

The
Economist

SPECIAL REPORT
CLIMATE CHANGE

NOVEMBER 28th 2015



AND BOTHERED



Running the world without
consuming the earth?

Naturally.

Hot and bothered

Not much has come of efforts to prevent climate change so far. Mankind will have to get better at tackling it—but must also learn to live with it, says Joel Budd

LOOKING BACK FROM the early 24th century, Charlotte Shortback suggests, half-jokingly, that modern human history can be split into distinct periods. The most exciting was the Accelerando, from about 2160 to 2200, when human lifespans were greatly extended and the terraforming of Mars was completed. That was followed by the Ritard, when the people of Mars lapsed into isolationism. Long before, though, came a strange spell, from 2005 to 2060, when people understood the science of climate

change but did little to prevent it; nor did they try to colonise other planets. She dubs it the Dithering.

Charlotte Shortback is a character in “2312”, a science-fiction novel by Kim Stanley Robinson—one of an oddly small band of authors who have written imaginatively and precisely about climate change. In his fictional future, global warming has turned the Earth into a wet, jungle-like planet. New York City is 11 metres under water. In other places, desperate efforts are under way to hold glaciers in place with liquid nitrogen and dams. Will the world really turn out this way? Almost certainly not: strict accuracy is neither the strength nor the purpose of science fiction. But Mr Robinson is right about the present.

What is happening today might not seem like dithering. In a few days world leaders will gather in Paris for a grand conference on climate change, the 21st such get-together since the United Nations

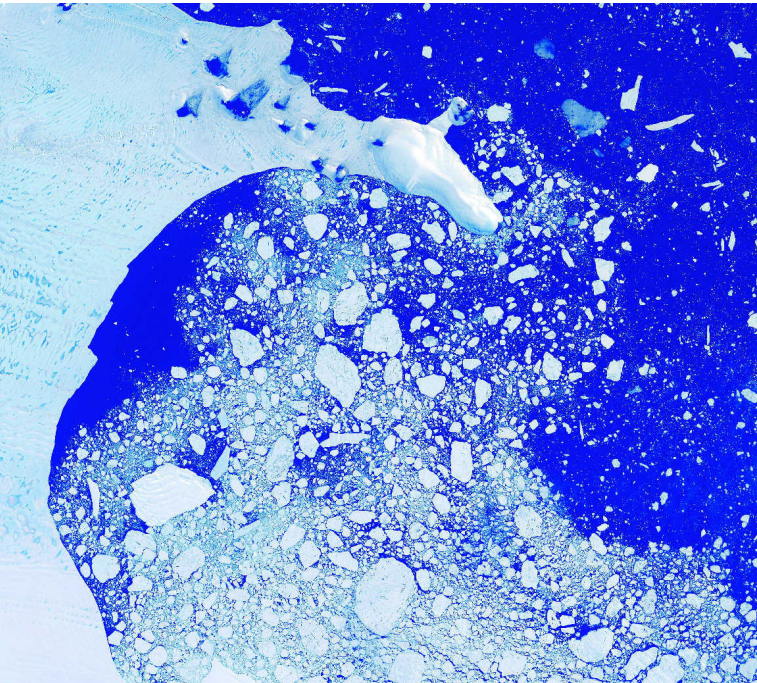
began to grapple with the issue. A torrent of pronouncements and promises has already issued forth—from Pope Francis, Xi Jinping, Barack Obama and many others. The IMF warns that human fortunes will “evaporate like water under a relentless sun” if climate change is not checked soon.

Especially in western Europe, but increasingly in America and China too, wind turbines and fields full of solar photovoltaic panels are becoming familiar features of the landscape. If you buy a car or a house in Europe, or even book a hotel room, you may well be told about its cost in carbon. Many companies, including The Economist Group, monitor their carbon-dioxide emissions and often set targets to reduce them. There is gleeful talk of coal, oil and gas falling from favour so quickly that energy firms will be left sitting on heaps of stranded assets.

None of this, however, amounts to much. At the time of the first UN climate-change conference in 1995, the atmospheric concentration of carbon dioxide was 361 parts per million. Last year it reached 399 parts per million. Between 2000 and 2010 the rise in greenhouse-gas emissions was even faster than in the 1980s or 1990s. The hottest year since records began was 2014; average surface air temperatures so far this decade are

CONTENTS

- 3 The science of climate change**
Supermodels
- 4 Public opinion**
Groupthink
- 5 Energy**
When the wind blows
- 7 China**
Seeing daylight
- 8 Adaptation**
If you can't stand the heat
- 10 Biodiversity**
A modern ark
- 11 Geoengineering**
If all else fails
- 13 The way forward**
Second-best solutions



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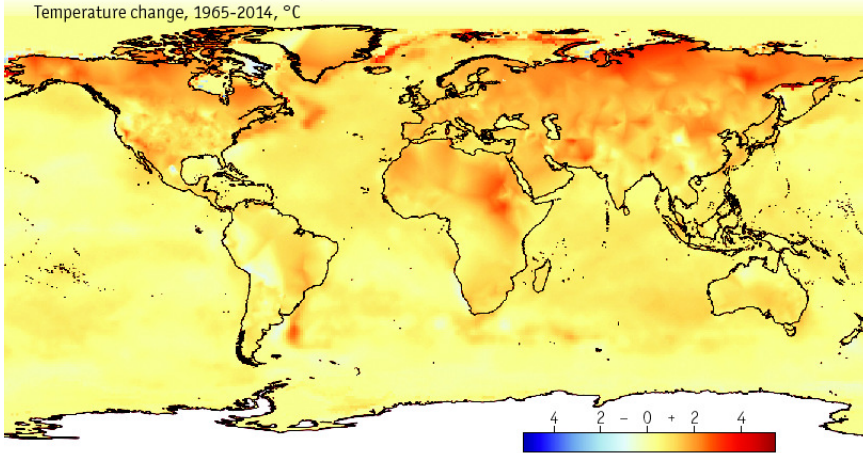
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the author is at
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Trends in land and ocean temperatures

Temperature change, 1965-2014, °C



Source: Prepared by Dr David Schoeman, University of the Sunshine Coast, from data provided by HadISST and CRUTS

agreed: global temperatures must not be allowed to rise by more than 2°C (3.6°F) above pre-industrial levels. Politicians and green groups have argued for years that anything more would be wildly dangerous. Almost every book and report about climate change treats this limit as inviolable.

A question of degree

Barring a global catastrophe or the spectacular failure of almost every climate model yet devised, though, emissions of greenhouse gases will warm the world by more than 2°C. “It’s nice for people to talk about two degrees,” says Bill Gates, a philanthropist and investor. “But we don’t even have the commitments that are going to keep us below four degrees of warming.”

Changes in the atmospheric level of carbon dioxide, the biggest contributor to

global warming, persist for centuries. So it is useful to imagine that mankind has a fixed carbon budget to burn through. Pierre Friedlingstein, a climatologist at Exeter University, calculates that if temperature rises are to be kept below 2°C, the world can probably emit about 3,200 gigatonnes of carbon dioxide in total. The tally so far is 2,000 gigatonnes. If annual emissions remain at present levels, the budget will be exhausted in just 30 years’ time.

Global greenhouse-gas emissions might indeed hold steady for a while. Total man-made emissions in 2014 were about the same as in 2013, according to the International Energy Agency. This year’s figure could even be slightly lower than last year’s. As this special report will show, the pause has little to do with the forests of wind turbines and solar panels that have popped up in Western countries, and much to do with developments in China. Still, given the steep rise in greenhouse-gas emissions in recent years (see chart below), it is welcome.

The bad news is that even if greenhouse-gas emissions are stabilising, they are doing so at an exalted level, and there is little reason to suppose that the plateau will be followed by a downward slope. China might burn a little less coal in the next few years, but India will burn more—and the Chinese will drive more cars. “A lot of poor countries are going to get a lot richer by burning fossil fuels,” predicts Bjorn Lomborg of the Copenhagen Consensus Centre, a think-tank. Rich countries will continue to become cleaner, but not dramatically so, at least when the carbon

▶ about 0.9°C higher than they were in the 1880s. Dieter Helm, an energy expert at Oxford University, points to “a quarter of a century of nothing of substance being achieved”.

The International Energy Agency, a think-tank, estimates that 13.5% of the world’s primary energy supply was produced from renewable sources in 2013. That sounds like a decent slice, but almost three-quarters of this renewable energy came from what are euphemistically known as “biofuels”. This mostly means burning wood, dung and charcoal in poor countries. Hydro-electric power, which has fallen from favour in the West because of its often ruinous effect on river ecosystems, was the world’s second most important source of renewable energy. Nuclear power, which is green but not renewable, supplied 5% of energy needs, and falling. Wind turbines, solar farms, tidal barriers, geothermal power stations and the like produced just 1.3% between them.

The global effort to tackle climate change by imposing caps on countries’ greenhouse-gas emissions, which until recently was described as essential for saving the planet, is over. The UN’s boldest attempt to bind countries, the Kyoto protocol of 1997, expired in 2012. It had achieved little and become unworkable; its passing was not much lamented. No ambitious global deal will be signed in Paris, although whatever document emerges from the conference will no doubt be hailed as significant progress.

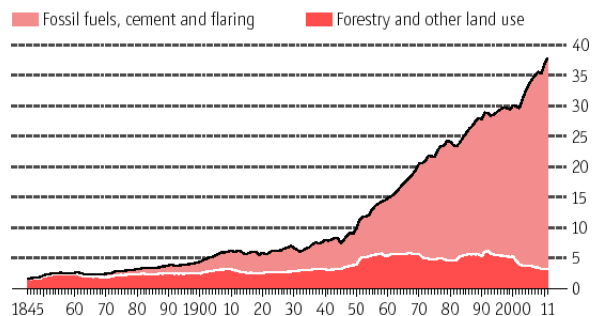
Rather than submitting themselves to caps, most countries now say they intend to reduce, or at least restrain, their own emissions. This fragmented, voluntary approach avoids the debate that had paralysed climate talks for years, about whether the burden of cutting greenhouse gases should be carried just by the rich world or spread more widely (a debate rendered absurd by the rise of China). It has the advantage of inclusiveness. Outside the oil-rich Middle East, which is mostly ignoring the process, countries are at least thinking about what they could do.

The promises they will bring to Paris, known as “intended nationally determined contributions”, are diverse and hard to compare. Still, some are plainly more ambitious than others. America pledges that by 2025 it will cut its greenhouse-gas emissions by 26-28% below 2005 levels. South Korea says that by 2030 its emissions will be 37% below where they would be if the recent upward trend in emissions were projected forward. But even if it manages this, South Korea will be emitting 81% more greenhouse gases in 2030 than it did in 1990.

On one matter the conference delegates have already

Undeniable

Global anthropogenic CO₂ emissions, gigatonnes per year



Source: IPCC

▶ content of the goods they import is added to the reckoning.

Climate change will not be bad for everything and everyone. Some cold countries will find that their fields can grow more crops; others will see fish migrate into their waters. With its ocean-moderated climate, Britain stands out as exceptionally favoured. Yet bad effects will increasingly outnumber benign ones almost everywhere. Some organisms will run into trouble well before the 2°C limit is breached.

This special report will argue that climate change will have to be tackled more intelligently and more economically than it has been so far. Renewable energy is crucial. Contrary to what many claim, though, it is not true that existing solar and wind technologies could cheaply save the planet while also creating lots of green jobs if only they were subsidised for just a few more years. Those renewable power sources have cost consumers dear and mangled energy markets. Paying for yet more wind turbines and solar panels is less wise than paying for research into the technologies that will replace them.

Mankind will also have to think much more boldly about how to live under skies containing high concentrations of greenhouse gases. It will have to adapt, in part by growing crops that can tolerate heat and extreme weather, in part by abandoning the worst-affected places. Animals and plants will need help, including transporting them across national and even continental boundaries. More research is required on deliberately engineering the Earth's atmosphere in order to cool the planet.

It is often said that climate change is an urgent problem. If that were true, it might be easier to tackle. In fact it is a colossal but slow-moving problem, spanning generations. As the next article will show, it is also rather wonderfully mysterious. ■

The science of climate change

Supermodels

What is known about global warming—and what remains dark

IN AN APPROPRIATELY sweltering lecture theatre at the University of Pierre and Marie Curie in Paris, scientists gathered earlier this year to discuss a phenomenon called the global-warming hiatus. Between 1998 and 2012 humans pumped unprecedented quantities of greenhouse gases into the atmosphere, but the average global temperature barely rose. Why?

Because much energy went into melting ice, explained one. Because it was absorbed by the oceans, said another. Because many small volcanic eruptions threw particles into the atmosphere, deflecting solar radiation, explained a third. Nonsense, said a fourth. There was no hiatus at all—1998 was a freakishly hot year, so it was hardly surprising that temperatures bumped around the same level for a few years. At the end, the moderator summed up: “Well, that’s science!”

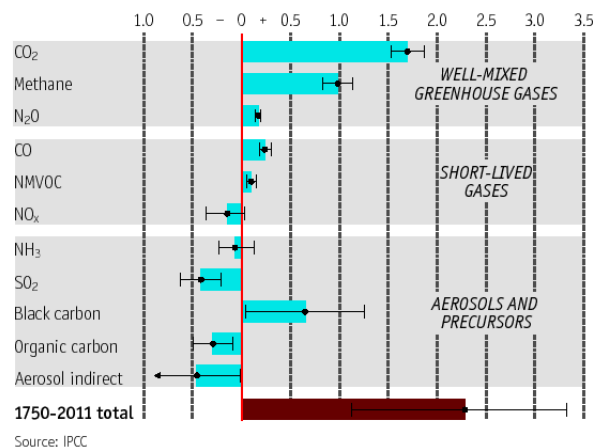
This sort of thing drives green-minded politicians mad. It is hard enough to persuade voters that global warming is a serious danger that they must pay to avoid, in the form of higher energy bills and unsightly wind farms. If the scientists seem unsure, the task becomes impossible. Despite appearances, though, key parts of climate science are settled. Although the remaining uncertainties are a little larger than green groups generally admit, they are not nearly as big as global-warming sceptics suppose.

The greenhouse effect itself is straightforward; it just does

It adds up

Components of anthropogenic radiative forcing 1750–2011, watts per square metre

← 95% confidence limits



not work much like a greenhouse. About one-third of the energy that pours into the Earth from the sun reflects off clouds and the planet's surface and heads back into space. Much of the rest is absorbed by the land and the oceans, which then emit it largely in the form of infra-red radiation. This is absorbed by trace gases in the atmosphere, which in turn release infra-red upwards, sideways and downwards to the Earth's surface. It is this bouncing around of energy that is known as the greenhouse effect. It is essential to life on Earth; without it, the average temperature at the Equator would be -10°C.

The most important greenhouse gas is water vapour. Were there no water vapour or clouds, the greenhouse effect would be only about one-third as powerful as it is. Carbon dioxide is the second most important, followed by methane, then chlorofluorocarbons (CFCs), industrial chemicals that were cracked down on in the 1980s and 1990s because of their ozone-depleting properties but are still hanging around. These gases are more or less potent and durable. Tonne for tonne, methane is a much more powerful greenhouse gas than carbon dioxide, but it breaks down more quickly. Carbon dioxide, which reaches its maximum warming effect about ten years after being released, is so stable that even 1,000 years after a bump in emissions, atmospheric levels will still be substantially higher than normal.

The basic science is hardly novel. In the 1890s a Swedish scientist, Svante Arrhenius, ran some “tedious calculations” on the greenhouse effect and went on to explain how burning fossil fuels might intensify it (living in a cold country, he thought this a thoroughly good thing). Things get complicated when scientists try to work out what happens to the extra energy that remains in the Earth system and how other human activities, beyond emitting greenhouse gases, might also affect the climate.

Beware the feedback loops

Greenhouse warming sets off a cascade of effects known as feedbacks, which are harder to measure. On balance, warming begets more warming. Higher temperatures enable the atmosphere to hold more water vapour. Oceans absorb huge amounts of carbon dioxide, keeping a lid on climate change—but as they warm up, their absorption capacity declines. Melting ice produces dark pools of water that absorb more energy. Partly for this reason, the Arctic is warming faster than other places.

Inadvertently, though, humans also cool the Earth. Al- ▶▶

▶ though the overall effect of deforestation is to warm the planet, replacing trees with crops or grassland makes the land paler and more reflective. Particles created from sulphur dioxide—the cause of acid rain—reflect lots of light back into space. China has probably been shielded from higher temperatures by air pollution, and might heat up quickly if it gets serious about scrubbing its skies.

The greatest mystery is the effect of human activity on clouds. Because clouds grow on aerosol particles, more of them are likely to form in a more polluted atmosphere. Clouds are also affected by temperature changes. But precisely how is unclear—and this matters, because whereas high clouds tend to keep the Earth warm, low clouds tend to cool it. Part of the problem in measuring their effect is that many clouds are small. Climate models tend to simplify the world by dividing the atmosphere and the oceans into boxes, perhaps 50km by 50km in the hori-

zontal plane, and treating these as pixels in a giant three-dimensional computer simulation. To capture cloud processes properly might require climate models with cells just tens of metres square. No computer in the world could handle that.

Add up all these difficulties, throw in some problems with measuring temperatures, and you get a lot of uncertainty. The chart on the previous page, which shows the estimates by the International Panel on Climate Change (IPCC) of “radiative forcing”—perturbations to the Earth’s energy system from human and other activities—contains black bars showing 95% confidence ranges. Some of those bars are long. It is especially hard to be sure of the effect of aerosols.

If the past is a little hazy, the future is more so. Not only does it depend on the outcome of physical processes that are inadequately understood. It also depends on human actions. How many people will be living in 2100? How rich will they be? Will they make strenuous efforts to cut greenhouse-gas emissions, do nothing, or something in between?

If mankind makes heroic efforts, the Earth system will remain within familiar bounds, making predictions easier. If concentrations of greenhouse gases increase steeply, though, things become highly unpredictable. Passing irreversible tipping points, such as the collapse of the Greenland ice sheet, becomes more likely. If nothing were done to avert climate change by 2200, the IPCC estimates, the world would probably warm by between 3°C and 10°C. That enormous range is manageable at one end, unimaginable at the other.

Much remains unknown, then. But, equally, much has been settled—it is just that the settled stuff generates fewer papers and conference panels, because researchers have moved on. Some possibilities that seemed troubling a few years ago have been probed and revealed to be less so. It now appears unlikely, for example, that climate change will lead to the irreversible collapse of the Gulf Stream. Melting permafrost will emit methane, but not as much as some once feared.

Even those mysterious clouds are giving up some of their secrets. Satellite-based radar and laser measurements have enabled scientists to peer into clouds; small-scale models designed to capture their behaviour have been refined and plugged into global models. It seems increasingly likely that low cloud cover will diminish as the Earth warms, speeding the process.

Most important, the basic proposition of climate change—the causal relationship between greenhouse-gas emissions and higher temperatures—has become almost unassailable. As it happens, the interesting debate about the global-warming hiatus has a boring coda: 2013 turned out slightly hotter than 1998, and 2014 was roasting, setting a new record. That will not stand for long. ■

Groupthink

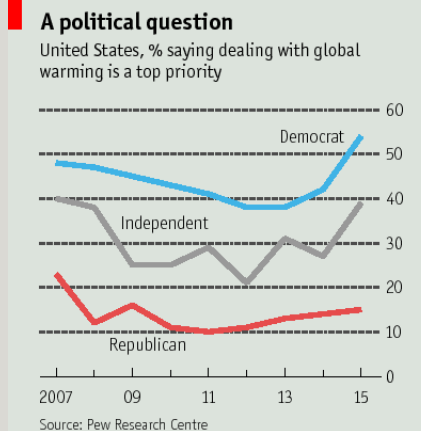
People’s views on climate change go hand in hand with their politics

FOR ALL THE torrent of scientific reports, books and television documentaries on the subject, climate change commands a good deal less public attention than Kim Kardashian, a reality-TV star. Early in 2007 Google searches for Ms Kardashian’s name overtook searches for “climate change”. She has never fallen behind since. Even Bangladeshis Google her more than they do the forces that threaten their country—in English, at least.

The rich are more concerned about climate change than the poor, who have many other things to worry about. A giant opinion-gathering exercise carried out by the United Nations finds that people in highly developed countries view climate change as the tenth most important issue out of a list of 16 that includes health care, phone and internet access, jobs, political freedom and reliable energy. In poor countries—and indeed in the world as a whole—climate change comes 16th out of 16.

Even in the rich world, interest flagged for a few years following the financial crisis of 2007. It is now recovering a little. But in America, another psephological trend is plain: attitudes to climate change have become sharply polarised along political lines (see chart).

“The partisan divide started in 1997,” says Jon Krosnick of Stanford University. That was when a Democratic president, Bill Clinton, threw his weight behind the UN effort to introduce mandatory caps for greenhouse-gas emissions. It has since widened. YouGov, a pollster, found in 2013 that 70% of Democratic voters saw evidence of man-made climate change in recent weather patterns, whereas only 19% of



Republican voters did. A similar, though smaller, divide was found in Britain.

It is not that conservatives are ignorant. Knowledge of science makes little difference to people’s beliefs about climate change, except that it makes them more certain about what they believe. Republicans with a good knowledge of science are more sceptical about global warming than less knowledgeable Republicans.

The best explanation for the gap is that people’s beliefs about climate change have become determined by feelings of identification with cultural and political groups. When people are asked for their views on climate change, says Dan Kahan of Yale University, they translate this into a broader question: whose side are you on? The issue has become associated with left-wing urbanites, causing conservatives to dig in against it. The divide will probably outlive Ms Kardashian’s fame.



Energy

When the wind blows

Renewable power is good. More renewable power is not always better

ON A BREEZY, sunny day in north-east Germany it seems as though the world is running on renewable energy. Near Altentreptow 50-odd giant wind turbines, the tallest 200 metres high, spin above a potato field, making a gentle swishing sound. The hum from the base of each turbine is the sound of electricity being generated, much of it bound for Berlin. The view from the wind farm, across flat fields, is of another wind farm.

Sadly, this is not how the world's power is generated. In truth, the view from Altentreptow does not even properly reflect how Germany's power is generated. The battle to drive carbon dioxide out of the world energy system, which accounts for about two-thirds of human greenhouse-gas emissions, has seen some heartening and visible advances. But clean energy is still being soundly thrashed by the dirty sort.

Even as the wind turbines and solar panels began to spread across the fields of Europe, an ancient black fuel was making a comeback (see chart). In 2000 the world's coal-fired power stations were capable of producing 1,132 gigawatts of electricity between them, according to Enerdata, a Paris-based research firm. By 2014 so many new power stations had been built that they could put out 1,980 gigawatts. Coal, which is about twice as polluting as natural gas, now supplies 41% of the world's electricity and 30% of its overall energy needs.

The biggest single cause of the fossil-fuel boom is China, which is examined in the next article. But rich Western countries are more culpable than they think. They have transformed their rural landscapes with wind farms and pushed up electricity prices for consumers, yet have managed to drive surprisingly little carbon out of the energy system. The record would look even worse if Western countries had not simultaneously exported much of their heavy industry, and thus much of their pollution, to China and other emerging countries.

The large wind farm near Altentreptow is one of hundreds in Germany. Helped by some big storms, these turbines produced 41,000 gigawatt-hours of electricity in the first half of this

year, 15% of Germany's total electricity output. Add hydro-electric power stations, solar farms and biomass, and the country derived 35% of its electricity from renewable sources. Germany has become a world leader in green power, but also a warning about what can go wrong.

Wind and sunshine have two big drawbacks as sources of power. First, they are erratic. The sun shines weakly in winter when it shines at all, and the wind can drop. On January 20th this year the output from all of Germany's solar and wind farms peaked at just over 2.5 gigawatts—a small proportion of the 77 gigawatts Germany produced that day. A few months later, during a sunny, windy spell in early June, the combined wind and solar output jumped to 42 gigawatts.

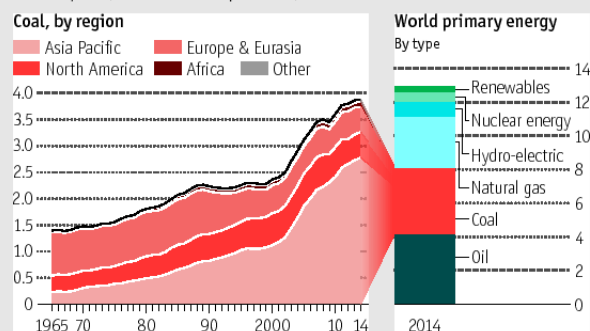
The second problem with wind and solar energy, oddly, is that it is free. Wind turbines and solar panels are not free, of course. Although the cost of solar photovoltaic panels has plunged in the past few years, largely because Germany bought so many, wind and solar farms still tend to produce more expensive electricity than coal or gas power stations on a “levelised cost” basis, which includes the expense of building them. But once a wind or solar farm is up, the marginal cost of its power output is close to zero.

The problem lies with the effect of renewables on energy markets. Because their power is free at the margin, green-power producers offer it for next to nothing in wholesale markets (they will go on to make money from subsidies, known as feed-in tariffs). Nuclear power stations also enter low bids. The next-lowest bids tend to come from power stations burning lignite coal—a cheap but especially dirty fuel. They are followed by the power stations burning hard coal, then the gas-fired power stations. The energy companies start by accepting the lowest bids. When they have filled the day's requirements, they pay all successful bidders the highest price required to clear the market.

The surge of solar and wind power is pushing down the clearing price and bending Germany's energy market out of shape. Power stations burning natural gas increasingly find no takers for their electricity, so they sit idle. Meanwhile the cheap, carboniferous lignite power stations burn on (see chart, next page). Coal-fired power capacity has actually increased in the past few years. Coal is likely to become even more important to

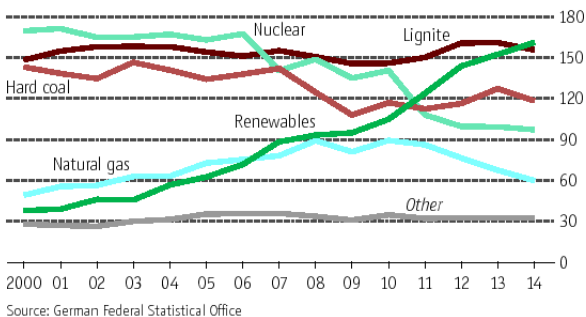
Where coal is king

Consumption, tonnes of oil equivalent, trn



A grubby mix

Gross electricity generation in Germany by energy source
Terawatt hours (TWh)



- ▶ Germany's energy supply in future because the government is committed to phasing out nuclear power by 2022.

One of Germany's biggest coal-fired power stations, Jämschwalde, sits near the border with Poland. Built in the 1980s, it burns 80,000 tonnes of lignite a day and can put out three gigawatts of power. Jämschwalde has also become ever more flexible, ramping up and down speedily as the weather changes. Lignite is proving to be an excellent partner for erratic wind and solar power, argues Olaf Adermann of Vattenfall, the firm that owns Jämschwalde. Sadly for the environment, he is right.

Earlier this year a shamefaced German government moved to regulate lignite-burning power stations out of existence, but after thousands of miners protested in Berlin, it dropped that

Terrified of looming blackouts, many Western governments are increasingly paying fossil-fuel power stations to stay open

policy. The country appears to be stuck with coal. It is likely to miss its self-imposed target for reducing greenhouse-gas emissions, reckons McKinsey, a consultancy. And because of generous feed-in tariffs for renewables that are guaranteed for 20 years, consumers in Germany are paying high prices for their not especially clean power. In the first half of this year households there paid €0.30 for a kilowatt-hour of electricity, whereas the French paid a mere €0.16.

Germany has made unusually big mistakes. Handing out enormous long-term subsidies to solar farms was unwise; abolishing nuclear power so quickly is crazy. It has also been unlucky. The price of globally traded hard coal has dropped in the past few years, partly because shale-gas-rich America is exporting so much. But Germany's biggest error is one commonly committed by countries that are trying to move away from fossil fuels and towards renewables. It is to ignore the fact that wind and solar power impose costs on the entire energy system, which go up more than proportionately as they add more.

Many wealthy countries have too many power stations, the result of a building boom before the financial crisis. This oversupply, combined with the solar- and wind-power boom and the falling wholesale price of electricity, has crushed investment in modern, efficient power stations. It has also turned all energy producers into beggars. Owners of power stations burning coal and gas point out that if they are frequently undercut by wind and solar farms, their costs per watt of electricity produced rise.

The government ought to compensate them for that, they say, otherwise they might have to close down.

Terrified of looming blackouts, Western governments are increasingly paying fossil-fuel power stations to stay open. Some offer "capacity payments"—money for standing by. Texas tries to keep the power stations open by promising higher prices at times of strong demand. These payments are a hidden cost of using more wind and solar energy.

Moreover, in many countries, including America, renewable-power producers rely on coal- and gas-fired power stations to set the market price of electricity at a healthy level, points out Frank O'Sullivan, an energy researcher at the Massachusetts Institute of Technology. Solar farms that offer their power for next to nothing will eventually depress the market so much that they render themselves uneconomic without heavy subsidies.

There are ways out of this mess. If governments were to levy a hefty tax on carbon, they would drive the most polluting power stations off the system. Germany does not do this: it relies on the European Emissions Trading System, which sets a rock-bottom carbon price. But Sweden does, and Britain has a floor price, which amounts to the same thing. Better still, says Mr Helm at Oxford University, a heavy carbon tax could be combined with market reforms that would force renewable power producers to bear the costs of their intermittency.

It would help if electricity grids were bigger and more efficient. The larger the grid, and the less power lost per kilometre of transmission, the less intermittency matters: cloudy and windless conditions rarely prevail across an entire continent. Denmark gets away with relying heavily on wind turbines because it has a connection to Norway, which can supply hydro-electric power on demand. But Germany's efforts to build long-distance transmission lines have been stymied by not-in-my-backyard protests.

Better energy storage would help, too. Hydro-electric power stations have been used to store energy for decades. But there is not always an uphill reservoir handy, and other ways of storing energy, such as lithium-ion batteries, are expensive. More promising, probably, is automatic demand reduction. Smart meters can turn down household freezers and air-conditioning units briefly when power is in short supply and then power them up again, thereby shifting demand. Sia Partners, a consultancy, estimates that European countries could cut peak demand by 9% with such methods.

But they can do only so much. Energy storage and demand-response technologies are good for matching supply with demand during the course of a single day. In a place like California, power demand is highest on sunny summer afternoons, when people turn up their air-conditioners. Solar farms produce most of their power around the same time, so with a bit of clever demand adjustment the peaks of supply and demand could be aligned. In northern Europe, however, electricity demand is highest in the early evening in winter, when solar farms are producing no power.

Near Altentreptow, electricity from the wind farm is being used to turn water into hydrogen and oxygen. The hydrogen is stored in tanks and burned to produce power when the wind drops. The firm doing this, WIND-Projekt, just wants to be able to keep the lights on. The process is inefficient: 84% of the original electricity gets lost in being converted and reconverted. But perhaps the hydrogen could be sold directly to consumers, or the heat could be captured. At any rate, suggests Marcus Heinicke of WIND-Projekt, the days of being able to sell power only when the wind blows will not last for ever. ■

China

Seeing daylight

The world's biggest polluter cleans up

WHEN THE NATIONS of the world first tried to cut a deal to reduce greenhouse-gas emissions, in the late 1990s, a gorilla stood in the way. America, then the world's biggest polluter, would not consent to mandatory reductions, all but strangling the accord. These days China is the biggest polluter and the country without which no global agreement will stick. But it is not quite the climate pariah that it is often thought to be, and it has started to change.

China emits more greenhouse gases than anywhere else in the world partly because it has a lot of people: 1.4 billion, compared with 800m for America and the EU put together. And much of the pollution it causes comes from making goods for other countries. The chart on the next page, which uses data from Michael Grubb of Imperial College London, controls for both of these things. It shows that, once the pollution that goes into traded goods is assigned to the country that consumes them, the average Chinese person harms the planet less than does the average European and much less than the average American. He is catching up fast, though.

China was responsible for three-quarters of the net coal-fired power-generating capacity added worldwide between 2000 and 2014. And the country's hunger for the black stuff is not

limited to its power stations. At least a quarter of Chinese coal is used in what Laszlo Varro, a fossil-fuels expert at the International Energy Agency, calls a "Dickensian" manner. Burned, inefficiently, in boilers to heat buildings and power textile mills, it has fouled the air around Chinese cities, turning them into simulacra of 19th-century Manchester.

Climate-change denial is strikingly rare among China's political leaders, some of whom trained as engineers. They understand that their country is expected to suffer some of the worst consequences of global warming: northern China, which is increasingly hot and dry, will probably become hotter and drier still. The politicians are also well aware that their country's urbanites are fed up with breathing toxic air. Earlier this year an online documentary film about air pollution, "Under the Dome", was watched perhaps 300m times before being ordered off the Chinese internet.

Before 2012 no city disclosed air-quality data, recalls Ma Jun of the Institute of Public and Environmental Affairs in Beijing. Now about 400 do. Around the big cities, heavy polluters are increasingly chivvied to clean up. To an extent, the problem is simply being pushed from China's coastal cities towards the interior. But that is progress of a kind. The coal-fired power stations that are shutting on the east coast are some of the most polluting in the world. The new ones being built in the west are some of the world's best. They burn coal at higher temperatures and use higher pressures, making them more efficient.

China is also throwing money at nuclear power and renewables. It spent almost one dollar in every three invested in renewable energy around the world in 2014, according to Bloomberg New Energy Finance, a research firm. Last year China got about 11% of its energy from renewables, helped by an unusual quantity of rainwater to power its hydro-electric stations. The country ▶▶



A hazy prospect of cleaner air

▶ also claims to have connected five gigawatts of solar-power capacity to the grid in the first three months of this year—almost the equivalent of all the solar panels in France.

Some of this renewable power is wasted. In China's command-and-control energy market, power stations are contracted to produce electricity months in advance. Although the energy companies are supposed to favour renewables, they find them hard to handle because their supply is not reliable. And many coal-fired power stations supply heat as well as electricity to local customers, making them preferable to solar and wind farms in winter. In short, says Li Shuo of Greenpeace, an environmental group, China is trying to plug 21st-century power sources into a 20th-century power grid. Behind closed doors, though, officials are working to make the energy market a little more welcoming to green power.

Tower blocks don't grow to the sky

Even more than the clean-air regulations or the renewables, it is China's economic slowdown and the shift from heavy industry and construction to services that has been curbing demand for coal. Mr Varro points out that China can hardly go on consuming energy-intensive goods like steel and cement the way it has done. In 2012 Chinese cement consumption amounted to 1,581 kilograms per person, compared with just 232kg in America. Eventually the roads and tower blocks will have been built and demand will plunge.

Nobody quite knows how much coal is burned in China. Misreporting is common: earlier this year official statistics were amended to suggest that the country had consumed 14% more coal between 2000 and 2013 than had been thought. Yet the quantity might now be falling. Consumption seems to have dropped very slightly between 2013 and 2014. In the first seven months of this year China's mines produced 5% less coal than they did during the same period last year. If this trend were to continue, it would make the government's pledge to reach peak greenhouse-gas emissions by 2030 seem unduly modest.

China will remain a heavy polluter. Though steel and cement factories will probably use less energy in future, ordinary people will doubtless consume more. As they grow richer, they demand air-conditioning, cars and bigger homes: in 2012 the average city-dweller inhabited 33 square metres, compared with 25 square metres a decade earlier. Still, the astonishing surge in dirty, coal-fired energy consumption has probably subsided, thinks Mr Grubb. It might just be a little hard to see, through the hazy, choking air. ■



Adaptation

If you can't stand the heat

How farmers in poor countries are responding to climate change

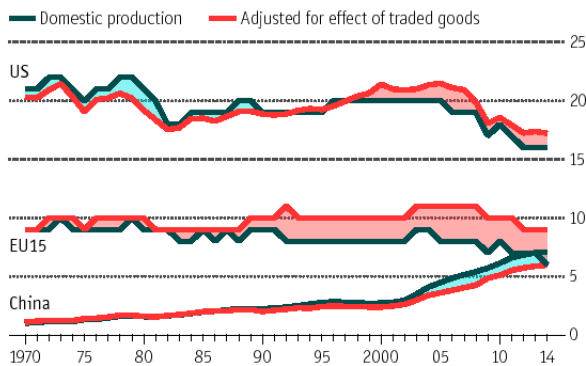
IN THE BRACKISH coastal districts of southern Bangladesh, weather can be measured in centimetres. Women in Bujbunia, 140km (about 90 miles) south of Dhaka, hold their hands at knee height to show how deeply the village flooded during the most recent big cyclonic storm. Aila swept northward through the Bay of Bengal and hit Bangladesh in May 2009. The country had seen much bigger weather events; in 1991 a huge cyclone killed about 140,000 people. Still, Aila's storm surge brought enough seawater to inundate villages and wipe out rice crops. The inhabitants of Bujbunia still wince when they recall how hungry they were afterwards.

Few countries of any size are more gravely threatened by climate change than Bangladesh (which has more than 110m people). Sarder Shafiqul Alam of the International Centre for Climate Change and Development in Dhaka checks off the many hazards. North-west Bangladesh seems to be turning drier. In the north-east and central parts of the country, flooding is a growing danger. The south and east are vulnerable to cyclones, which will probably intensify as the planet heats up (the higher the temperature, the more energy in the weather system). The south is also becoming saltier, partly because the sea is rising and partly because many farmers are inundating their fields with seawater so they can grow shrimp.

To counter the most spectacular threat to human life, Ban- ▶▶

Learning curves

CO₂ emissions per person, tonnes



Source: Michael Grubb



who are living far away. Adaptation requires none of these things. “Because of the free-rider problem, each of us has very weak incentives to alter our behaviour,” says Matthew Kahn, of the University of California, Los Angeles. “But we have very strong incentives to respond to whatever the climate throws at us.”

Bewket Amdu, Azemeraw Ayehu and Andent Deressa have surveyed almost 400 villagers in the upper catchment of the Blue Nile in Ethiopia and found that almost everybody believes temperatures are rising. Most villagers also think less rain is falling, although some are convinced the weather has become wetter. They have responded by tweaking their farming techniques. The villagers now plant potatoes two to three weeks later than they used to and harvest them a week earlier. The growing seasons for wheat and barley have also contracted by about a month. Yields are lower, but that is preferable to losing an entire crop to flooding or drought.

To save farmers from having to make such dismal trade-offs, laboratories in Africa and elsewhere are developing crops that can survive more extreme weather. One poetically nicknamed innovation is “scuba rice”, which can endure being submerged for up to two weeks.

BRAC, a large NGO based in Bangladesh, is training farmers to switch from ordinary rice to salt-tolerant varieties, or to grow sunflowers instead. It has also pioneered a combination of agriculture and aquaculture. During the monsoon season farmers raise freshwater fish in their flooded fields. As the ground dries out, the fish move to a pool at one end, freeing the remainder of the field for rice-growing.

Adaptations like these are conservative. They enable farmers to keep living in the same place and working the same fields, albeit growing different things. The hope is that higher agricultural productivity will protect people against climate shocks and also keep them from encroaching on forests. The rate of deforestation has slowed around the world in the past few decades, mostly because of better policing in Brazil, but last decade it still accounted for about 12% of global greenhouse-gas emissions.

Yet poor farmers will continue to live dangerous, precarious lives. Homes built of bamboo and corrugated iron in southern Bangladesh will not survive a really big cyclone, no matter how high they are raised off the ground. And cyclones are far from the only hazard in the region. To cook food, the farmers who live in these flimsy homes burn wood and animal dung, and thereby gradually poison themselves. Some of the water wells are contaminated not just with salt but with arsenic.

Urban idyll

To protect themselves against these diverse dangers, the farmers of southern Bangladesh need to make drastic changes. They are doing that by investing in their children’s education. In a secondary school in the settlement of Sreefaltola, a class of eighth-graders, mostly farmers’ children, shout out their plans for the future. Almost every one of them aspires to be an electrical engineer or a doctor, or at least to find a job in a nearby city. Not all will succeed; many will probably stay in farming. But those who make it might be able to move their parents out of one

▶ Bangladesh’s government has built several thousand cyclone shelters—at best, sturdy buildings sitting atop pillars of reinforced concrete, which in normal times are often used as schools. One new shelter a few kilometres from Bujbunia could accommodate more than 1,000 people if they were to press closely together, and might even hold a few hundred cows on the ground floor. Women and children will rush there if a big cyclone threatens; men will head for the nearest brick-built mosque.

Farmers are also preparing for storm surges in a humbler way. Scooping up greyish mud, they build plinths up to a metre high. Levelled and packed down, these become the floors of their homes; walls and roofs are made of palm fronds, bamboo and corrugated iron. The aim is to build the plinth higher than the flood waters will reach, to prevent the family’s food and possessions being swept away. Even stoves would be destroyed; they are only made of earth.

Whereas the global attempt to avert global warming by cutting emissions is not exactly racing forward, adaptation to climate change is well under way. Between 1993 and 2009 the proportion of American households with air-conditioning rose from 68% to 87%. Californian cities are coping with an epic four-year drought, which may have been exacerbated by climate change, by buying water rights from farmers and recycling more waste water. San Diego is building an expensive desalination plant. In sub-Saharan Africa many farmers are diversifying from growing wheat to sorghum and other crops. Few of the people making such adjustments are thinking explicitly about global warming; they are simply trying to make themselves more comfortable and secure. Yet their actions add up to the most profound and intelligent response to climate change so far.

Bringing down emissions of greenhouse gases asks a good deal of people, not least that they accept the science of climate change. It requires them to make sacrifices today so that future generations will suffer less, and to weigh the needs of people



► of the most hazardous places in Asia.

This is not normally what is meant by adaptation to climate change. All the same, it is the most effective method of adaptation in Bangladesh, says Mr Alam. Some have taken it even further. In the village of Gobindapur, a grand new house is being built, two storeys high and made of solid brick. It belongs to Reshma Begum, an imperious woman in a pink sari. Clutching two mobile phones, she complains that it is becoming increasingly hard to find domestic workers now that so many young women in the village are running small businesses. Some of her income comes from a son who works in Malaysia.

Migrations such as these are beginning to show up in official statistics. Between 2001 and 2011 the population of Barisal division in southern Bangladesh fell slightly, even as numbers in the country as a whole went up. Within the district, people moved from the countryside to cities, so that Barisal's rural population dropped from 1.96m to 1.81m. By removing people from the most flood-prone areas, urbanisation may be doing as much to preserve life as any number of cyclone shelters.

A decade ago adaptation was almost taboo in international discussions about climate change, because it was believed to distract attention from the task of stopping global warming altogether. Now both are recognised as important. Rich countries are trying to rustle up \$100 billion a year by 2020 to help poor countries cope with climate change—a bribe to keep them coming back to the climate talks, to be sure, but also a welcome sign of changing priorities. Even China is chipping in.

It is not yet clear whether the money will be spent on better crops and fertilisers or on solar panels and other green-energy schemes that will help poor countries hold down their greenhouse-gas emissions. Britain, which spends an unusually large share of its budget on foreign aid, suggested in September that its contribution to the Green Climate Fund would be divided evenly between those two things.

That is the wrong balance. Solar panels are nice to have; many Bangladeshi farmers already possess small ones which they use for charging mobile phones and powering a couple of light bulbs. But these are no substitute for reliable electrical power, and there are plenty of more important things. Diverting money that would otherwise be spent on health and sanitation to expensive forms of clean energy will make it harder, not easier, for the world's poorest people to cope with climate change. ■

Biodiversity

A modern ark

To save endangered species, move them to more congenial places

ALONG THE BANKS of the Apalachicola river, near the border between Florida and Georgia, lives a rare tree called a stinking cedar. Once common, *Torreya taxifolia* seems to have got stuck in this tiny pocket as the continent warmed after the last ice age. It cannot migrate northward because the surrounding soils are too poor. Attacked by fungi, just a few hundred stinking cedars remain along the river. Rising temperatures now threaten to kill them off entirely.

Spying a looming extinction, a group of people is engaged in a kind of ecological vigilantism. The self-styled "Torreya Guardians" collect thousands of seeds a year and plant them in likely places across the eastern United States. Stinking cedar turns out to thrive in North Carolina. The Torreya Guardians are now trying to plant it in colder states like Ohio and Michigan as well. By the time the trees are fully grown, they reason, temperatures might be ideal there.

Some are dubious. The Torreya Guardians were at first seen as "eco-terrorists spreading an invasive species", remembers Connie Barlow, the group's chief propagandist. She rejects that charge, pointing out that she is only moving the tree within America. She also thinks that drastic action of this kind will soon be widespread: "We are the radical edge of what is going to become a mainstream action."

Conservation is nearly always backward-looking. It aims to keep plants and animals not just where they are but where they were before humans meddled. The only real debate is over how far to turn back the clock. Scotland and Wales have been heavily grazed for centuries, giving them a bald beauty. Should they now be reforested, or "rewilded", as the trendy term has it? Should wolves be encouraged to reclaim their ancient territory in America's Rocky Mountains?

In a rapidly warming world, this attitude is becoming outdated. No part of the Earth can be returned to a natural state that prevailed before human interference, because humans are so rapidly changing the climate. Conservation, as traditionally practised, is being overtaken by fast-moving reality. In future the question will no longer be how to preserve species in particular places but how to move them around to ensure their survival.

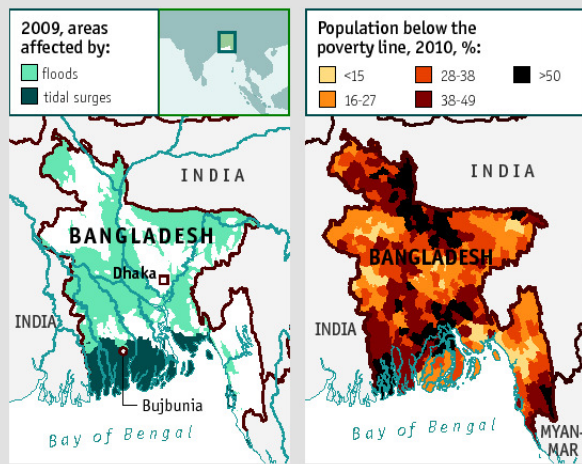
A cool move

Global warming has already set off mass migrations. Having crossed the Baltic Sea, purple emperor butterflies (pictured above) are fluttering northward through Scandinavia in search of cooler temperatures. Trees and animals are climbing mountains. The most spectacular migrations have taken place in the oceans, says Elvira Poloczanska of CSIRO, Australia's national science agency. Many sea creatures can move quickly, which is just as well: in the oceans it is generally necessary to travel farther than on land to find lower temperatures. Phytoplankton populations are moving by up to 400km a decade.

Not all plants and animals can make it to new homes, though. Some will be hemmed in by farmland, cities or coasts. Animals that live in one mountain range might be unable to cross a hot plain to reach higher mountains. And many will find that the species they eat move at a different speed from their



In the climate crosshairs



Sources: World Bank; Bangladesh Bureau of Statistics; World Food Programme

► own: carnivorous mammals can migrate more quickly than rodents, which in turn migrate faster than trees. The creatures that already inhabit the poles and the highest mountains cannot move to cooler climes and might be done for.

It is not clear that climate change has yet driven any species to extinction. Frogs native to Central and South America have been wiped out by a fungus to which they may or may not have become more vulnerable as a result of changing temperatures. Yet the speed at which species' habitats are shifting suggests they are already under great pressure—which will only increase in the next few decades. Chris Thomas, an evolutionary biologist at the University of York in England, has estimated that by 2050 between 18% and 35% of species could be on the path to extinction.

A few years ago Mr Thomas helped transport hundreds of butterflies—marbled whites and small skippers—to Durham, at least 50km north of their usual range, and released them into the cooler air. The butterflies fared well. These days he thinks bigger. Why not move creatures farther, he suggests, to places where they have never lived?

He suggests several candidates for “assisted colonisation” to Britain. The Caucasian wingnut tree, which clings on in a few moist parts of Turkey and Iran, could probably be planted widely. De Prunner's ringlet, an endangered butterfly native to southern Europe, feeds on grasses that are common in Britain. The Iberian lynx, an endangered cat, would find lots of rabbits to eat. Britain is a highly suitable ark for other countries' endangered species: thanks to the Gulf Stream, its climate is expected to remain broadly constant over the next few decades.

The notion of deliberately moving species a long way from home is starting to look a little less heretical. The International Union for Conservation of Nature, which shapes biodiversity policy, recently revised its guidelines, apparently giving a slight nod to such relocations. It insists upon great caution. But “if you have too much risk assessment, nothing will happen, and these species will go extinct,” says Mr Thomas. ■

Geoengineering

If all else fails

Man-made global cooling is scary, but may become necessary

THE SUM OF human tinkering with the climate since the beginning of the industrial era is sometimes likened to a planetary science experiment. That captures the magnitude of what is happening and the unpredictability of its results, yet it is also misleading. Global warming is not an experiment, because it is not intentional. Greenhouse-gas emissions are the unfortunate side effects of useful things like modern agriculture, electricity generation and convenient transport. Mankind has not really started experimenting with the climate yet.

But perhaps, given the slow progress in keeping down emissions, it should. A small, underfinanced and somewhat obsessive group of scientists is working on ways of “geoengineering” the Earth to reverse global warming. Some of their proposals are absurdly costly; others are exceedingly dangerous. Still, geoengineering deserves much more serious consideration than it has so far received.

Since climate change is mostly caused by greenhouse gases, the obvious way of reversing it is to remove those gases from the atmosphere. Removing carbon dioxide from the air would also help marine creatures: the oceans are becoming less alkaline as a result of dissolved carbon, which seems to be harming corals. Some scientists are exploring ways of speeding up the natural processes that already do this. Carbon-absorbing minerals like olivine, which is in abundant supply, could be mined, crushed and spread out. Lime or limestone could be tipped into the ocean to react with dissolved carbon dioxide to create bicarbonate ions, allowing the water to absorb more carbon dioxide from the air. Iron and other nutrients could be added to the water to stimulate the growth of algae, which feed on carbon dioxide.

Plants could be grown and then burnt in power stations capable of capturing the carbon that the plants had removed from the air; the gas could then be compressed and buried under the ocean. Carbon dioxide could be filtered out of the smoke that rises from factories and power stations, or even just out of the air. A Canadian firm, Carbon Engineering, has just opened a pilot plant that will do this.

All methods of removing carbon dioxide from the atmosphere are even more challenging than they might seem at first sight. That is because the ocean and the land currently absorb about half of human emissions. If atmospheric concentrations were brought down, some carbon dioxide would naturally “out-gas” from the seas and the land, adding to the amount that would have to be removed.

And two fundamental (though contradictory) criticisms are levelled at the carbon-suckers. First, their methods are so costly that they could not possibly be deployed on the scale required to alleviate climate change. And second, if those methods could be made to work, they might introduce moral hazard. If greenhouse gases could magically be removed from the atmosphere tomorrow, why bother with cutting emissions today?

The first objection is a good one. Carbon-removal techniques are indeed extraordinarily costly, and not just in a financial sense. Tim Kruger of the Oxford Martin School estimates that in order to remove just one gigatonne of carbon (roughly one-tenth of current annual emissions) from the atmosphere, 4.5 ►►



Any room for a lynx?

▶ gigatonnes of lime would have to be dumped into the ocean. That would require 6.5 gigatonnes of limestone, or almost one tonne for every man, woman and child on Earth, and 4,500 factories to make it into lime. Alternatively, growing plants and then capturing their carbon would require enormous quantities of agricultural land to make much difference to the climate.

Still, many of these technologies deserve to be tried out. The costs of some carbon-removal methods might come down in time, though others might turn out to be even more expensive than their proponents think. And at some point in the future one of them, or a combination, will have to be deployed if climate change is to be arrested. It will be impossible to prevent all greenhouse-gas emissions. There will always be individual national holdouts, and there will always be niche uses for gas and oil, such as powering passenger aeroplanes.

The second objection to carbon removal, that it encourages recklessness, would be persuasive only if it could be done cheaply. At the moment it looks so costly and so tricky that it cannot be used to justify putting more greenhouse gases into the atmosphere. Indeed, it would be good to have more research into these technologies if only to see just how costly they would be. Most of the theoretical means of avoiding large-scale global warming assume that tens or even hundreds of millions of hectares of land can be given over to growing energy crops. It would be helpful to know how realistic that might be.

At best, carbon-dioxide removal might turn out to be an expensive way of dealing with the chief cause of climate change. But there is another approach, which is to attack climate change directly. This could work out much cheaper. Indeed, it would almost certainly be cheaper than replacing fossil fuels with renewable sources of power. That is only one reason it is so unnerving.

For all that human activities are perturbing the climate, those actions appear trivial when set beside the enormous heat engines that create the Earth's weather. Even doubling the concentration of carbon dioxide in the atmosphere would create a radiative forcing of only four watts per square metre, a number dwarfed by the 240 watts per square metre that pours into the Earth from the sun. That suggests a straightforward and highly appealing calculation. Four divided by 240 is 0.017. To offset the warming effect of a doubling of carbon dioxide, then, it might be necessary to intercept only about 1.7% of the solar radiation that currently reaches the Earth.

Spray and pray

Some early satellite pictures contained what appeared to be scratches, says John Latham, a scientist who lives in Colorado. These turned out to be ship tracks—linear clouds that grow on aerosols emitted by ships as they traverse the seas. What has been done inadvertently could be done better deliberately. If ships were to create tiny salt particles from seawater in just the right places, water droplets would form on them. That would alter a type of cloud called a marine stratocumulus. With more droplets of a smaller size, the cloud would become lighter and



Ship tracks are linear clouds that grow on aerosols emitted by ships. What has been done inadvertently could be done better deliberately

thus more reflective. Seawater is innocuous; “it’s benign and it’s infinite,” explains Mr Latham. And marine stratocumulus clouds are so common that the Earth might be cooled substantially.

The big technical problem so far has been to produce nozzles capable of consistently producing tiny droplets. Many ships would be needed to trundle up and down the best cloud-lightening corridors (the west coast of Africa is especially good). But these difficulties hardly seem insurmountable. A report published in 2012 for the Copenhagen Consensus Centre estimated that marine-cloud brightening would prevent global warming even more effectively than a carbon tax.

If spraying seawater into the air would probably cool the Earth, spraying sulphur into the stratosphere would be almost certain to do so. It has been done, after all. Volcanoes spew out sulphur that creates particles which reflect sunlight back into space; those particles also bounce light around the atmosphere, producing wonderful sunsets. These can cool the Earth significantly, albeit briefly (see chart, next page): within a year or so the particles are washed out of the atmosphere.

Sulphur could be sprayed at precisely the right height and in very fine droplets, which would reflect more light for longer. It might take only a small fleet of high-altitude aircraft flying in relays to put enough in the stratosphere to cancel out the entire temperature rise resulting from human greenhouse-gas emissions. The sulphur would eventually fall as acid rain, but not in alarming quantities: the amount of sulphur required would be much less than is currently thrown up into the air by vehicles and factories.

Both marine-cloud brightening and stratospheric aerosols carry risks. One is that cooling the Earth without removing carbon dioxide does not quite return the climate to normal. The more carbon dioxide that is present in the air, the less plants perspire, affecting the water cycle. And the heat-trapping greenhouse effect would still operate, just with less heat in the system. ▶▶

▶ With temperatures more evenly distributed in the atmosphere, there would be less convection and, presumably, less precipitation. So a cooler world with lots of greenhouse gases would probably be a drier world. Any country that suffered a drought would surely blame the geoengineers.

But the biggest problem is what would happen if the engineering stopped. Assuming that greenhouse-gas emissions continued while the ships or aeroplanes were doing their work, abruptly ending the artificial shielding would lead to a sudden jump in temperatures, which would be disastrous for people and the natural world alike. Ken Caldeira of the Carnegie Institution points out that an abrupt “termination shock” could be avoided if geoengineering were used only to slow global warming and then gradually wound down. But that assumes the nations of the world can agree on how to manage the climate. The history of United Nations climate talks suggests they can’t.

Still, these methods ought to be developed and even—very carefully—tested. The Earth might need a drastic intervention, particularly if it became clear that something alarming was about to happen, such as a breakdown of the Indian monsoon. Marine-cloud brightening could be deployed on a small scale to avert specific disasters. Mr Latham suggests that cooling just a few hundred square kilometres of ocean in the right place could make a hurricane less severe. If the climate-modellers are right that hurricanes will become more intense as the ocean warms, this will become increasingly tempting.

Better the devil you know

The most persuasive reason for investigating geoengineering further is that somebody is likely to try it. Countries will have different ideas about when global warming becomes truly dangerous: Britain, for instance, is a lot more sanguine than the Maldives. Some of the more skittish states might start injecting aerosols into the lower stratosphere, perhaps in a clumsy way. If no formal experiments had been carried out and thus scientists in other countries did not know what to look for, it might not be obvious for some time that this was going on.

David Victor, who studies the politics of climate change at the University of California, San Diego, doubts that nations would ever formally agree to engineer the Earth’s climate: their interests are too diverse. He thinks it much more likely that a country would just go ahead and try it. That would put the others in a quandary. Should they forcibly stop that country from acting, or should they step in with superior geoengineering techniques? Before long, Mr Victor says, they could find themselves acting as zookeepers to the planet. ■

The way forward

Second-best solutions

If the best method for tackling climate change is not on offer, try something else

ECONOMISTS LIKE TO argue, about climate change as much as anything else. Some of the fiercest rows are over the discount rate—how to weigh the likelihood that future generations will be richer than the current one when deciding how much to spend on averting climate change today—and over how to price catastrophic but unlikely events such as the collapse of the Greenland ice sheet. But on the biggest issue of all they nod in agreement, whatever their political persuasion. The best way to tackle climate change, they insist, is through a global carbon tax.

Politicians tend to assume that subsidising clean energy has the same effect as taxing carbon, says Ottmar Edenhofer, an economist at the Potsdam Institute for Climate Impact Research. It does not. Subsidies for wind, solar and nuclear power increase the supply of wind, solar and nuclear energy, but they do not squeeze the polluters. Indeed, as has been shown earlier in this report, green-power subsidies can actually boost the most polluting fossil fuels. A carbon tax would bear down on the thing that most needs to be suppressed.

Carbon taxes have their problems, though, beginning with the word “tax”. New levies are never popular. Even if governments promised to cut other taxes, so that a carbon tax would be fiscally neutral, they would make enemies. It is a sound rule of politics that the winners from any reform are less delighted than the losers are angry. And no government could guarantee that carbon-dioxide emissions would fall by a specific amount. A carbon tax represents certain pain for uncertain gain.

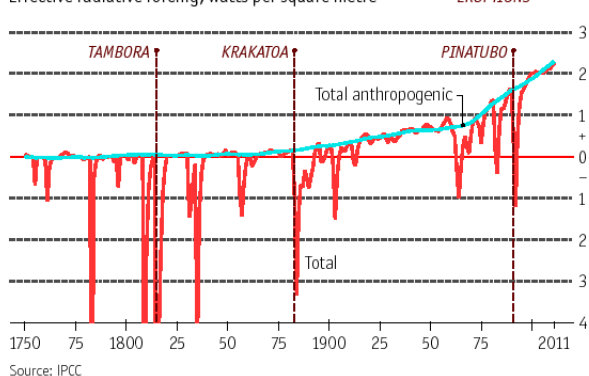
Instead, many countries have adopted “cap-and-trade” schemes. These specify the quantity of carbon that can be emitted and hand out, or auction, permits to pollute up to that limit. Polluters can buy and sell permits, which in theory means that the cheapest methods of reducing emissions are deployed first. By far the biggest cap-and-trade scheme was launched in 2005 by the European Union. It covers not only carbon dioxide but also nitrous oxide and perfluorocarbons, and includes emissions from commercial aircraft. California also has a cap-and-trade scheme, which is linked to projects run by some Canadian provinces. Earlier this year South Korea set one up. China, which already has six regional schemes of this sort, has promised a national one.

Capping and trading pollution is less good than taxing it. Under pressure from heavy industry, governments tend to hand out too many pollution credits, so the price is invariably too low to alter behaviour. As this report went to press, carbon was trading in Europe for less than €10 a tonne. And cap-and-trade schemes can encourage free-riding. If a country covered by an international emissions-trading scheme decides to enforce stricter regulations, the market will be flooded with cheap pollution credits, encouraging others to pollute more. It helps to set a minimum carbon price and keep raising it, as California is doing.

The big problem afflicting carbon taxes and cap-and-trade schemes alike is that not everybody wants to join the club. Carbon is best priced globally, partly because popular support will ebb if jobs move from virtuous countries to less virtuous ones, and partly because such schemes work much better on a large scale. William Nordhaus, a climate economist at Yale University, ▶▶

Earth’s natural air-conditioner

Effective radiative forcing, watts per square metre





► calculates that if every country in the world were to tax carbon, temperatures could be held to 2°C above pre-industrial levels at a cost of 1-2% of world income per year. If the scheme were confined to countries representing only half of global emissions, the two-degree target would be almost impossible to hit.

The obvious way to get countries to join a climate club is by threatening their exporters. Taxing imports at the border according to their carbon content, but giving credits for any carbon taxes already paid at home, might encourage exporting countries to levy their own taxes. But this would be brutally difficult to implement. Besides, border taxes on carbon would suppress trade, just as other tariffs do. And they might well prove illegal.

Count to three

A global carbon tax—or even one involving many countries—is likely to remain an economic theory for a long time. Certainly, nothing of the sort will be seriously discussed in Paris. Even so, there are three perfectly good things everybody could be getting on with right away. Two are humdrum, though no less worthwhile for that. The third requires greater ambition.

First, countries should be nudged to upgrade their promises for cutting emissions. In advance of the Paris conference, an untidy mess of pledges has been dumped on the table. Some countries say, fairly straightforwardly, that they will cut greenhouse-gas emissions by such-and-such a percentage compared with a particular year. But they pick different base years—invariably ones in which their emissions were very high—to make their promises look better. Australia goes for 2005; Russia plumps for 1990, just before its heavy industries collapsed. Other countries do not even propose to hold emissions to a specific level. Some countries go in for statistical tricks, arguing, for example, that their efforts to prevent deforestation should be weighed more generously. The pledges should be made more comparable.

A good second move would be to ditch the carbon monomania. Tackling carbon dioxide, the most important greenhouse gas, is essential. Yet aside from its effect on ocean chemistry and the fact that it is warming the world, though so gradually that most people cannot detect it, carbon dioxide is innocuous. And the effects of emissions persist in the atmosphere for so long that even a drastic cut would have only a slight effect on climate change in the short term.

Carbon dioxide is not, however, the only greenhouse pollutant. Methane, black carbon (ie, soot) and hydrofluorocarbons

also warm the world a good deal. It has been estimated that if strong action were taken to suppress them, the world might be 0.6°C cooler by 2050 than it would otherwise be—a quick, fairly noticeable change. There is talk of regulating hydrofluorocarbons under the Montreal Protocol, which cracks down on ozone-depleting chlorofluorocarbons—an excellent idea.

The best target is black carbon, which comes off open wood fires and out of the exhaust pipes of unsophisticated diesel vehicles. This is an immediate killer, and it is easier to tackle than carbon dioxide. California cut black-carbon emissions by half in 20 years, mostly by cracking down on vehicles. More research on cheap, clean stoves for poor countries would be money well spent.

The most important thing of all is to innovate. Bill Gates, the philanthropist, laments that in all the discussions about climate change around the UN, almost nothing is said about research. Yet there is a crying need to develop technologies that are cheaper and more dependable than today's wind turbines and solar farms. Mr Gates has invested in new types of nuclear reactor—but he also holds out hope for artificial photosynthesis, which uses solar energy to make hydrogen from water. "It's not like the Manhattan Project," he says. "There are maybe a hundred different paths."

Mr Gates points out that annual spending on energy research in America is only about \$6 billion, compared with \$30 billion on medical research—and America is much more open-handed than many other countries. Energy firms do not spend a lot on research because there is no product differentiation in energy

(electrons are electrons) and thus nothing exciting to sell until the price falls below that of the existing technology. So taxpayers will have to stump up most of the cash.

If more money were forthcoming, a good deal of it would be wasted on dead-end projects. But that is the nature of research and development. Only a few successes would be needed in order to avert calamitous climate change. And the funds that governments are currently pouring into subsidies for things like offshore wind farms are not doing much good. "We're spending almost all our money on wind turbines and solar panels that we know are not effective," says Bjorn Lomborg of the Copenhagen Consensus Centre. But then, he points out, people are used to doing things that make them feel good about climate change, rather than things that actually do good. ■

More research on cheap, clean stoves for developing countries would be money well spent



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