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The Science: How It Shapes the Economics, Ethics, Politics, and the Possible Prognoses

The science of climate change should be the foundation both for an understanding of the issues and challenges and for any proposed responses to those challenges. The science has been built over the past two centuries and is based on the simple and strong physics of the greenhouse effect: greenhouse gases inhibit the outward flow of energy from the earth.

Human activity is causing the concentrations of those gases to rise. Inaction or delayed action could increase greenhouse gas concentrations on a scale that might profoundly alter the relationship between humans and the environment on which we depend.

Although we cannot predict the full consequences of postponed or weak action on climate change with great precision, the science tells us that the risks over the next hundred years, across all sectors of every economy on the planet, could be immense, as could the risks of severe and extended conflict. And it tells us that delay is dangerous.

Chapters 1 and 2 constitute part I of this book and frame the choices the world faces: in the most basic sense between peril and prosperity. Chapter 1 first explains the nature and scale of the risks involved and the historical supporting evidence (sections 1.1 to 1.2). The remaining sections set out the logic of how the science shapes the economics, ethics, and politics of the choices we face in the context of managing the immense risks, undertaking emissions reductions at the necessary scale, and the dangers of delay. Chapter 2 then sets out an analysis of possible transitions to a low-carbon economy and what can drive such a transition. And it suggests that the paths themselves, and the destinations to which they could lead, would embody an attractive, sustainable, and prosperous economy and society.

1.1 How the science shapes the questions

It is almost as if the science of climate change has conspired to make the generation of action as difficult as possible. These difficulties arise from four key elements of the processes at work: (1) scale; (2) risk and uncertainty; (3) lags and delays in consequences; (4) the "publicness" of greenhouse gas emissions—it is the total, global volume that matters, rather than an individual source. An understanding of these four features is crucial to an understanding of the obstacles to, and thus how to create, the necessary political will for accelerating action.

The scale of possible consequences is such that we may, through neglect in the coming decades, rewrite the relationship between humans and the planet. The questions at stake are: where we can live, what we can do, and how many of us might be here?

People find it difficult to comprehend threats of extreme scale, such as those involved in climate change, particularly if they are seen to be fairly distant in time. Most of the consequences cannot be predicted with certainty—this is about risk and probabilities, or indeed about uncertainty in the technical economic sense, where even though we think the bad outcomes are far from remote, we may find it difficult to assign probabilities. We know from the work of psychologists on behavior in relation to risk that, even in situations where probabilities are easier to assess, where results are in the near future, and where the stakes are much less large, many or most people do not appear to behave in anything resembling a "rational" manner. We often find risk difficult to understand, decide on, or manage.

The effects of emitting greenhouse gases appear with lags of many years and they last, particularly in the case of carbon dioxide (CO_2), for a very long time. This is a "flow-stock" process in which emissions (the flow) cause the concentrations (stock) to build over time because of the longevity of CO_2 in the atmosphere. That is one key reason why delay is dangerous: the later we take action, the greater the stock or concentration of greenhouse gases and thus the more difficult the starting point for action to reduce emissions on the necessary scale. Delay is dangerous also because capital and infrastructure can lock in carbon-intensive activities and equipment, in some cases for many decades. Humans again seem to find it difficult to assess consequences of actions with such lags and lock-ins. Those who would regard a friend driving dangerously or when drunk with great concern, because they can picture clearly the risk of killing people on the road, may not react to the potential creation of similar types of dangers where consequences, just as real, occur some decades in the future.

Finally, the scientific consequences of the emission of a kilogram of CO_2 are the same whether it is emitted in London, Johannesburg, Beijing, São Paulo, or Los Angeles. It is the sum total that counts. Economists refer to such circumstances as involving “public goods,” or in this case, “public bads.” Any individual person might understandably think that they are only a small part of the problem (given their small contribution to global emissions), and so may leave corrective actions to others, or may decline to act because of a lack of confidence that others will act. The “public good” nature of the process again follows from the science, and plays its part in severely hampering the creation of the political or public will for action.

Taking these crucial aspects of the science together, we can begin to understand why fostering action can be so difficult. Part of the contribution of serious analysis of these issues is to show what can—and with ethical criteria, *should*—be done. That itself is a step on the way to creating political will.

These four aspects of the scientific process strongly influence how we shape the ethics and economics. The ethics must consider responsibilities and consequences for those living many decades from now and whose lives and livelihoods could, through our inaction, be placed at great risk. These are not issues involving losses of income of a few percent—for many the potential problems are existential. At the same time we must be wary of the term “future generations,” as if the only individuals affected are some abstract entities who may or may not someday exist. There could be huge, possibly existential, effects on young people alive today. We can look directly, now, at those who may suffer terribly from our neglect. The science also tells us that those in poorest areas are likely to be hit earliest as well as hardest, raising further fundamental ethical issues.

Further, we must make sure our economic analysis is structured in a way that allows us to assess risks of such magnitude. All too often economists are tempted to force everything into simplistic cost-benefit analysis in which changes are marginal and all relevant effects can be expressed in terms of a single common denominator, such as money. When someone has a hammer, every problem looks like a nail.

For all these reasons a policy analysis must begin with the science of climate change. It must examine where we may be going under different assumptions about policy. Worryingly, some plausible assumptions on current intentions suggest we are headed in a very dangerous direction.

1.2 The history of scientific theory and evidence

The science of climate change has been building theory and evidence over the past two centuries. In the 1820s the French physicist and mathematician Joseph Fourier recognized that the atmosphere was trapping heat. He examined heat balance equations for the Earth from the perspective of incoming solar radiation and outgoing infrared radiation, concluding that the planet was around 30°C warmer than these equations indicated it should be; something, he argued, was preventing the outflow of energy. In the early 1860s the Irish physicist John Tyndall discovered by experimentation some of the atmospheric gases trapping the outflow. He identified molecules, later to be known as greenhouse gases (GHGs)—including CO_2 and water vapor—that were trapping heat. At the end of the nineteenth century, the Swedish chemist Svante Arrhenius provided preliminary calculations of the possible magnitude of the effects. By the 1940s, insights from quantum mechanics, through the work of Walter Elsasser and others, helped to explain the mechanism of "trapping," showing that the oscillations of the GHG molecules were at frequencies/wavelengths which interfered with the outgoing infrared energy. Over the past several decades we have continued to make strong progress in our understanding of climate science. For example, we can now take into account various interactions and feedbacks, including, for example, the effect of water vapor, in our estimates of temperature increases. This rapid advance in our understanding is likely to continue over the coming decades. However, the basic logic, from simple physics, that greenhouse gases trap heat, is clear and is the underlying driver in the story of climate change.

The scientific chain of causation

Understanding the relevant scientific processes involves recognizing that GHG emissions and anthropogenic climate change start with people and end with people. The logic, to keep it very simple (and thus to ignore some subtleties), is, in five steps, as follows: (1) human activity results in the emission of GHGs, a flow. Total global emission flows are currently more than the planet can absorb through its carbon cycle; (2) this leads to increased "stocks" or concentrations of GHGs in the atmosphere. There is a ratchet effect here from the flow-stock process; (3) as stocks of GHGs increase, more infrared energy from the surface of the Earth is prevented from passing out through the atmosphere, and average global surface temperatures across the land and oceans increase. The amount of warming across the surface depends on "climate sensitivity." (4) The local and regional climates and weather patterns change; (5) these changes have impacts on the lives and livelihoods of people and the wider ecosystem.[1] Each of the links in the chain involves substantial risk and uncertainty.[2]

The impacts from climate change operate in large measure through water, or its absence, in some shape or form: storms, floods, inundations, droughts, desertification, ocean acidification, and/or sea level rise. Changing temperatures and growing seasons also affect people directly.

The patterns and combinations of rivers, rainfall, wind, and temperatures across the year all influence what people can do. We have adapted to conditions as they are, and those conditions, in terms of average global surface temperatures, have been fairly stable for around 8,000 years or so since the warming at the end of the last ice age. The impacts of climate change concern what happens to us if the conditions change. It is the *change* that is crucial, and it can be deeply damaging.

The science is the foundation of our thinking on managing climate change. We now examine each of the four key elements of the scientific process in detail.

1.3 Scale and risk: a potential rewriting of the relationship between humans and the planet

We can understand the potential scale and risk by starting with concentrations of GHGs in the atmosphere. GHG concentrations or stocks have increased from around 285 ppm carbon dioxide equivalent (CO_2e) in the mid-1800s to around 445 ppm CO_2e today.[3] In this book we focus on the six gases managed under the 1997 Kyoto Protocol—CO_2, methane

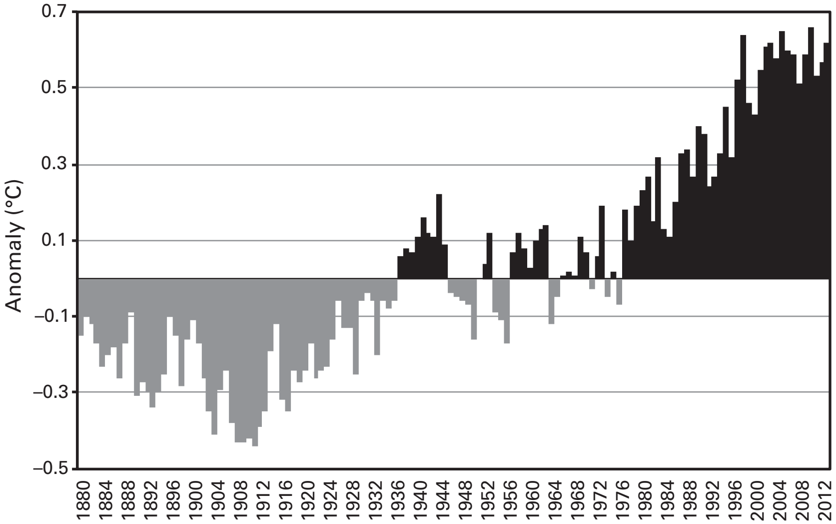

Figure 1.1
Annual global land and ocean temperature anomalies. The figure shows the departure of the annual global mean temperature over land and ocean from the twentieth-century average temperature of 13.9°C (represented as zero on the vertical axis). Source: National Oceanic and Atmospheric Administration (NOAA 2014a).

(CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). If we were to extend our analysis to those gases under the 1987 Montreal Protocol,[4] this would add perhaps another 30 ppm CO_2e to the 445 ppm CO_2e. Carbon dioxide, the main component of radiative forcing among these GHGs,[5] has risen from 280 ppm in the mid-1800s to around 400 ppm in 2014. During the period 1930–1950 we were adding at a rate of 0.5 ppm CO_2e per year, increasing to 1 ppm CO_2e per year during 1950–1970 and to 2 ppm CO_2e per year during 1970–1990. Now the rate is around 3 ppm CO_2e every year, and with little or weak action this rate is likely to increase still further.

The increase in concentrations of GHGs in the atmosphere to date has corresponded to an average warming across the Earth's surface (combined land and ocean temperature) of around 0.8°C since the late nineteenth century (see figure 1.1 from the US National Oceanic and Atmospheric Administration), the usual period of reference and one that will be used in this book. Similar results are reported by NASA in the US and the Met Office Hadley Centre in the UK. The 2011 Berkeley Earth Surface Temperature study further confirmed the patterns of temperature increase.[6]

If the world continues to emit GHGs along a "business as usual" path, concentrations of GHGs could rise to the region of 750 ppm CO_2e by around the end of the century. At these levels of GHG concentrations, some climate models suggest a median temperature increase over the next one or two centuries of about 4°C or more, with substantial probabilities of well above 4°C.[7]

The physical and human geography of the planet would likely be transformed with temperature increases of 4°C or more:[8] deserts, coastlines, rivers, rainfall patterns—the reasons we live where we do—would be redrawn. One way of trying to grasp what might happen with global increases in temperature is to look at past periods of changes in CO_2 concentrations or temperature. In the period following the industrial revolution beginning approximately 200 years ago, the intensifying use of fossil fuels has rapidly increased CO_2 concentrations in the atmosphere. Before this, CO_2 concentrations were driven according to naturally occurring processes on timescales of many thousands or even millions of years. The planet has not seen CO_2 levels as high as the current 400 ppm for at least 800,000 years[9] and likely not for around 3 million years.[10] Global mean temperatures regularly exceeding 4°C above preindustrial have likely not been seen for at least 10 million years, perhaps much more.[11] The last time CO_2 levels exceeded 750 ppm, with surface temperatures well beyond 4°C above preindustrial figures, was likely about 35 million years ago during the Eocene epoch, when the planet was entirely ice-free. Today that would drive a sea level rise of 70 meters.[12]

Modern *Homo sapiens* is probably no more than 250,000 years old[13] and has not experienced anything like this. Our own civilizations, living in villages and towns, appeared after the last ice age during the Holocene period. The early Holocene, between around 12,000 and 7,000 years ago, saw rapid changes in ice sheets, sea levels, and temperature.[14] Following this transition, over the last seven or eight millennia, temperatures have been remarkably stable, fluctuating in a range of plus or minus 1.5°C around an average.[15] These Holocene temperatures allowed our societies to develop: grasses were cultivated to become cereals, thus requiring sedentary populations to tend and protect crops until harvest, and allowing both surplus and storage. This provided time and opportunity to develop villages and towns and much of the skills of civilization, culture, and ways of life as we know them.

We are already on the upper edge of that range of Holocene temperature fluctuation, in large measure as a result of changes brought about by humans. A temperature increase of 3–4°C would be well outside that range. It seems possible that we have not seen sustained temperatures around 3°C above preindustrial for around 3 million years. We appear to be embarked on a massive experiment of which the consequences are hard to predict and the effects may be irreversible.[16]

1.4 Consequences of increasing temperatures

Damages from climate change will accelerate as the world gets warmer. We are already seeing the impacts of 0.8°C, but that is a small temperature increase relative to what we risk. Future impacts from climate change will be largely about water—whether too little or too much—with human costs and impacts unevenly distributed across countries. It is difficult to overstate the fact that poor people and poor countries are likely to be hit earliest and hardest. And there are significant risks of nonlinearities and tipping points in the climate system, such as the collapse of the Amazon forest or thawing of permafrost releasing vast quantities of methane. Not only are the risks huge, but the associated probabilities are not small: they are not confined to the "tails of the distribution."[17]

The effects from rising temperatures are not mainly about local temperatures. This is a global problem, and the scientific evidence points to immense consequences from higher average global temperatures. In November 2012 the World Bank released a review (updated June 2013) of the latest scientific literature examining the risks and likely consequences of a world that is 4°C warmer than the preindustrial period. Such a world would be characterized by "unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on human systems, ecosystems, and associated services."[18]

Temperature rises will not be evenly distributed across the land and oceans; a 4°C rise in average global surface temperature might correspond to average land temperatures as much as 4–10°C above the preindustrial. This could see average summer temperatures rise by around 6°C in regions like the US, the Mediterranean, North Africa, and the Middle East. These temperatures could lead to regular summer heat waves that are similar in intensity to the devastating example in Russia in 2010, in which 55,000 people died and 25% of crops failed, and to increased likelihood of wildfires. There would also be impacts from likely sea level rise, possibly between 0.5 to 2 meters by 2100 and increasing thereafter, and greater frequency and intensity of droughts and floods, with associated biodiversity and ecosystem damage that could be overwhelming. It is far from certain that it will be possible to adapt to a 4°C or warmer world, particularly for the poorest and those threatened by sea level rise. Where adaptation in any particular location is not possible, the only viable option, if available, may be relocation. In many regions, this would likely lead to extreme conflict and loss of life. The World Bank report states that in a world warmer by 4°C or more, sub-Saharan Africa is particularly at risk in this regard.

Empirical evidence on forced migration from climate change is limited; recall that we have seen "only" 0.8°C so far. But we know there have been important examples in history. Widespread depopulation and abandonment occurred around 5,000 years ago in what is now the Sahara desert, which for some thousands of years prior to this event had had large areas of grassland and lakes.[19] Coastal Greenland was able to support a marginal pastoral economy several hundred years ago. Both of these examples were in the fairly "narrow" temperature bracket (±1.5°C) of the Holocene.

Under conditions of escalating demand for often unevenly distributed ground resources, unprecedented changes in local or regional temperature, changing weather patterns and events, changes in river course and flows, and storm surges and inundations in coastal regions, the reasons for very large numbers of people living where they do could be substantially rewritten, and so rapidly that adaptation would be very difficult. For example, patterns of rainfall around the Himalayas, water retention by ice and snow, and the pattern of the monsoon could all radically change, potentially affecting hundreds of millions of people.

History indicates that vast movement of populations could involve severe, widespread, and extended conflict, particularly where migration is across country borders. There is a growing literature examining possible disruptive migration from climate change and its potential implications for conflict.[20]

We cannot be certain about outcomes: the issues concern the management of risk and uncertainty. The nature, scale, and possible location of the effects are difficult to describe with confidence, but the science does indicate that the potential risks are immense, and furthermore that they are not remote. Table 1.1 gives a summary of what the various concentration levels of GHGs mean in terms of likelihoods of staying below temperature increases of 2°C, 3°C, and 4°C in 2100. This table, from the recent IPCC review, suggests that even at concentrations around 550 ppm CO_2e by 2100 (and note that we look likely to reach 550 by mid-century if we continue adding around 3 ppm each year for three more decades), the chances of staying below a 3°C increase in 2100 are less than 50% (table 1.1). A century or so from now, on current emissions paths, the probabilities of eventual warming of 4°C or more may be of the order of 20–60%.[21] Remember that the planet has not seen a sustained 3°C above preindustrial for probably around 3 million years, nor 4°C for probably tens of millions of years. These are not tiny probabilities of inconveniences, but substantial probabilities of catastrophes.

It is important to remember that 2100 is an arbitrary cutoff date. It is one date of relevance but we should look beyond it, because it is very difficult to reduce CO_2 once it is in the atmosphere; thus we get locked in to high concentrations whose consequences are potentially severe. In my view, the current IPCC report (2013/2014) is overly focused on that date. Earlier reports give guidance on the probabilities in terms of eventual stabilization. This is about management of risk, and we can gain an impression of how the probabilities change concerning “eventual” temperatures from table 1.2. Always bear in mind that these estimates have many qualifications, but they do give indications of how risks rise as concentrations rise. Meinshausen suggests that concentrations similar to today of around 450 ppm CO_2e give us a <5% to 35% chance of a temperature increase at stabilization of greater than 4°C.[22]

The scientific evidence on climate change is becoming stronger and its conclusions and implications ever more worrying: emissions are rising; the absorptive capacity of the planet, particularly the oceans, is less than expected; ocean acidification is rising; methane release from the thawing of permafrost is accelerating; and so on. While the situation is looking

Table 1.1
Possible concentration levels of GHGs in 2100, with resulting global mean temperature increases relative to preindustrial levels

Concentration of GHGs (ppm CO_2e)[a]	Expected temperature increase (°C) (range given in source)[b]	Likelihood of staying below a temperature increase of[c]		
		2°C	3°C	4°C
450	1.0–2.8	≥66%		
500	1.2–2.9	≥50%	≥66%	
550	1.4–3.6	≤50%	≤50%	≥66%
685	1.8–4.5	≤50%		
860	2.1–5.8	≤33%	≤33%	

Source: IPCC (2014b, table SPM.1, page 13).

[a] Concentration levels in 2100, including scenarios for 500 ppm (no overshooting of 530 ppm) and 550 ppm (no overshooting of 580 ppm), and midpoints for 650–720 (upper range of RCP4.5 pathway) and 720–1,000 (RCP6.0 pathway).

[b] Global mean temperature increase above preindustrial levels (1850–1900).

[c] Likelihood corresponds to those given in IPCC (2014b): *likely* (≥66%), *more likely than not* (≥50%), *about as likely as not* (33–66%), *more unlikely than likely* (≤50%), and *unlikely* (≤33%).

increasingly concerning, however, many still fail to grasp the magnitude of the problem—and some continue to deny there is a problem at all.

Communication of the science is crucial

If the world is to comprehend the scale of the problem and understand the implications from the science, it will require much more effective communication from scientists.[23] This is not a simple task, but it is also one that has not been handled well. It will involve scientists communicating with the public and decision-makers on the science and its implications with greater frequency, clarity, timeliness, transparency, and openness. To do this, scientists need to rebuild the public's trust in their competencies and repair a perceived lack of integrity, the result of repeated attacks over the last few years. There are a number of ways climate scientists might go about rebuilding the public's trust. This could include the key scientific academies and meteorological institutions taking a stronger leadership role in the process of debate and policy-making.[24] We are seeing improvement—see for example the joint publication from the Royal Society and the US National Academy of Science

Table 1.2
Stabilization levels of GHGs and implied probabilities of exceeding 2°C and 4°C temperature increases

Stabilized greenhouse gas concentration (ppm CO_2e)	IPCC (2007) "best guess" and "likely" range of global mean temperature rise (°C above preindustrial levels)	Implied probability of exceeding 2°C above preindustrial levels (Meinshausen 2006)	Implied probability of exceeding 4°C above preindustrial levels (Meinshausen 2006)
450	2.1 [1.4–3.1]	25%–80%	<5%–35%
500	2.5 [1.6–3.8]	50%–95%	<5%–45%
550	2.9 [1.9–4.4]	65%–>95%	5%–55%
650	3.6 [2.4–5.5]	80%–>95%	15%–65%
750	4.3 [2.8–6.4]	90%–>95%	30%–80%

Note: The second column from the left gives information on the "best guess" and the likely (i.e., the 66–90% probability range, from IPCC 2007) levels of warming at different stabilization concentrations of GHG. The third and fourth columns give estimates of the implied probability of exceeding a 2°C or 4°C global temperature increase at stabilization (above the temperature in the mid-nineteenth century, at a preindustrial GHG concentration of 280 ppm CO_2e).
Source: Bowen and Ranger (2009), table 1.2, p. 9.

(2014) on evidence and causes of climate change—but there is a long way to go.

What our targets should be

The scale of the problem and the risks we face if we fail to act are potentially immense. It is possible to reduce these risks. Much discussion over recent years has focused on the scale of action required to limit temperature increases to less than 2°C from levels in the mid-nineteenth century. This is a widely accepted target in international discussion as a temperature beyond which climate change is "dangerous," and it is embodied in international agreements such as that of the UNFCCC in Cancún in December 2010. At temperature increases above 2°C, the probabilities of nonlinearities and tipping points are believed to increase greatly. Clearly, a higher probability of success would be preferable (for instance offering us at least a 66% chance of limiting the increase to 2°C). The target is sometimes expressed in terms of 66% but more often in terms of a 50–50 chance of a 2°C increase. We have to use such a formulation because outcomes are not defined with certainty and there is a probability distribution around any central estimate. Indeed, a 50% chance of going above "dangerous" levels is itself worrying, but this has been a standard benchmark.[25]

It will be broadly necessary to hold concentrations of GHGs to below 500 ppm CO_2e, and reduce from there, to give a reasonable (50%) chance of staying below 2°C. A plausible emissions path would see global emissions fall from around 50 billion tonnes of CO_2e in 2013[26] to under 35 billion tonnes in 2030, and under 20 billion tonnes in 2050. We are actually likely to have to go well under 20 billion tonnes by 2050. We can do less now and more later. For example, with strong assumptions about the ability to go to zero or negative emissions in the second half of the century, the 35 billion tonnes in 2030 might be raised to 42.[27]

Figure 1.2 illustrates a range of feasible paths we could follow that are consistent with at least a 50–50 chance of holding temperature

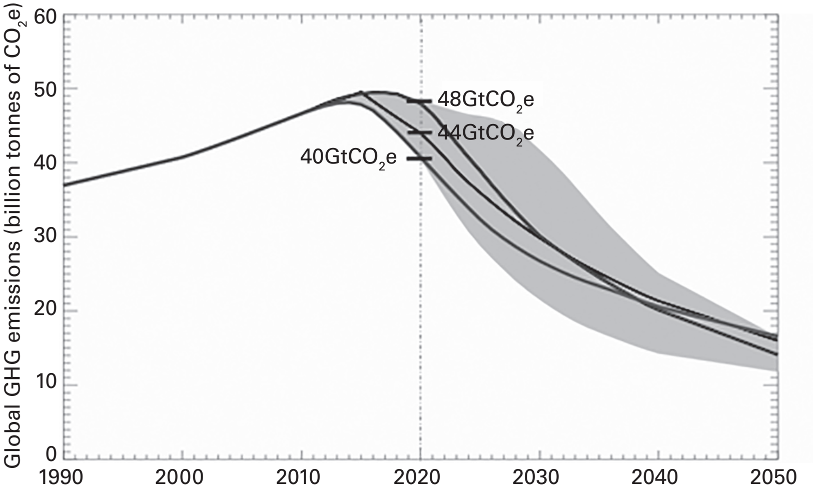

Figure 1.2
Paths for global annual emissions that lead to a reasonable chance of a temperature rise of no more than 2°C. The shaded area represents the range of emissions paths that are consistent with a commonly regarded 50–50 chance of the 2°C goal, and the three lines show specific paths within this range. Results are based on Hadley Centre climate model IMAGICC. Source: based on Bowen and Ranger (2009).

increase to 2°C. The message is the same in all: for that objective, the emissions trend needs to change significantly and rapidly. While we can in principle do more earlier and less later, or vice versa, the shape of the plausible paths will be similar, and it could be very costly to catch up if we postpone actions.

An alternative way of expressing future possible paths is to think of there being only a certain allowance of total cumulative emissions remaining—a limited "carbon space"—if we are to keep warming to only 2°C. While figure 1.2 shows several emissions trajectories, the area under each curve is similar,[28] and it is this area that must fit into the "carbon space" remaining. New important reports such as from the IPCC estimate the remaining "space" consistent with 2°C trajectories as being in the region of 1–1.5 trillion tonnes of CO_2 emissions.[29] To a rough approximation,[30] this is equivalent at the very most to current annual world CO_2 emissions over a 40-year period. Given that emissions are rising, that space would be exhausted well before 40 years without strong action.

A 2°C path requires strong action on emissions over this century and beyond. We should be aware of the risks and consequences of weaker action. Holding emissions below 550 ppm CO_2e would give around a 65–95% chance of eventual temperatures exceeding 2°C and around a 5–55% chance of exceeding 4°C, as shown in table 1.2; thus the risks of temperature increases far beyond human experience would be large. Let us not forget that stronger action could also increase the probability of reaching a 2°C path; in the case above, limiting cumulative future emissions to below 1 trillion tonnes of CO_2 could increase the likelihood of reaching the target to at least 66% by 2100 (table 1.1). Later in this chapter we will examine where the world looks to be heading in emissions and temperatures, and ask about the possibilities for—and realism of—different targets.

1.5 Lags, publicness, risk, and the dangers of delay

An understanding of lags, the publicness of the problem, risks, and the dangers of delay is crucial to the generation of the political will to act strongly. The potential effects of climate change appear with long lags. This is, in part, due to the flow-stock process: there is a lag between emissions (flows) and the impacts in terms of warming and climate change from the accumulation of additional GHGs in the atmosphere (stock) which trap the heat. The influence of increased concentrations can last for many centuries. For example, sea level will go on rising for many centuries after we have stopped adding GHGs to the atmosphere.

GHG emissions are also public in the sense that the effect of a kilogram of GHG emissions is independent of the location of its source. Emissions are "public bads," in the language of economics. The publicness of the causes may tempt people to leave action to others on the articulated ground that each individual contribution to global emissions is small, or may tempt some to decline to act altogether because they do not have confidence that others will act. When combined with uncertainty, the publicness of the causes may suggest that delay while we learn more is the sensible response rather than early and strong action, in the sense that we have to have more explicit and immediate evidence if we are to convince large numbers of people to participate in action.

Whether or not we focus on how to convince others, the uncertainty itself associated with the potential scale and impacts of climate change might lead to the argument that we should wait for more precise information and forecasts before we act. For some examples of decisions under uncertainty, "wait and see" might be reasonable, but in this case it would be profoundly mistaken. The powerful flow-stock process, and the ratchet effect it implies, mean that delay in taking action can lead to concentration levels that would be very difficult to reduce and severe impacts that might be irreversible. Once GHGs are in the atmosphere they are very hard to remove, especially CO_2 which lasts in the atmosphere for very long periods, much of it for 100 years or more and some of it for 1,000 years. We are already at a difficult starting point in terms of concentrations of GHGs. Another 20 years of delay could add a further 50–60 ppm CO_2e, which would make a concentration of 550 ppm hard to avoid, let alone 450 ppm, with consequent risks of exceeding 4°C much higher, e.g., a 5–55% chance (table 1.2).

Furthermore, much of the infrastructure and capital investment required over the coming decades—in power generation, industry, buildings, transport, and agriculture—can result in technological lock-in, as such infrastructure and capital can stay in operation for long periods of time, perhaps many decades. Delay increases the chance that we would need to undertake radical, rapid, disruptive, and expensive decarbonization two or three decades from now, which would result in the writing off of vast amounts of locked-in capital.

The dangers of delay are particularly relevant for investments taking place in developing countries such as India and China, which are investing strongly as their current rapid growth and building of cities require the creation of infrastructure with lifetimes of many decades. Work of the economics consultancy Vivid Economics considers a possible case in which China and India delay strong action on GHG emissions until 2030 and then are part of a very rapid global transition consistent with GHG concentrations at stabilization of 450 ppm CO_2e.[31] India would then need to scrap $20–70 billion of coal plant (35–140% of current value),[32] and China would need to scrap $50–200 billion of coal plant (40–70% of current value). Would such a scenario be politically possible, given the likely choice that would need to be made between cutting emissions and keeping the lights on? Scrapping vast amounts of high-carbon plant also seems highly unlikely in countries like India and China where demand for energy is forecast to grow strongly over coming decades, and where supply will struggle to keep up, even with rapid deployment of low-carbon electricity generation technologies.

The International Energy Agency also provides estimates of the costs of delay (for a 2°C / 450 ppm CO_2e stabilization scenario) by considering additional investment required after 2020: for every $1 of investment in cleaner technology that is avoided in the power sector before 2020, an additional $4.30 would need to be spent after 2020 to compensate for the increased emissions.[33]

1.6 In denial of the risks from inaction

The scale, the risks and uncertainties, the lags, the publicness of the issue, and the dangers and costs of delay make decisions difficult but also increase their urgency. If the political will to act is to be generated and turned into action on the scale required, these basic elements of the scientific process and their implications must be at the heart of our understanding and processes of decision-making. The arguments for inaction or "wait and see" are generally extremely weak and usually stem from confusion and/or misplaced intuition concerning the science, as well as a poor understanding of the related ethics and economics. And in some cases they arise from deliberate ignoring or misreading of the evidence; seeking to spread doubt and to argue for delay on the back of casual and unscientific arguments is dangerous and irresponsible.

Here are a few examples of some misguided or twisted arguments. Some argue that because we have to speak mainly in terms of probabilities and risks and thus cannot speak with certainty about specific outcomes, we may as well assume very small or zero effects until the contrary is proved. But a position that says "the risks are small" seems hard to sustain given the weight of the scientific evidence, only a small part of which we have assembled here, and it contradicts any sensible handling of choice under uncertainty.

Others argue that "uncertainty means we should wait and see": but as I have already argued, the flow-stock process (ratchet effect) and the lock-in of high carbon capital and infrastructure suggest that delay is not only dangerous if uncorrected by subsequent action, but also very costly if it is corrected via very rapid reductions later on. Another common argument is that "we can adapt to whatever comes our way." That argument seems reckless given the scale of the effects we risk, which are far outside the experience of modern human civilizations and far beyond the capabilities and resources of current technology.

To present a convincing case for inaction or delay, you have to show that (i) you are very confident that the risks are small, or (ii) the risks of delay are small, or (iii) that a "silver bullet" to solving our climate change problems will be discovered; or else (iv) you simply care little about the future and choose to ignore the immense risks. The first two fly in the face of the science. The third would involve a reckless betting the planet on some vague possibility. And the fourth would, I hope, be regarded by many as deeply unethical.

It is important to remember that the science predicts outcomes with risk and uncertainty. If we accept the science as giving us a strong signal to act, and the science turns out to have overestimated risk, then we will have incurred possibly unnecessary costs of action. But in this case we are likely, for example, to have invested in valuable new technologies and in cleaner, more efficient and secure energy infrastructure. And we will have saved forests and biodiversity. If, on the other hand, we reject the science and argue that it is misleading, e.g., that the risks are small, and then the science turns out to be correct, concentrations of GHGs will have built up to very dangerous levels and it will be extremely difficult to back out because CO_2 is so long-lasting in the atmosphere.[34] Basic common sense (and indeed the basics of statistical decision theory) in this case points strongly to action.

Those who propose inaction often adopt, explicitly or implicitly, deliberately or via confusion, a variety of methods to undermine the science or its implications:

1. In presenting or assessing evidence they deliberately fail to distinguish between oscillations and trends, or suggest it is impossible to say anything about the difference. Oscillations in climate changes will continue, but it is the underlying trend that is very powerful both in the evidence and the understanding of its causes. There are examples of oscillations at the scale of every decade or few years (such as El Niño/La Niña, where warmer or colder water comes to the surface of the Pacific Ocean, or a similar phenomenon in the Atlantic Ocean called the North Atlantic Oscillation). There are oscillations or randomness in solar activity with somewhat longer or shorter frequencies. There are variations in the Earth's orbits around the sun with cycles of tens of thousands of years. But the logic of the flow-stock process of emissions and concentrations of GHGs points to a powerful cause for an underlying trend of temperature increase. And we can be quantitative about these trends (as we have tried to be in the above discussion), and we see that they are extraordinarily rapid in relation to changes that have occurred over climate history.
2. They find a handful of erroneous papers and imply that all the other many thousands of papers, from a wide range of reputable and geographically separate research institutions, can be disregarded. The evidence is so strong and the papers so many that striking out a few papers would make no difference to the overall strength of the established body of evidence accumulated over many years and across institutions.
3. Some fail to recognize, or deliberately ignore, the compelling refutation of spurious arguments: examples of such arguments include attributing increased global temperatures to the increase in urban heat islands, overly simplified explanations of climate changes and variations (see

below), conspiratorial interpretations of University of East Anglia emails, etc. And so an argument or allegation is thrown into the air in the hope that it will float around even though it can be, and is, quickly refuted.[35]

Those who wish to delay and spread doubt often do this through a series of queries and often simpleminded objections. If you keep these coming, however flimsy they may be, the doubt may be refueled. There was a famous internal memorandum in the tobacco industry concerning smoking and health with the phrase "doubt is our product."[36] So too with climate change.

There are now extensive collections of spurious arguments against the science, and their refutations.[37] One objection that is repeated with regularity is: "Global average temperatures have stopped rising, so global warming has stopped." While there is evidence of a recent flattening in the rise of average global temperature (see figure 1.1), to conclude from this that global warming has stopped displays a poor understanding of the science, particularly around stochastic oscillations (natural variability in climate or "noise") and the main climate forcing mechanisms (largely GHG forcing and aerosol forcing).[38] While scientists do not know with certainty, the recent flattening is thought to be caused, in part, by a reduction in the growth rate of the net climate forcing.[39] The phasing out of ozone-depleting gases, a reduction in the growth rate of methane, an increase in stratospheric aerosols, and a decrease in solar irradiance are thought to be responsible. The planet remains out of energy balance, however, which means something else must also be contributing to the flattening. This is believed to be natural variability or "noise" caused by factors such as ocean oscillations (particularly La Niña "cooling" conditions that have prevailed over the last few years).[40] The "Summary for Policymakers" of the IPCC's most recent assessment report confirms this explanation and notes that "global mean surface temperature exhibits substantial decadal and interannual variability. … Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends."[41]

Another common argument is that the twentieth-century warming trend is simply explained by the world coming out of a natural oscillation known as the "little ice age" that occurred in Europe between the sixteenth and nineteenth centuries. The exact cause of the little ice age is not settled, but scientists believe it was due to a combination of natural forces including changes in solar activity and high volcanic activity that had a cooling effect.[42] Solar activity did increase from the end of the little ice age, but only until around 1950. Natural factors such as solar activity and volcanic eruptions cannot explain the recent warming since 1950. Also the little ice age was a European rather than global phenomenon.[43] Global average surface temperatures have stayed within a small range over the last eight millennia (roughly plus or minus 1.5°C); we are already at the upper end of that range.[44]

Other tactics are more simplistic, such as using a local climate event to question the long-term rise in global average temperature. For example, some claim the extremely cold European winter of 2009–2010 is evidence inconsistent with rising global temperature. However, this weather event was most likely due to a strong phase of the Arctic oscillation with impacts local to Europe.[45] While Europe was shivering, the rest of the world was experiencing above-average warmth; in terms of global average temperature, 2010 ended up equal with 2005 as the warmest year on record before 2014 (which looks likely to be the warmest yet).[46] Indeed, the 10 warmest years on record have all occurred since 1997.[47]

Another common position asserts that as water vapor is the main GHG, it cannot be CO_2 that is responsible for warming. Water vapor is the main GHG, but its levels are dependent on temperature. Additional CO_2 raises temperature, which increases evaporation, which leads to higher levels of water vapor in the atmosphere, which raises temperature further. This is what is called a positive feedback loop. It is the rising CO_2 that is the principal driver of the process.[48]

Others have questioned the role of CO_2 by claiming that emissions from volcanos far exceed anthropogenic CO_2 emissions. The latest evidence indicates that anthropogenic CO_2 emissions are around 130 times greater than the highest estimate of both subaerial and submarine volcanic emissions.[49]

There is also the issue of emissions from human respiration. Humans emit CO_2, but this comes from the food we eat, such as vegetables, which have absorbed the CO_2 during photosynthesis, so the emissions are "netted out." Emissions that arise from the processes involved in growing our food, such as nitrous oxide from fertilizer use, methane from cows, and CO_2 from soil disturbance, are counted in national emissions inventories.

The constant repetition of, and misinformation around, these types of positions has not helped to strengthen the political case for stronger action.

1.7 Where are we heading?

If we understand where we are now and where we are heading in terms of likely future global emissions paths, we will see far more clearly the scale of the problem, the immense risks we face, and the magnitude of the emissions reduction challenge. This will allow us to assess the urgency with which we need to act and change direction as a world.

We discuss the current state of international agreement and discussion in chapter 8; here we are concerned with examining current levels of emissions, current commitments to reduce the growth of emissions in the decade to 2020 (as embodied in the Copenhagen and Cancún plans of 2009 and 2010, the most recent broad international formal statements of intention; COP 21 in Paris at the end of 2015 will be seeking to construct a formal climate agreement which will include new targets), and where emissions are likely to head in the decade to 2030.[50] The overall pace of change is recklessly slow. We are acting as if change is too difficult and costly and delay is not a problem. In fact, while the commitments in the Copenhagen Accord and Cancún Agreements represent a significant deviation from what might be described as business as usual, they are not on a sufficient scale to be consistent with the reduction in emissions required for managing climate change responsibly in the sense of, for example, a 50–50 chance of 2°C.[51]

The future of global emissions will be strongly influenced by a changing world economy and the plans and commitments in the Copenhagen Accord and Cancún Agreement and, I hope, a strong Paris agreement at COP 21 in 2015. Figure 1.3 presents actual emissions in 2005 and 2010, prospects for world emissions in 2020 based on the Copenhagen/Cancún targets and plans, and some illustrative and somewhat speculative estimates of what emissions may be in 2030.[52]

It is quickly apparent from figure 1.3 that prospects for global emissions, based on current plans (and assuming of course that these

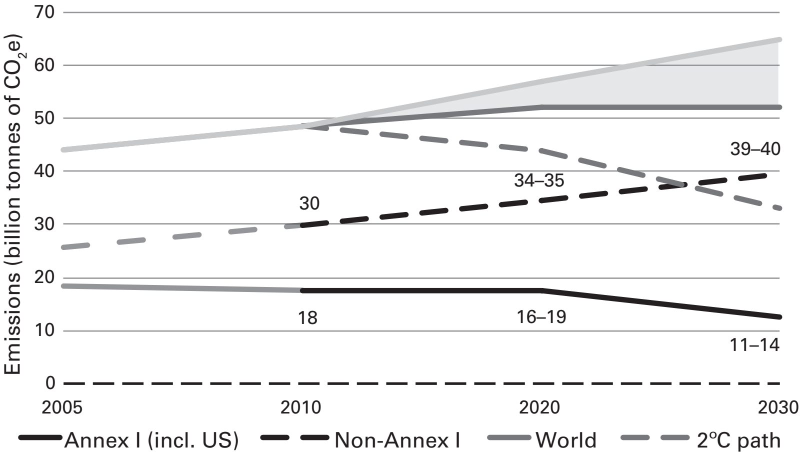

Figure 1.3
Prospects for world emissions based on current targets and plans: 2020 and 2030. The shaded area represents possible trajectories if we are unable to plateau global emissions around 50 billion tonnes CO_2e. Annex I countries are, roughly speaking, developed countries; for a formal list, see the UNFCCC website (http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php).
Source: UNEP (2012), appendix; author's calculations.

plans are successfully implemented and achieved), look like plateauing at best at around 50 billion tonnes CO_2e per annum. This figure also illustrates that big increases of emissions are now coming from the developing world (non-Annex I countries). These already contribute around two-thirds of the 50 billion total, and their emissions are likely to rise strongly over the decade to 2020. Much of the increase in annual emissions by 2020 is likely to come from China (possibly +3 billion tonnes per annum) and from India (possibly +1.5). Developed countries' plans, in contrast, indicate that emissions are likely to remain near current levels, with a range of between 16 and 19 billion tonnes per annum.[53]

For the decade 2020 to 2030 the estimates are more speculative and illustrative, as the Copenhagen/Cancún plans extend only to 2020, but the developing world may add another 5 to 6 billion tonnes CO_2e per annum by 2030, possibly more if economic growth rates and population growth remain high or accelerate in some regions. This could see emissions from the currently developing world reach around 40 billion tonnes in 2030 (giving it around 70% of global emissions, to go with perhaps around 55–60% or more of world GDP in 2030). To put the world on a path toward a 2°C average global temperature increase (and no higher), the *global* constraint for 2030 is around 35 billion tonnes per annum, which means that strong action on emissions from developing countries will be required, even if rich countries show very strong reductions by 2030. Even with the assumption that emissions could be around 42 billion tonnes CO_2e by 2030 for a 2°C target (which requires zero or negative total global emissions by the second half of the century), current Copenhagen/Cancún plans would leave total developing country emissions roughly equal to the entire budget.

Discussions with senior policymakers in China and India suggest that these two countries will account for much of the increase in emissions in the decade 2020 to 2030, just as they are likely to do in this decade (see figure 1.4). However, the combined population of India and China, although large at 2.6 billion people, is today only just over 40% of the population of the developing world (currently around 6 billion in a world population of around 7 billion). In 2030, their combined population will

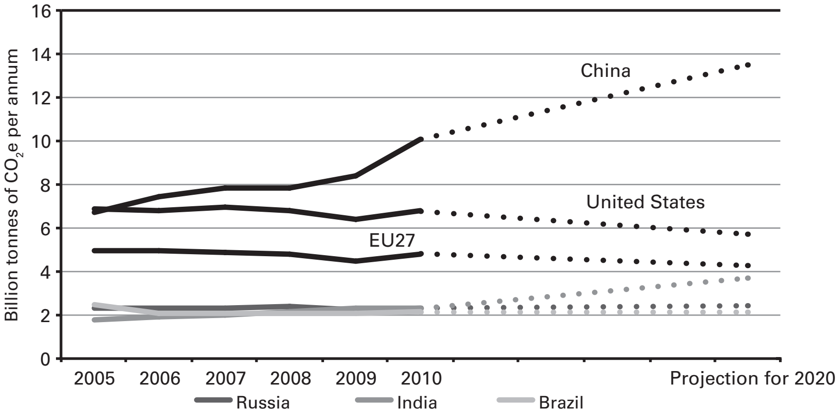

Figure 1.4
Prospects for emissions for the top six emitters in 2010 (collectively representing around 60% of world emissions). The emission paths shown between 2010 and 2020 are illustrative. Source: 2005–2010 data from World Resources Institute (2013). Estimates for 2020: UNEP (2012) for China and India; World Resources Institute (2013) for the US; European Commission (2010) for Europe; Brazilian Federal Government (2009) for Brazil; and Russian Federation (2013) for Russia.

likely be about 3 billion in a developing world population of around 7 billion (and a world population around 8 billion); Africa's population will likely be 1.5–2 billion by 2030. Many developing-country economies beyond India and China are likely to see strong growth in the coming two decades. A figure of 40 billion tonnes per annum will likely be at the lower end of total developing-world emissions in 2030, on the back of apparent current intentions (see figure 1.3). I should emphasize, however, that emissions intentions are under active discussion in much of the developing world, and there is increasing awareness of both the dangers of high emissions and the reduction in costs of low-carbon technologies.

The developed world may be able to reduce emissions by another 5 billion tonnes to get to between 11 and 14 billion tonnes per annum by 2030, but this is unlikely to offset the growth in emissions from developing countries.

The estimates to 2020 (figure 1.3), based on work by the United Nations Environment Programme (UNEP), and our more illustrative and speculative estimates to 2030, based on discussions with senior policymakers from developed and developing countries and on current growth and population trends, suggest that the world may see total emissions plateau, at best on current intentions and projections, at around 50 billion tonnes CO_2e for the next couple of decades. There are many ways we can look at where we might be heading for 2030, and the numbers here are only illustrative, but all point in a similar and worrying direction. Consistent with our estimates, the "New Policy Scenario" (which includes all commitments and plans announced or enacted) of the International Energy Agency's *World Energy Outlook 2012* forecasts emissions of just over 50 billion tonnes per year into the 2030s.[54]

These estimates assume that growth in developing countries continues: a reasonable assumption based on the evidence and a key part of a strategy to overcome poverty. Therefore, without intensification of plans for emissions reductions around the world, embodying a substantial reduction in emissions per unit of output, the plateau at 50 billion tonnes may prove to be very optimistic and we may end up somewhere in the shaded region of figure 1.3, at around 55–60 billion tonnes CO_2e.

(As proofs of this book were being finalized, the European Union set out targets in October 2014 of 40% reductions in emissions by 2030 from 1990 levels. On 12 November the US and China made a joint declaration in Beijing, with China indicating that its emissions would peak by 2030 and the US setting a target of 26–28% reductions by 2025 from 2005 levels. These areas generate around half of world emissions. A rough calculation on the basis of these targets suggests world emissions in 2030 of 50–55 billion tonnes CO_2e.)

The consequences of these high levels of global emissions should be carefully examined, communicated, and understood. It is clear from figure 1.3 that under the scenario we describe, any reasonable chance of meeting the 2°C target would be lost. To achieve that target, emissions will need to fall from current levels of around 50 billion tonnes of CO_2e to around 35 billion tonnes in 2030 (or around 42 with the very strong assumption that emissions could be zero or negative in the second half of the century). Our current ambitions as a world are not ambitious enough. Emissions are heading in a wrong direction that appears thoroughly inconsistent with a 2°C path.

Emissions in the region of 50 billion tonnes CO_2e into the 2030s would likely imply concentrations of GHGs in the atmosphere of over 650 ppm at stabilization a century or so from now, consistent with temperature increases of around 3.5°C (with a 50–50 chance).[55] And a 50–50 chance of around 3.5°C will leave us exposed to associated risks of still higher temperatures, perhaps around a 20% chance of 5°C and around a 10% chance of 6°C.

Climate impacts and risks are likely to be immense under such a scenario. The sensible path is to constrain emissions to a path that resembles a 2°C outcome (50–50 chance). In 2030, on the basis of a target of around 40 billion tonnes CO_2e in global annual emissions, this would mean that developing countries would need to be emitting below 30 billion tonnes per annum, which is less than they do at present, and developed countries would need to be below 10 billion tonnes per annum. For developed countries this would mean close to halving emissions. In per capita terms this would necessitate developing-country emissions of around 3 to 4 tonnes per capita and developed-country emissions of around 8 tonnes per capita (compared with the present figures of 6 tonnes for developing countries and 15 for developed countries).[56] Again all these numbers should be seen as illustrative, but the necessary scale and direction of travel are clear.

Stronger action across developing and developed countries is possible, but it will require more coordinated, collaborative, and rapid action than we have seen until now. Crucial here will be recognition of the strong moral responsibility and self-interest in long-term support from the developed world. Stronger action will require a shared understanding that the two defining challenges of our century are overcoming world poverty and managing climate change. The only way to achieve both together is by promoting the conditions for new low-carbon paths. We shall argue in this book that this is indeed possible and indeed a very attractive future path for growth and poverty reduction. On the other hand, if we fail on one challenge, we will fail on the other.

There are signs of growing enthusiasm from the developing nations for low-carbon growth, as they recognize the great risks of climate change and the opportunities in low-carbon growth for development and overcoming poverty. The growing need for energy and the risks from weather events were illustrated in India in July 2012 when the northern electricity grid collapsed, leaving around 330 million people without power one day, almost doubling to 650 million people the next day. In population terms, these were the largest power outages in history. The failure of the monsoon had led to a huge increase in electricity demand as farmers were forced to pump water for their crops. The grid was unable to cope with the demand and collapsed. Growth based on a low-carbon strategy could reduce these risks with a decentralized electricity supply, for example through solar and wind power located on the farm or in the district. This would avoid exposure to the manipulation and corruption of those running the grid and to grid collapse itself. It could provide farmers with cheap power, under their own control, and extend access to electricity to the many millions currently without it.

Support for low-carbon growth is increasing in many developing countries, e.g., in China's twelfth five-year plan and in South Africa, Korea, and Ethiopia. We discuss these plans in chapter 7. Support from businesses in developing countries is also growing: a 2011 survey by McKinsey shows that a higher percentage of respondents in China and India believe climate change policy will strengthen over the coming decades than in the US and Europe.

Geoengineering

Given the immense scale of the risks, where we are heading, and the apparent current lack of political will for stronger action, it is sensible to have an informed discussion on ways of removing GHGs from the atmosphere or preventing solar energy from reaching the Earth. These are known as geoengineering and are increasingly being discussed. However, most geoengineering techniques are undeveloped, largely untested in the real world (mostly they have been examined and tested to date via computer modeling), and are likely to involve significant costs and risks.[57] Such geoengineering itself could radically change the climate, the seas, and the atmosphere in ways that are unpredictable and could be deeply damaging. There are also very worrying governance and democracy issues around the research, development, and deployment of geoengineering techniques. For example, do appropriate governance mechanisms exist or can they be developed for geoengineering techniques with uncertain and cross-border impacts, such as the injection of aerosols into the atmosphere?

A 2013 report from the World Economic Forum discusses the risk of possible unilateral geoengineering actions by states or individuals.[58] They give the example of a US businessman who dumped 100 tonnes of iron sulfate into the Pacific Ocean to generate an artificial plankton bloom that would absorb CO_2 and generate carbon credits. The legal status of such action is unresolved, and they may be in breach of two United Nations agreements. Nevertheless, given the immense risks we face and our dithering on action, it is sensible to continue research in this area.

The most promising route to extraction of carbon dioxide is the natural one of reforestation, restoring of degraded forests, and the restoring of degraded grasslands and agricultural land. There are indeed prospects for extraction here; see for example the report of the Global Commission on the Economy and Climate titled *Better Growth, Better Climate*.[59] Carbon capture and storage from biomass energy is another possibility which could offer zero or perhaps negative emissions, by capturing carbon emissions from burning biomass energy. At present it is constrained to some extent by the prior development of power and industrial applications of CCS technology. While carbon dioxide removal technologies like this have not been applied at scale, the 2014 IPCC *Fifth Assessment Report* emphasizes that they may be necessary in many emissions pathways (to have a good chance to stay below 2°C); it looks increasingly as though we will have to aim for negative net emissions toward the end of the century, given our possible slowness in reducing emissions in the coming years.[60]

Is the 2°C window still open?

Before we continue our analysis we should ask whether the 2°C window is open, closing, or has already shut. The International Energy Agency's *World Energy Outlook 2012* suggests that the window has not closed but is getting more difficult each year as we fail to accelerate action.[61] Almost 80% of all energy emissions consistent with a 2°C scenario are already locked in by existing power plants and other infrastructure. This will rise to 100% in 2017, unless there is significant acceleration in energy efficiency measures, which can push this ceiling out to around 2022. The IEA's 2012 report also shows that only around one-third of currently proven fossil fuel reserves can be burned before 2050 to be consistent with 2°C, unless there are significant advances in and deployment of carbon capture and storage technology. Even given the potential role of carbon capture and storage, the agency's 2013 report projects that only 1% of global fossil-fuel-fired power plants will be equipped with the technology by 2035.[62]

The IEA's 2013 report suggests four policy measures that could keep the 2°C window open. These could be implemented rapidly (prior to 2020) and at no net economic cost (they would represent investments with strong returns) yet cut 80% of the excess emissions in 2020 relative to the 2°C path. In addition to continued development of renewable energy, the measures include: a strong push on energy efficiency measures; preventing new coal-fired plants and limiting the use of the least efficient ones; reducing the release of methane from upstream oil and gas production; and accelerating the reduction in fossil fuel subsidies. Although the challenges we face to keep the 2°C possibility alive are formidable, the increase in the scale of the risks from higher temperatures, the uncertainty around impacts and the dangers of delay, the risks around geoengineering, and the attractiveness and many benefits of the alternative paths (which we discuss in the next chapter) all mean that it makes sense to continue to push hard to achieve this goal. Real options using existing and proven technologies to keep the window open are there. It would be irresponsible and reckless to delay further, to let the

2°C window close, and to hope for the best at some higher temperature target.

Achieving a 2°C target will involve leaving around 70% or more of proven hydrocarbon reserves in the ground, so-called "unburnable carbon" (unless the deployment of carbon capture and storage proceeds far faster than currently seems likely).[63] The financial markets, and some industry players, are operating as if, or assuming that, the shadow price of carbon for the medium and long run is near zero. Many do not understand, or do not wish to understand, that the era of unabated hydrocarbons is at an end. Many are still seeking more and more hydrocarbons, pursuing unconventional sources,[64] and valuing hydrocarbons as if their unabated use has a strong future.

1.8 Conclusions

Analysis and understanding must start with the science. This chapter has provided the scientific foundations for the case for action on climate change. By looking at the uncertainty, the lags, and the "publicness" of the emissions it has also pointed to reasons, following from the science, why action has, so far, been too weak and slow.

In summary, the main lessons we have learned from this chapter are:

- The risks of climate change are potentially immense. The relationship of humans to the planet could be rewritten, with temperature increases not seen for millions of years occurring in a hundred years or so. People will often find risks of this magnitude difficult to understand, decide on, or manage.
- Consequences of climate change appear with long lags and are difficult to reverse. There is a lag between emissions (what we called the flows) and the impacts in terms of warming and climate change from the accumulation of additional CO_2 in the atmosphere (the stock). The influence of increased concentrations on climate can last for many centuries. And the impact of climate change can be very destructive and long-lasting or irreversible. Delay is dangerous.
- The sum of carbon matters, not the location. The effect of a kilogram of GHG emissions is independent of the location of its source. The

"publicness," in this sense, of the phenomenon requires strong participation of the many.

- The science is inadequately incorporated into policy decision-making. For the reasons discussed above, there is a grave risk that inaction or delay will result from confusion, inadequate understanding of the science, and misunderstanding of evidence.
- The window within which we may limit global temperature increases to 2°C above preindustrial times is still open, but is closing rapidly. Urgent and strong action in the next two decades, with deep and economy-wide progress this decade, is necessary if the risks of dangerous climate change are to be radically reduced.

These arguments form the basis for the discussion and analysis in the following chapters on what can and should be done in order to make good economic policy for the transition to a low-carbon economy and society. This path and this destination could be very attractive. A transition to a low-carbon path inevitably has its own risks and uncertainties, but they are far less than those we face from unmanaged climate change. Understanding and communicating the relevant risks is a crucial part of the story if the political will necessary to drive progress forward is to be fostered.

Why Are We Waiting?

The Logic, Urgency, and Promise of Tackling Climate Change

By: Nicholas Stern

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