore alternative technological, socioeconomic and policy futures.

The researchers believe that the parallel process is a significant improvement for several reasons. First, climate model simulations no longer need to be rerun each time emissions scenarios change. In the past, when the socioeconomic scenarios were modified, the climate model simulations were run again, even though the changes seldom resulted in detectable alterations to the modelled future climates. Indeed, many socioeconomic projections can lead to very similar concentration trajectories.

Eliminating the need to rerun models for each new scenario will save considerably on computing time. The plan is to use this time to generate larger ensembles (running the same model many, many times) at higher resolution. It is anticipated this will lead to better simulations of regional change and extreme events, and more robust understanding of the uncertainties.

Second, in the future, as climate models improve, the newer updated climate models can be run using the same pathways, allowing modellers to isolate the effects of changes in the climate models themselves.

Third, researchers working on impacts, adaptation and vulnerability will get model outputs from climate modellers and emissions and socioeconomic modellers much earlier.

If successful, this approach will be a marked improvement on the previous assessments, and allow WGII more time to complete its part of the Fifth Assessment Report.

At the highest end of the scale, the 8.5 pathway represents a failure to curb emissions. Emissions do not stabilise: they rise beyond 2100.

But is 8.5 still too low given the upshot of the climate negotiations in Copenhagen, the US's internal struggle to curb emissions, the fallout from IPCC's minor blunders and the public outcry at the content of hacked emails from the University of East Anglia?

"Some wanted a much higher radiative forcing. The policy people did not want to hear that," says Hibbard.

But Moss, while not ruling out a higher value, thinks 8.5 is a reasonable upper bound. "You'd have to work hard to get to 8.5. It means burning a lot of coal. Of course, if we get certain feedbacks like more methane escaping from the seabed or forest die-back then this could go higher."

The most ambitious pathway, 2.6, also led to heated debate. Initially, scientists suggested a lowest scenario of 2.9. But policymakers pushed for a harder target claiming society needed a tough goal.

Hibbard says, "The policy people said 2.9 did not represent the full range. It was a charged environment with meetings going into the early morning."

Scientists felt anything below 3 W/m^2 will be tough to achieve. Eventually, the European Union commissioned two groups to redo the analysis. From this there was agreement that 2.6 was possible and it became the fourth pathway. But, 2.6 is going to be difficult if you exclude geoengineering options or some new technology.

"To make 2.6, we'd need universal participation from all the main emitters very soon, including those in developing countries," says Moss. Among many assumptions, it could mean global meat consumption would need to almost reach zero by 2100 – livestock accounts for 18 percent of greenhouse-gas emissions when you factor in the clearing of forested land, making and transporting fertiliser, burning fossil fuels in farm vehicles and the front- and rear-end emissions of cattle and sheep.

A second element of the scenarios is a new focus on atmospheric emissions up to 2035, as well as 2100. This satisfies policymakers' requests for decadal climate predictions. Up to 2035, the four RCP are tightly grouped, so researchers only need to examine one scenario – 4.5. "This frees up processing power and you can work at higher resolution with the expectation that this will provide better information for planning adaptation options in the near term," explains Moss.

An immediate benefit of the RCPs is that they are bringing together a diverse range of research communities. This is an essential step in the drive to create fully integrated Earth-system models that go beyond general circulation models to include the global economy and society, impacts and vulnerabilities.

Beyond this, the outcome of the Copenhagen climate talks notwithstanding, humanity seems to be gearing up to set emissions targets.

Producing future scenarios

Producing future scenarios for climate-change research requires three approaches: integrated assessments, climate models and impact assessments.

Integrated assessments include the main features of human systems: demography, energy use, technology, the economy, agriculture, forestry and land use. They split the world into a dozen or more regions with time steps of about a decade. Some include a rudimentary climate system, ecosystems and climate impacts.

Climate models have a wide variety and complexity. The most complex simulate interactions between the atmosphere, oceans, land and ice. Earth-system models also include additional ecological and chemical processes.

Impact assessments focus on adaptation and vulnerability to climate change. They use a range of approaches to explore the consequences of climate change for agriculture, water resources, human health, ecosystems and coastal infrastructure. Economic evaluation is an important part of this work.

"Science is not going to tell us which trajectory we need to be on," says Moss. "That is a policy decision based on how much risk we want to take and what we value – economic growth? Ecosystems?"

But, it seems certain that global and national emissions controls will be influenced strongly by these kinds of scenarios. Scientists realise this and are careful to avoid any accusation that they are advocating one scenario over another. Indeed, this is reflected in one rationale for choosing four RCPs instead of three.

"We decided on four because if you choose three, people will assume society should aim for the middle," says Hibbard.

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OWEN GAFFNEY is Director of Communications at IGBP.

Moss R H *et al.* (2010) The next generation of scenarios for climate change research and assessment. *Nature* 463: 747-756.