

# Projected Impacts of Climate Change

Global temperature change (relative to pre-industrial)

0°C

1°C

2°C

3°C

4°C

5°C

## Food

*Falling crop yields in many areas, particularly developing regions*

*Possible rising yields in some high latitude regions*

*Falling yields in many developed regions*

## Water

*Small mountain glaciers disappear – water supplies threatened in several areas*

*Significant decreases in water availability in many areas, including Mediterranean and Southern Africa*

*Sea level rise threatens major cities*

## Ecosystems

*Extensive Damage to Coral Reefs*

*Rising number of species face extinction*

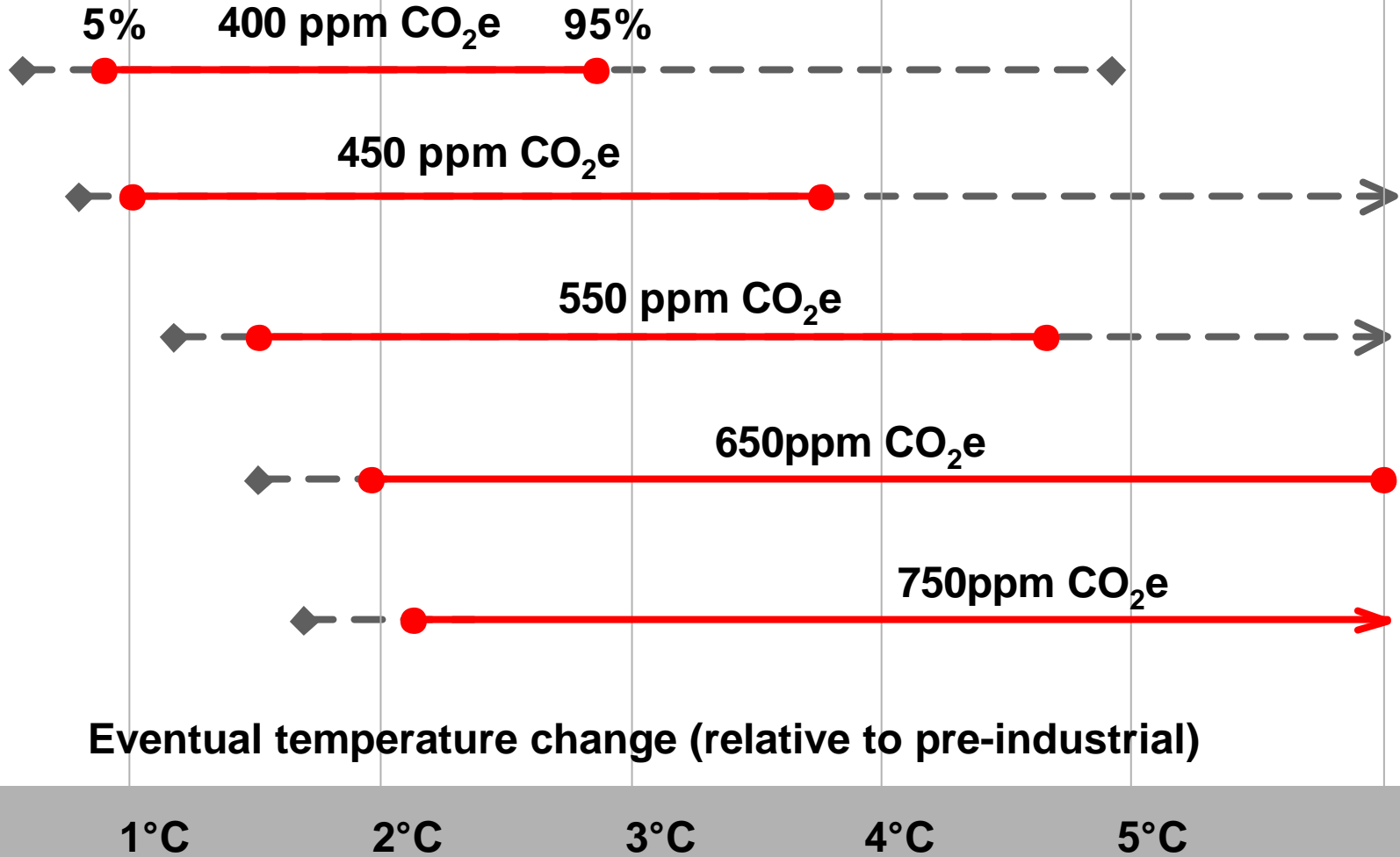
## Extreme Weather Events

*Rising intensity of storms, forest fires, droughts, flooding and heat waves*

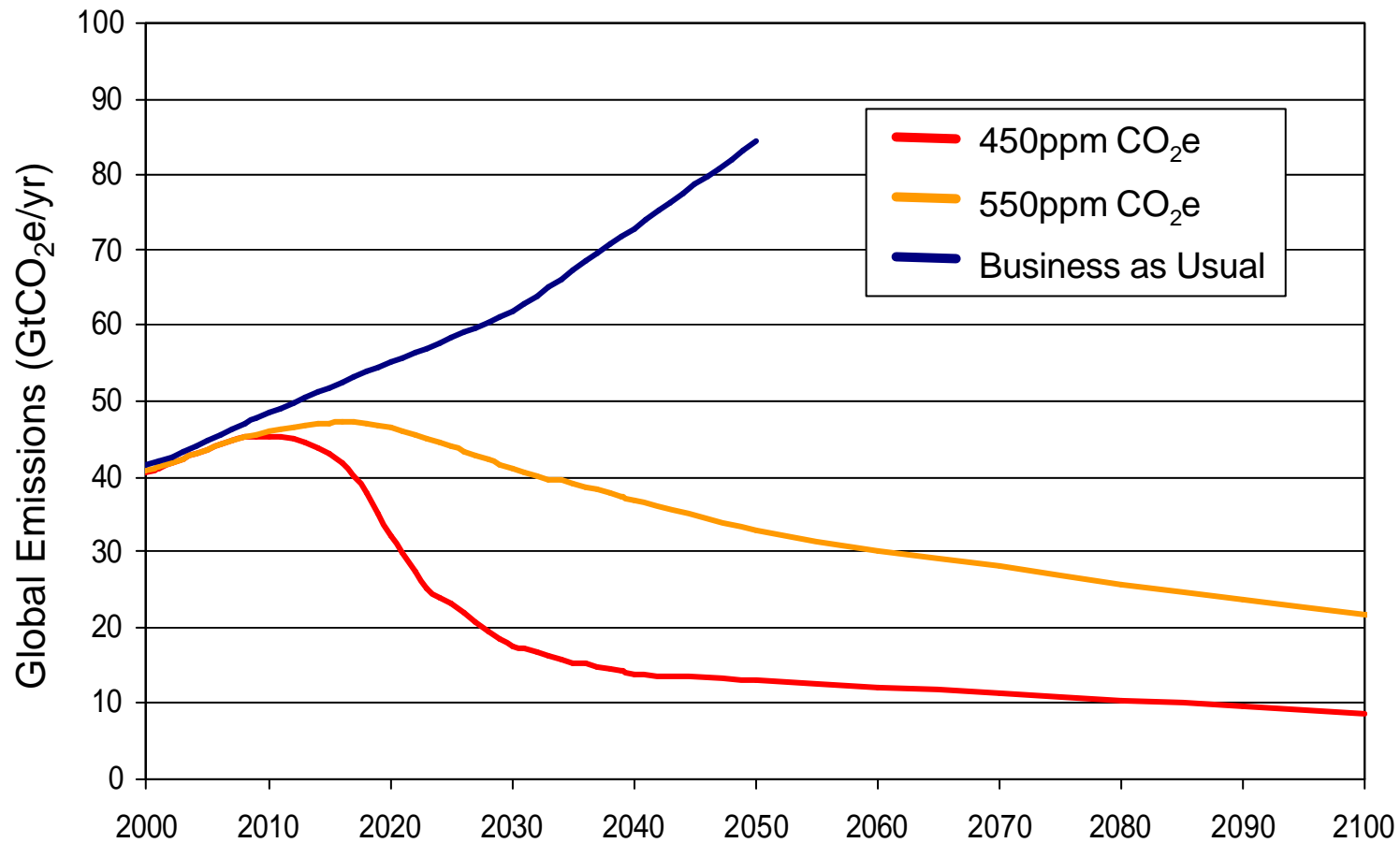
## Risk of Abrupt and Major Irreversible Changes

*Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system*

# Stabilisation and Commitment to Warming



# Emissions Paths to Stabilisation



## Part I

### Climate Change – our approach

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Part I of the Review considers the nature of the scientific evidence for climate change, and the nature of the economic analysis required by the structure of the problem which follows from the science.

The first half of the Review examines the evidence on the economic impacts of climate change itself, and explores the economics of stabilising greenhouse gas concentrations in the atmosphere. The second half of the Review considers the complex policy challenges involved in managing the transition to a low-carbon economy and in ensuring that societies can adapt to the consequences of climate change that can no longer be avoided.

The Review takes an international perspective. Climate change is global in its causes and consequences, and the response requires international collective action. Working together is essential to respond to the scale of the challenge. An effective, efficient and equitable collective response to climate change will require deeper international co-operation in areas including the creation of price signals and markets for carbon, scientific research, infrastructure investment, and economic development.

Climate change presents a unique challenge for economics: it is the greatest example of market failure we have ever seen. The economic analysis must be global, deal with long time horizons, have the economics of risk and uncertainty at its core, and examine the possibility of major, non-marginal change. Analysing climate change requires ideas and techniques from most of the important areas of economics, including many recent advances.

Part I is structured as follows:

- **Chapter 1** examines the latest scientific evidence on climate change. The basic physics and chemistry of the scientific understanding begins in the 19th century when Fourier, Tyndall and Arrhenius laid the foundations. But we must also draw on the very latest science which allows a much more explicit analysis of risk than was possible five years ago.
- **Chapter 2** considers how economic theory can help us analyse the relationship between climate change and the divergent paths for growth and development that will result from 'business as usual' approaches and from strong action to reduce emissions. We look at the range of theories required and explain some of the technical foundations necessary for the economics that the scientific analysis dictates.
- **The technical annex to Chapter 2** addresses the complex issues involved in the comparison of alternative paths and their implications for individuals in different places and generations. Building on Chapter 2, we explore the ethical issues concerning the aggregation of the welfare of individuals across time, place and uncertain outcomes. This annex also provides a technical explanation of the approach to discounting used throughout the Review, and in particular in our own analysis of the costs of climate-change impacts.

## Summary of Conclusions

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***There is still time to avoid the worst impacts of climate change, if we take strong action now.***

The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response.

This Review has assessed a wide range of evidence on the impacts of climate change and on the economic costs, and has used a number of different techniques to assess costs and risks. From all of these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting.

Climate change will affect the basic elements of life for people around the world – access to water, food production, health, and the environment. Hundreds of millions of people could suffer hunger, water shortages and coastal flooding as the world warms.

Using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.

In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year.

The investment that takes place in the next 10-20 years will have a profound effect on the climate in the second half of this century and in the next. Our actions now and over the coming decades could create risks of major disruption to economic and social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20<sup>th</sup> century. And it will be difficult or impossible to reverse these changes.

So prompt and strong action is clearly warranted. Because climate change is a global problem, the response to it must be international. It must be based on a shared vision of long-term goals and agreement on frameworks that will accelerate action over the next decade, and it must build on mutually reinforcing approaches at national, regional and international level.

***Climate change could have very serious impacts on growth and development.***

If no action is taken to reduce emissions, the concentration of greenhouse gases in the atmosphere could reach double its pre-industrial level as early as 2035, virtually committing us to a global average temperature rise of over 2°C. In the longer term, there would be more than a 50% chance that the temperature rise would exceed 5°C. This rise would be very dangerous indeed; it is equivalent to the change in average temperatures from the last ice age to today. Such a radical change in the physical geography of the world must lead to major changes in the human geography – where people live and how they live their lives.

Even at more moderate levels of warming, all the evidence – from detailed studies of regional and sectoral impacts of changing weather patterns through to economic

models of the global effects – shows that climate change will have serious impacts on world output, on human life and on the environment.

All countries will be affected. The most vulnerable – the poorest countries and populations – will suffer earliest and most, even though they have contributed least to the causes of climate change. The costs of extreme weather, including floods, droughts and storms, are already rising, including for rich countries.

Adaptation to climate change – that is, taking steps to build resilience and minimise costs – is essential. It is no longer possible to prevent the climate change that will take place over the next two to three decades, but it is still possible to protect our societies and economies from its impacts to some extent – for example, by providing better information, improved planning and more climate-resilient crops and infrastructure. Adaptation will cost tens of billions of dollars a year in developing countries alone, and will put still further pressure on already scarce resources. Adaptation efforts, particularly in developing countries, should be accelerated.

***The costs of stabilising the climate are significant but manageable; delay would be dangerous and much more costly.***

The risks of the worst impacts of climate change can be substantially reduced if greenhouse gas levels in the atmosphere can be stabilised between 450 and 550ppm CO<sub>2</sub> equivalent (CO<sub>2</sub>e). The current level is 430ppm CO<sub>2</sub>e today, and it is rising at more than 2ppm each year. Stabilisation in this range would require emissions to be at least 25% below current levels by 2050, and perhaps much more.

Ultimately, stabilisation – at whatever level – requires that annual emissions be brought down to more than 80% below current levels.

This is a major challenge, but sustained long-term action can achieve it at costs that are low in comparison to the risks of inaction. Central estimates of the annual costs of achieving stabilisation between 500 and 550ppm CO<sub>2</sub>e are around 1% of global GDP, if we start to take strong action now.

Costs could be even lower than that if there are major gains in efficiency, or if the strong co-benefits, for example from reduced air pollution, are measured. Costs will be higher if innovation in low-carbon technologies is slower than expected, or if policy-makers fail to make the most of economic instruments that allow emissions to be reduced whenever, wherever and however it is cheapest to do so.

It would already be very difficult and costly to aim to stabilise at 450ppm CO<sub>2</sub>e. If we delay, the opportunity to stabilise at 500-550ppm CO<sub>2</sub>e may slip away.

***Action on climate change is required across all countries, and it need not cap the aspirations for growth of rich or poor countries.***

The costs of taking action are not evenly distributed across sectors or around the world. Even if the rich world takes on responsibility for absolute cuts in emissions of 60-80% by 2050, developing countries must take significant action too. But developing countries should not be required to bear the full costs of this action alone, and they will not have to. Carbon markets in rich countries are already beginning to deliver flows of finance to support low-carbon development, including through the Clean Development Mechanism. A transformation of these flows is now required to support action on the scale required.

Action on climate change will also create significant business opportunities, as new markets are created in low-carbon energy technologies and other low-carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly.

The world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. Indeed, ignoring climate change will eventually damage economic growth.

Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries.

***A range of options exists to cut emissions; strong, deliberate policy action is required to motivate their take-up.***

Emissions can be cut through increased energy efficiency, changes in demand, and through adoption of clean power, heat and transport technologies. The power sector around the world would need to be at least 60% decarbonised by 2050 for atmospheric concentrations to stabilise at or below 550ppm CO<sub>2</sub>e, and deep emissions cuts will also be required in the transport sector.

Even with very strong expansion of the use of renewable energy and other low-carbon energy sources, fossil fuels could still make up over half of global energy supply in 2050. Coal will continue to be important in the energy mix around the world, including in fast-growing economies. Extensive carbon capture and storage will be necessary to allow the continued use of fossil fuels without damage to the atmosphere.

Cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also essential.

With strong, deliberate policy choices, it is possible to reduce emissions in both developed and developing economies on the scale necessary for stabilisation in the required range while continuing to grow.

Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections. Three elements of policy are required for an effective global response. The first is the pricing of carbon, implemented through tax, trading or regulation. The second is policy to support innovation and the deployment of low-carbon technologies. And the third is action to remove barriers to energy efficiency, and to inform, educate and persuade individuals about what they can do to respond to climate change.

***Climate change demands an international response, based on a shared understanding of long-term goals and agreement on frameworks for action.***

Many countries and regions are taking action already: the EU, California and China are among those with the most ambitious policies that will reduce greenhouse gas emissions. The UN Framework Convention on Climate Change and the Kyoto Protocol provide a basis for international co-operation, along with a range of partnerships and other approaches. But more ambitious action is now required around the world.

Countries facing diverse circumstances will use different approaches to make their contribution to tackling climate change. But action by individual countries is not enough. Each country, however large, is just a part of the problem. It is essential to create a shared international vision of long-term goals, and to build the international frameworks that will help each country to play its part in meeting these common goals.

Key elements of future international frameworks should include:

- *Emissions trading*: Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries: strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths.
- *Technology cooperation*: Informal co-ordination as well as formal agreements can boost the effectiveness of investments in innovation around the world. Globally, support for energy R&D should at least double, and support for the deployment of new low-carbon technologies should increase up to five-fold. International co-operation on product standards is a powerful way to boost energy efficiency.
- *Action to reduce deforestation*: The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large-scale international pilot programmes to explore the best ways to do this could get underway very quickly.
- *Adaptation*: The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honour their pledges to increase support through overseas development assistance. International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought and flood.

The first half of the Review considers how the evidence on the economic impacts of climate change, and on the costs and benefits of action to reduce greenhouse gas emissions, relates to the conceptual framework described above.

***The scientific evidence points to increasing risks of serious, irreversible impacts from climate change associated with business-as-usual (BAU) paths for emissions.***

The scientific evidence on the causes and future paths of climate change is strengthening all the time. In particular, scientists are now able to attach probabilities to the temperature outcomes and impacts on the natural environment associated with different levels of stabilisation of greenhouse gases in the atmosphere. Scientists also now understand much more about the potential for dynamic feedbacks that have, in previous times of climate change, strongly amplified the underlying physical processes.

The stocks of greenhouse gases in the atmosphere (including carbon dioxide, methane, nitrous oxides and a number of gases that arise from industrial processes) are rising, as a result of human activity. The sources are summarised in Figure 1 below.

The current level or stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO<sub>2</sub><sup>1</sup>, compared with only 280ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades, because of the inertia in the climate system.

Even if the annual flow of emissions did not increase beyond today's rate, the stock of greenhouse gases in the atmosphere would reach double pre-industrial levels by 2050 - that is 550ppm CO<sub>2</sub>e - and would continue growing thereafter. But the annual flow of emissions is accelerating, as fast-growing economies invest in high-carbon infrastructure and as demand for energy and transport increases around the world. The level of 550ppm CO<sub>2</sub>e could be reached as early as 2035. At this level there is at least a 77% chance - and perhaps up to a 99% chance, depending on the climate model used - of a global average temperature rise exceeding 2°C.

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<sup>1</sup> Referred to hereafter as CO<sub>2</sub> equivalent, CO<sub>2</sub>e

Using this model, and including those elements of the analysis that can be incorporated at the moment, we estimate the total cost over the next two centuries of climate change associated under BAU emissions involves impacts and risks that are equivalent to an average reduction in global per-capita consumption of at least 5%, now and forever. While this cost estimate is already strikingly high, it also leaves out much that is important.

The cost of BAU would increase still further, were the model systematically to take account of three important factors:

- First, including direct impacts on the environment and human health (sometimes called 'non-market' impacts) increases our estimate of the total cost of climate change on this path from 5% to 11% of global per-capita consumption. There are difficult analytical and ethical issues of measurement here. The methods used in this model are fairly conservative in the value they assign to these impacts.
- Second, some recent scientific evidence indicates that the climate system may be more responsive to greenhouse-gas emissions than previously thought, for example because of the existence of amplifying feedbacks such as the release of methane and weakening of carbon sinks. Our estimates, based on modelling a limited increase in this responsiveness, indicate that the potential scale of the climate response could increase the cost of climate change on the BAU path from 5% to 7% of global consumption, or from 11% to 14% if the non-market impacts described above are included.
- Third, a disproportionate share of the climate-change burden falls on poor regions of the world. If we weight this unequal burden appropriately, the estimated global cost of climate change at 5-6°C warming could be more than one-quarter higher than without such weights.

Putting these additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in consumption per head, now and into the future.

In summary, analyses that take into account the full ranges of both impacts and possible outcomes - that is, that employ the basic economics of risk - suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range.

Economic forecasting over just a few years is a difficult and imprecise task. The analysis of climate change requires, by its nature, that we look out over 50, 100, 200 years and more. Any such modelling requires caution and humility, and the results are specific to the model and its assumptions. They should not be endowed with a precision and certainty that is simply impossible to achieve. Further, some of the big uncertainties in the science and the economics concern the areas we know least about (for example, the impacts of very high temperatures), and for good reason - this is unknown territory. The main message from these models is that when we try to take due account of the upside risks and uncertainties, the probability-weighted costs look very large. Much (but not all) of the risk can be reduced through a strong mitigation policy, and we argue that this can be achieved at a far lower cost than

### 5 Costs Of Climate Change In Developed Countries

#### Key Messages

**Climate change will have some positive effects for a few developed countries for moderate amounts of warming, but will become very damaging at the higher temperatures that threaten the world in the second half of this century.**

- In higher latitude regions, such as Canada, Russia and Scandinavia, climate change could bring net benefits up to 2 or 3°C through higher agricultural yields, lower winter mortality, lower heating requirements, and a potential boost to tourism. But these regions will also experience the most rapid rates of warming with serious consequences for biodiversity and local livelihoods.
- Developed countries in lower latitudes will be more vulnerable. Regions where water is already scarce will face serious difficulties and rising costs. Recent studies suggest a 2°C rise in global temperatures may lead to a 20% reduction in water availability and crop yields in southern Europe and a more erratic water supply in California, as the mountain snowpack melts by 25 – 40%.
- In the USA, one study predicts a mix of costs and benefits initially ( $\pm$  1% GDP), but then declines in GDP even in the most optimistic scenarios once global temperatures exceed 3°C.
- The poorest will be the most vulnerable. People on lower incomes are more likely to live in poor-quality housing in higher-risk areas and have fewer financial resources to cope with climate change, including lack of comprehensive insurance cover.

**The costs of extreme weather events, such as storms, floods, droughts, and heatwaves, will increase rapidly at higher temperatures, potentially counteracting some of the early benefits of climate change. Costs of extreme weather alone could reach 0.5 - 1% of world GDP by the middle of the century, and will keep rising as the world warms.**

- Damage from hurricanes and typhoons will increase substantially from even small increases in storm severity, because they scale as the cube of windspeed or more. A 5 – 10% increase in hurricane windspeed is predicted to approximately double annual damages, resulting in total losses of 0.13% of GDP each year on average in the USA alone.
- The costs of flooding in Europe are likely to increase, unless flood management is strengthened in line with the rising risk. In the UK, annual flood losses could increase from around 0.1% of GDP today to 0.2 – 0.4% of GDP once global temperature increases reach 3 to 4°C.
- Heatwaves like 2003 in Europe, when 35,000 people died and agricultural losses reached \$15 billion, will be commonplace by the middle of the century.

**At higher temperatures, developed economies face a growing risk of large-scale shocks.**

- Extreme weather events could affect trade and global financial markets through disruptions to communications and more volatile costs of insurance and capital.
- Major areas of the world could be devastated by the social and economic consequences of very high temperatures. As history shows, this could lead to large-scale and disruptive population movement and trigger regional conflict.

#### 5.1 Introduction

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***While the most serious impacts of climate change will fall on the poorest countries, the developed world will be far from immune.***

On the whole, developed countries will be less vulnerable to climate change because:<sup>1</sup>

- A smaller proportion of their economy is in sectors such as agriculture that are most sensitive to climate.

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<sup>1</sup> Tol *et al.* (2004) set out these arguments in some detail and with great clarity.

## PART II: The Impacts of Climate Change on Growth and Development

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losses of 0.13% of GDP in the USA each year on average or insured losses of \$100 – 150 billion in an extreme year (2004 prices).<sup>29</sup> If temperatures increase by 4 or 5°C, the losses are likely to be substantially greater, because any further increase in storm intensity has an even larger impact on damage costs (convexity highlighted in Chapter 3). This effect will be magnified for the costs of extreme storms, which are expected to increase disproportionately more than the costs of an average storm. For example, Swiss Re recently estimated that in Europe the costs of a 100-year storm event could double by the 2080s with climate change (\$50/€40 billion in the future compared with \$25/€20 billion today), while average storm losses were estimated to increase by only 16 – 68% over the same period.<sup>30</sup>

Rising sea levels will increase the risk of damages to coastal infrastructure and accelerate capital depreciation (Box 5.5). Costs of flood defences on the coast will rise, along with insurance premiums. A Government study calculated that in the UK the average annual costs of flood damage to homes, businesses and infrastructure could increase from around 0.1% of GDP currently to 0.2 – 0.4% of GDP if global temperatures rise by 3 to 4°C.<sup>31</sup> Greater investment in flood protection is likely to keep damages in check. Similarly, preliminary estimates suggest that annual flood losses in Europe could rise from \$10 billion today to \$120 – 150 billion (€100 – 120 billion) by the end of the century.<sup>32</sup> If flood management is strengthened in line with the rising risk, the costs may only increase two-fold. According to one recent report, storm surge heights all along Australia's East Coast from Victoria to Cairns could rise by 25 – 30% with only a 2°C increase in global temperatures.<sup>33</sup>

***Heatwaves like 2003 in Europe, when 35,000 people died and agricultural losses reached \$15 billion, will be commonplace by the middle of the century.***

People living and working in urban areas will be particularly susceptible to increases in heat-related mortality because of the interaction between regional warming, the urban heat island and air pollution (Chapter 3). In California, a warming of around 2°C relative to pre-industrial is expected to extend the heat wave season by 17 – 27 days and cause a 25 - 35% rise in high pollution days, leading to a 2 to 3-fold increase in the number of heat related deaths in urban areas.<sup>34</sup> In the UK, for a global temperature rise of 3°C, temperatures in London could be up to 7°C warmer than today because of the combined effect of climate change and the urban heat island effect, meaning that comfort levels will be exceeded for people at work for one-quarter of the time on average in the summer.<sup>35</sup> In years that are warmer than average or at higher temperatures, office buildings could become difficult to work in for large spells during the summer without additional air-conditioning. In already-dry regions, such as parts of the Mediterranean and South East England, hot summers will further increase soil drying and subsidence damage to properties that are not properly underpinned.<sup>36</sup>

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<sup>29</sup> Recent papers from Nordhaus (2006) and the Association of British Insurers (2005a) examined consequences of increased hurricane wind-speeds of 6% on loss damages, keeping socio-economic conditions and prices constant. Several climate models predict a 6% increase in storm intensity for a doubling of CO<sub>2</sub> concentrations (close to a 3°C temperature rise). The insurance study used existing industry catastrophe loss models validated with historic events to predict future losses. The extreme event costs are defined from an event with a 0.4% chance of occurring (1 in 250 year loss).

<sup>30</sup> Heck *et al.* (2006)

<sup>31</sup> UK Government Foresight Programme (2004) calculations for flooding from rivers, the sea and flash-flooding in urban areas. Prof Jim Hall at the University of Newcastle has provided some additional analysis. Assumes no change in flood management policies.

<sup>32</sup> Research from the Association of British Insurers (2005a) extrapolated from a UK-based study of flood losses that assumed no change in flood management policies beyond existing programme. Some of the increased cost is driven by economic growth of the century and greater absolute wealth in physical assets.

<sup>33</sup> Preston and Jones (2006)

<sup>34</sup> Hayhoe *et al.* (2006)

<sup>35</sup> London Climate Change Partnership (2004)

<sup>36</sup> Association of British Insurers (2004) estimates that subsidence costs to buildings could double by the middle of the century to £600 million (2004 prices).

### 5.5 Large-scale impacts and systemic shocks

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***Abrupt shifts in climate and rising costs of extreme weather events will affect global financial markets.***

Well-developed financial markets will help richer countries moderate the impacts of climate change – for example hedging with derivatives to smooth commodity prices. Such markets help to spread the risk across different regional markets and over time, but cannot reduce the risks by themselves. In addition, they are at risk of severe disruption from climate change:

- **Physical risks.** The world's major financial centres (London, New York and Tokyo) are all located in coastal areas. The insurance industry estimates that in London alone at least \$220 billion (£125 billion) of assets lie in the floodplain.<sup>38</sup>
- **Correlated risks.** At higher temperatures, climate change is likely to have severe impacts on many parts of the economy simultaneously. The shock may well exceed the capacity of markets and could potentially destabilise regions.<sup>39</sup> For example, a collapse of the Atlantic Thermohaline Circulation would have a massive effect on many parts of the economy of the countries around the Northern Atlantic Ocean and polar seas.<sup>40</sup> A collapse in the next few decades would lead to a decrease in temperatures across much of the northern hemisphere, with a peak cooling of around 2°C in the UK and Scandinavia. Preliminary estimates suggest that this would be accompanied by a reduction in rainfall over much of the northern hemisphere,<sup>41</sup> reducing agriculture productivity, water supplies and threatening ecosystems.
- **Capital constraints on insurance.** Increasing costs of extreme weather will not only raise insurance premiums - they will also increase the amount of capital that insurance companies have to hold to cover extreme losses, such as a hurricane that occurs once every 100 years (Box 5.6). The insurance industry will have to develop new financial products to gain more widespread access to international capital markets.<sup>42</sup> New opportunities for diversifying risk are already emerging, for example weather derivatives and catastrophe bonds, but in future these will require new risk valuation techniques to deal with the changing profile of extreme weather events. If the insurance industry looks to access additional capital from the securities and bond markets, investors are likely to demand higher rates of return for placing more capital at risk, causing a rise in the cost of capital.
- **Spillover risks to other financial sectors.**<sup>43</sup> Failure to raise sufficient capital could mean restrictions in insurance coverage. After seven costly hurricanes in the past two years, higher reinsurance prices have pushed up the cost of insurance coverage in the USA and contributed to decisions by some insurers to transfer more risk back to the homeowner or business, for example by raising deductibles or cutting back on coverage in riskier areas.<sup>44</sup> In future, if rising weather risks cause insurance to become even less available in high-risk areas like the coast, this could be severely disruptive for other parts of the economy. Banks, for example, would be unable to offer finance where insurance is required as part of the collateral package for mortgages or loans.

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<sup>38</sup> Association of British Insurers (2005b)

<sup>39</sup> As set out in a Pentagon commissioned report by Schwartz and Randall (2004)

<sup>40</sup> A complete collapse of the Thermohaline Circulation is considered to be unlikely (but still plausible) this century (Chapter 1).

<sup>41</sup> Vellinga and Wood (2002)

<sup>42</sup> Salmon and Weston (2006)

<sup>43</sup> Mills (2005)

<sup>44</sup> Mills and Lecomte (2006) provide many examples of increasing prices or withdrawing cover in the US. For example, reinsurance prices have increased by 200% in some parts of the US. Commercial customers are also being affected by the availability and affordability of insurance. Allstate insurance dropped 16,000 commercial customers in Florida in 2005, and some commercial businesses in the Gulf of Mexico are unable to find insurance at any price.

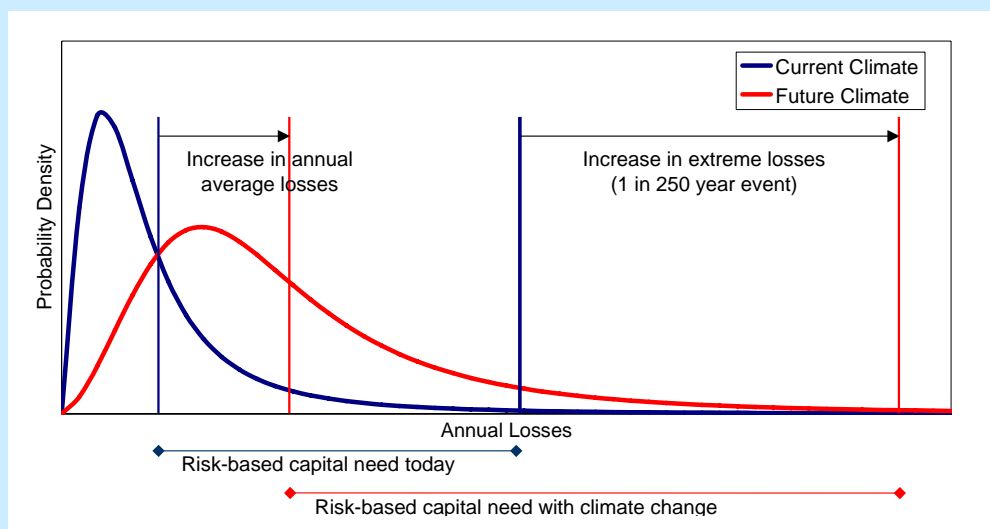
## PART II: The Impacts of Climate Change on Growth and Development

Lack of insurance could be particularly damaging for small and medium enterprises that will find it harder to access capital to protect against extreme events.<sup>45</sup>

### Box 5.6 Climate change and constraints on insurance capital

The insurance industry requires sufficient capital to bridge the gap between losses in an average year, which are covered by premium income, and those in an “extreme” year.<sup>46</sup> Today, the insurance industry holds around \$120 billion to cover extreme losses from natural weather catastrophes (principally hurricanes, typhoons and winter storms).

Climate change is likely to lead to a shift in the distribution of losses towards higher values, with a greater effect at the tail.<sup>47</sup> Average annual losses (or expected losses) will increase by a smaller amount than the extreme losses (here shown as a 1 in 250 year event), with the result that the amount of capital that insurers are required to hold to deal with extremes increases.



If storm intensity increases by 6%, as predicted by several climate models for a doubling of carbon dioxide or a 3°C rise in temperature, this could increase insurers' capital requirements by over 90% for US hurricanes and 80% for Japanese typhoons – an additional \$76 billion in today's prices.

Source: Association of British Insurers (2005a)

**Major areas of the world could be devastated by the social and economic consequences of very high temperatures. As history shows, this could lead to large-scale and disruptive population movement and trigger regional conflict.**

The impacts of climate change will be more serious for developing countries than developed countries, in part because poorer countries have more existing economic and social vulnerabilities to climate and less access to capital to invest in adaptation (Chapter 4). As the impacts become increasingly damaging at higher temperatures, the effects on the developing world may have knock-on consequences for developed economies, through disruption to global trade and security (Box 5.7), population movement and financial contagion. Climate change will affect the prices and volumes of goods traded between developed and developing countries, particularly raw materials for manufacturing and food products, with wider macroeconomic consequences.

<sup>45</sup> Crichton (2006) found that today in the UK one-third of small and medium-sized businesses had any form of business interruption cover against extreme weather.

<sup>46</sup> “Extreme” is defined by an insurers risk appetite and regulatory requirements.

<sup>47</sup> Heck *et al.* (2006)

## PART II: The Impacts of Climate Change on Growth and Development

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Climate change is likely to increase migratory pressures on developed countries significantly, although the potential scale and effect are still very uncertain and require considerably more research.

- **Income gap.** Pressures for long-distance and large-scale migration is likely to grow as climate change raises existing inequalities and the relative income differential between developed and developing countries (Chapter 4). Wage differentials were a strong driver of the mass migration of 50 million people from Europe to the New World in the second half of the 19<sup>th</sup> century, alongside over-population and the resulting land hunger.<sup>48</sup>
- **Environmental disasters.** As temperatures rise and conditions deteriorate significantly, climate change will test the resilience of many societies around the world. Large numbers of people will be compelled to leave their home when resources drop below a critical threshold. Bangladesh, for example, faces the permanent loss of large areas of coastal land affecting 35 million people, about one-quarter of its population, while one-quarter of China's population (300 million people) could suffer from the wholesale reduction in glacial meltwater. The Irish Potato Famine is an important example from history of how a dramatic loss in basic subsistence triggered large-scale population movement.<sup>49</sup> The famine took hold in 1845 with the appearance of "the Blight" - a potato fungus that almost instantly destroyed the primary food source for the majority of the population. It led to the death of 1 million people and the emigration of a further 1 million, many of them to the USA.

Developed countries may become drawn into climate-induced conflicts in regions that are hardest hit by the impacts (Chapter 4), particularly as the world becomes increasingly interconnected politically and socially. In the past, climate variability and resource management have both been important contributory factors in conflict.<sup>50</sup> So-called "water wars" have started because competition over water resources and the displacement of populations as a result of dam building have led to unrest.<sup>51</sup> Direct conflict between nation states because of water scarcity has been rare in the past, but dam building and water extraction from shared rivers has served to heighten political tensions in several regions, including the Middle East (discussed in detail in Chapter 4).

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<sup>48</sup> The fundamental drivers of past, current and future world migration are clearly set out by Hatton and Williamson (2002).

<sup>49</sup> See, for example, Woodham-Smith (1991)

<sup>50</sup> Brooks *et al.* (2005)

<sup>51</sup> Shiva (2002) describes several examples of conflict within a nation or between nations that has been exacerbated by tensions over construction of dams to manage water availability. Every river in India has become a site of major, irreconcilable water conflicts, including the Sutlej, Yamuna, Ganges, Krishna and Kaveri Rivers. The Tigris and Euphrates Rivers, the major water bodies sustaining agriculture for thousands of years in Turkey, Syria and Iraq have led to several major clashes among the three countries. The Nile, the longest river in the world, is shared by ten African countries and is another complicated site of water conflict, particularly following construction of the Aswan Dam.

## **Responses to the Stern Review**

"If the world is waiting for a calm, reasonable, carefully argued approach to climate change, Nick Stern and his team have produced one. They outline a feasible adjustment policy at tolerable cost beginning now. Sooner is much better."

**Robert M. Solow**  
**Nobel Prize economist 1987**

"The Stern report shows us, with utmost clarity, while allowing fully for all the uncertainties, what global warming is going to mean; and what can and should be done to reduce it. It provides numbers for the economic impact, and for the necessary economic policies. It deserves the widest circulation. I wish it the greatest possible impact. Governments have a clear and immediate duty to accept the challenge it represents."

**James Mirrlees**  
**Nobel Prize economist 1996**

"The stark prospects of climate change and its mounting economic and human costs are clearly brought out in this searching investigation. What is particularly striking is the identification of ways and means of sharply minimizing these penalties through acting right now, rather than waiting for our lives to be overrun by rapidly advancing adversities. The world would be foolish to neglect this strong but strictly time-bound practical message."

**Amartya Sen**  
**Nobel Prize economist 1998**

"The Stern Review of the Economics of Climate Change provides the most thorough and rigorous analysis to date of the costs and risks of climate change, and the costs and risks of reducing emissions. It makes clear that the question is not whether we can afford to act, but whether we can afford not to act. To be sure, there are uncertainties, but what it makes clear is that the downside uncertainties—aggravated by the complex dynamics of long delays, complex interactions, and strong non-linearities—make a compelling case for action. And it provides a comprehensive agenda—one which is economically and politically feasible—behind which the entire world can unite in addressing this most important threat to our future well being."

**Joseph Stiglitz**  
**Nobel Prize economist 2001**

"The Bank is committed to addressing the dangers of climate change and has made substantial progress in developing an Investment Framework for Clean Energy And Development. I very much welcome the Stern Review which provides a much needed critical economic analysis of the issues associated with climate change, and complements the recent IEA technology assessment and the World Bank's Clean Energy Investment Framework paper. The Bank is today working closely with its clients and partners to turn our analysis into practice, and will seek to substantially increase its own investment flows and those of the private sector.

A crucial next step is to involve the private sector in the EIF. I am therefore pleased to support a partnership between the World Bank and the World Economic Forum and the World Business Council on Sustainable Development to stimulate private sector investment through the Energy Investment Framework. Chancellor Gordon Brown and I will co-host a conference early next year to launch the partnership. "

**Paul Wolfowitz**  
**President of the World Bank**

"The Stern Review of the Economics of Climate Change is a vital step forward in securing an effective global policy on climate change. Led by one of the world's top economists, the Stern Review shows convincingly that the benefits of early global action to mitigate climate change will be far lower than the costs. The report establishes realistic guidelines for action (based on long-term stabilization ceilings for greenhouse gases), core elements of an effective global policy (carbon pricing, technology policy, and removing barriers to change), and a framework for international cooperation that must include all regions of the world, both developed and developing. The Stern Review will play an important role in helping the world to agree on a sensible post-Kyoto policy."

**Prof. Jeffrey D. Sachs**  
**Director of the Earth Institute at Columbia University**  
**Special Advisor to UN Secretary General Kofi Annan**

"The Economics of Climate Change sends a very important and timely message: that the benefits of strong, early action on climate change outweigh the costs. That conclusion is one that the International Energy Agency fully endorses - notably in its World Energy Outlook 2006 to be published next week. Congratulations to Sir Nick Stern and his team for producing a landmark review which I have no doubt will strengthen the political will to change of governments around the world."

**Claude Mandil**  
**Executive Director of the International Energy Agency**

“Climate change can impose enormous costs on mankind and particularly on the innocent poor people. The uncertainty that is used as an excuse not to act works both ways. If the impact is larger than expected it could be catastrophic. Sir Nick Sterns report is valuable as it shows the need to act now and that the costs of action are modest. One hopes it will spur to action those who are responsible for creating this threat.”

**Kirit Parikh**  
**Member, Planning Commission, Government of India**

“The scientific evidence of global warming is overwhelming but some commentators and lobby groups have continued to oppose offsetting actions on economic and competitiveness grounds. This comprehensive and authoritative report demolishes their arguments, explaining clearly the complex economics of climate change. It makes plain that we can cut emissions radically at a cost to the economy far less than the economic and human welfare costs which climate change could impose ”

**Adair Turner**  
**Former Director of UK Confederation of British Industry and Economic Advisor to Sustainable Development Commission**

“When the history of the world's response to climate change is written, the Stern Review will be recognized as a turning point.

Sir Nicholas and his team have provided important intellectual leadership as humanity engages with its greatest challenge.

While the details will be debated, the main thrust of the report is clear and compelling — the expected benefits of tackling climate change far outweigh the expected costs.”

**Cameron Hepburn**  
**Oxford University**

"I support the Stern Review's conclusion that there is a strong economic case for taking early, effective action to reduce greenhouse gas emissions. This clearly has important implications for transport policy, which my own study is taking into account - sustainable economic growth cannot be achieved in any sector without tackling the effects of our actions on the environment".

**Sir Rod Eddington**  
**Adviser to the UK Government on the long term links between transport and economic growth, and former Chief Executive of British Airways**