Chapter 6

Scientific understanding of climate change and consequences for a global deal

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Note: Photos and biographies of co-authors can be found in the appendix.

The scientific basis

Several important findings of climate research have been confirmed in recent decades and are now generally accepted as fact by the scientific community. These include the rapid increase in carbon dioxide concentrations in the atmosphere during the last 150 years, from 280 ppm (a value typical for warm periods during at least the past 700 000 years), to the 2007 level of 383 ppm (Global Carbon Project, 2008). This increase is entirely caused by humans and is primarily due to the burning of fossil fuels, with a smaller contribution from deforestation. Carbon dioxide is a gas that affects the Earth's climate by changing its radiation budget: an increase in its concentration leads to a rise in near-surface temperature. If the concentration doubles, the resulting global mean warming will likely be between 2 °C and 4 °C (the most probable value is approximately 3 ºC according to the IPCC – UN Intergovernmental Panel on Climate Change (Solomon *et al.,* 2007)). Since 1900, the global climate has warmed by approximately 0.8 °C. Temperatures in the past ten years have been the highest since measured records began in the nineteenth century and, as shown by other climate indicators, for many centuries before that (see Fig. 1).

Most of this warming is due to the rising concentration of carbon dioxide and other anthropogenic gases (Solomon *et al.,* 2007). It follows that a further increase in carbon dioxide concentration must lead to a further rise in global mean temperature (see Fig. 2). Considering a range of plausible assumptions about future emissions, this rise will be in a range from approximately 2 ºC to approximately 7 ºC above preindustrial levels.

By comparison, the last major period of global warming occurred at the end of the last great ice age (about 15 000 years ago), and involved global warming of approximately 5 ºC over a time span of 5000 years (Schneider von Deimling *et al.,* 2006). Unchecked anthropogenic warming could reach a similar magnitude over a fraction of this time – and, of course, starting from an already warm climate.

Impacts and risks

Whether this warming constitutes 'dangerous' change cannot, of course, be determined by scientists alone, as such an assessment depends on societal value judgments about what is dangerous. However, science can help to state and clarify the risks that arise from such unprecedented warming. Among the most important risks are the following:

- **Increase in sea level and loss of ice sheets.** In the twentieth century global sea level rose by 15 – 20 cm. Currently, sea level is rising at a rate of over three

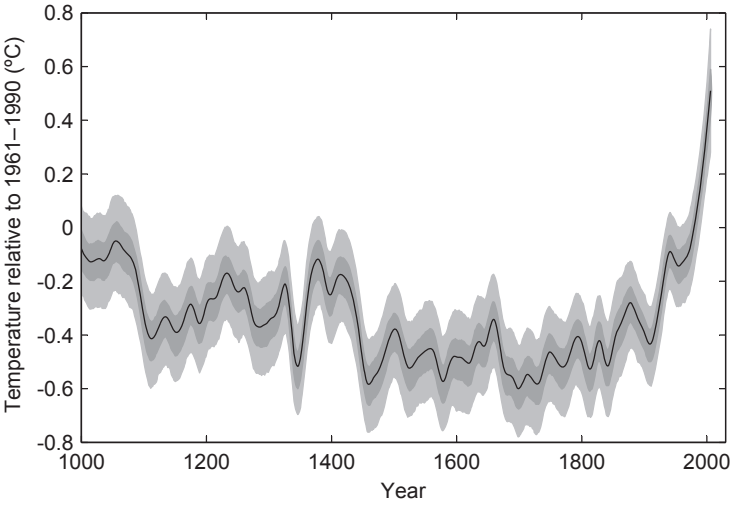

Fig. 1. Global temperature over land and ocean during the past millennium, based on a variety of proxies including ice cores, tree rings, corals and sediment data. The grey bands show the 25–75 and 5–95% uncertainty ranges. (*Source:* Mann *et al.,* 2008)

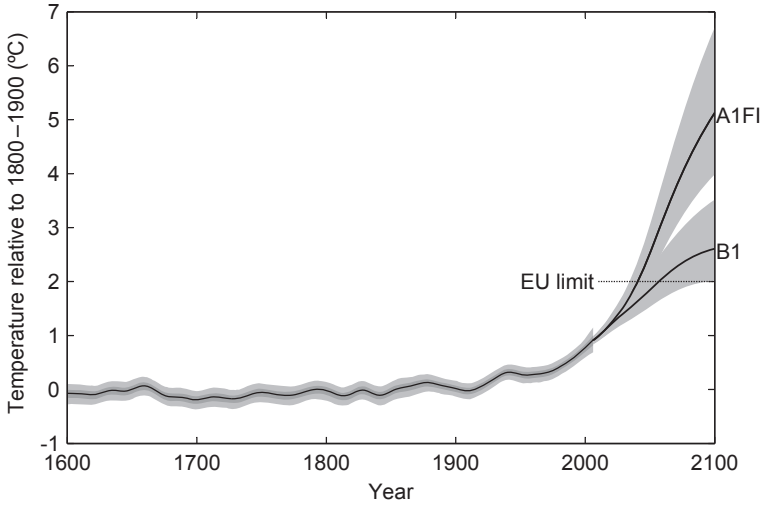

Fig. 2. IPCC projections for global mean temperature in the twenty-first century in comparison to past variability as shown in Fig. 1. The lowest (B1) and highest (A1FI) emission scenarios are shown with their respective projection uncertainties: for B1 emissions, warming will be between 2 °C and 3 °C, for A1FI emissions between 4 °C and 7 °C. The 2 °C limit adopted by the EU and many countries is also shown. (*Sources:* Mann *et al.,* 2008; Solomon *et al.,* 2007)

centimetres per decade, about 50 % faster than projected in the scenarios of the IPCC Third Assessment Report (Rahmstorf *et al.,* 2007). If warming is not limited, a rise of around one metre by 2100 is not unlikely (Rahmstorf, 2007). Even if warming is halted at 3 °C, the sea level will probably keep rising by several metres in subsequent centuries as a delayed response (see Fig. 3). Coastal cities and low-lying islands are at risk. What is now a once-in-a-century occurrence of extreme flooding in New York City (causing major damage, including flooded subway stations) would happen on average about every three years if the sea level were just one metre higher (Rosenzweig and Solecki, 2001).

- **Loss of ecosystems and species.** If climate change continues unabated global temperatures will reach a level higher than for millions of years and this increase will be much too fast for many species to adapt to. A large fraction of species – some studies suggest up to one third of all species – could be doomed to extinction by the year 2050 (Thomas *et al.,* 2004). Life in the oceans is not only threatened by climate change but by the equally serious problem of ongoing global ocean acidification, which is a direct chemical result of our carbon dioxide emissions independent of the warming effect.
- **Risk of extreme events.** In a warmer climate, the risk of extreme flooding events will increase, as warmer air can hold more water (approximately 7 % more for each degree Celsius of warming). Hurricanes are expected to become more destructive. Both physical considerations and data suggest an increase in the force of hurricanes in response to rising sea surface temperatures (see Fig. 4).
- **Risk to water and food supplies.** While total global agricultural production may increase with moderate global warming due to temperature gains in colder regions, many poorer and warmer countries may experience reductions in yields due to water shortages and weather extremes. Agricultural productivity is expected to decline globally in the event of warming between 2 °C and 4 °C. Should warming exceed 4 °C major losses are to be feared (Parry *et al.,* 2007). The water supply of major cities (such as Lima) and of agricultural lands (such as those fed by rivers draining the Tibetan Plateau) is threatened when mountain glaciers and snow packs disappear (WBGU, 2007).
- **Non-linear responses – tipping elements.** Positive feedbacks have been identified for a number of climatic subsystems, and these feedbacks may self-amplify the response to external disturbances (Lenton *et al.,* 2008). For example, the Arctic sea ice cover has shown a drastic reduction in recent years (see real-time sea ice data at the National Snow and Ice Data Center, http://nsidc.org). While, for instance, the melting of the Himalayan glaciers is a likely result of increased temperatures, other tipping elements, like global monsoon systems, represent a risk due to their extraordinary impact (Auffhammer *et al.,* 2006; Zhang *et al.,* 2008), but it remains difficult to assess the probability of their occurrence. The

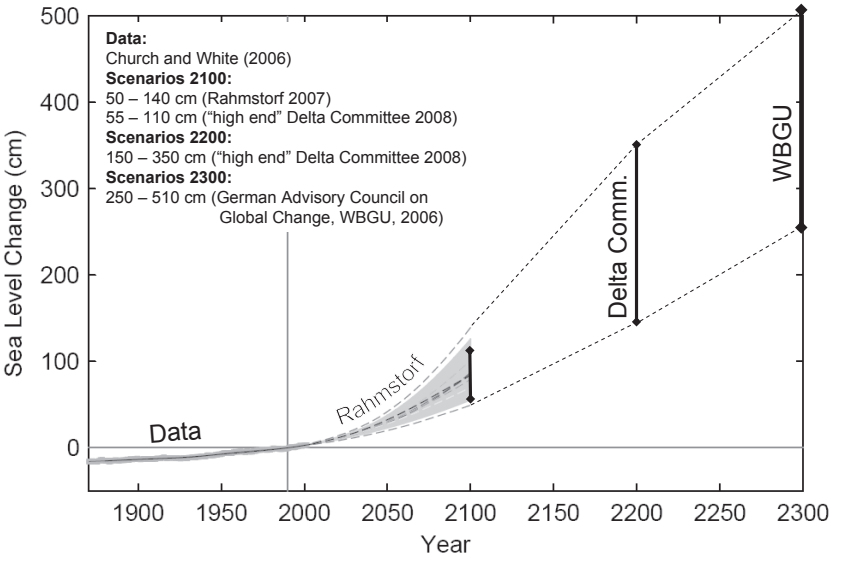

Fig. 3. Observed sea level up to 2000 and several recent projections up to the year 2300. (*Sources:* Church and White, 2006; Rahmstorf, 2007; WBGU, 2006; Vellinga *et al.,* 2008)

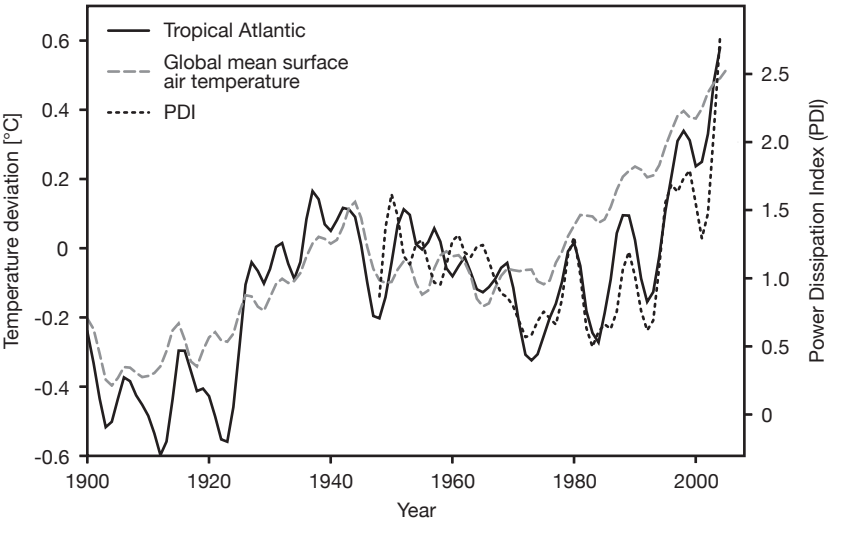

Fig. 4. Changes in the force of tropical storms over time (Power Dissipation Index – PDI, dotted) and the average sea-surface temperature in the tropical Atlantic from August to October (solid). For comparison the evolution of globally averaged near-surface air temperature is also shown (broken grey line). (*Source:* Emanuel, 2005)

triggering of some tipping elements, such as the major ocean circulation in the Atlantic and the great ice sheets in Greenland and West Antarctica, is likely to be irreversible (Toniazzo *et al.,* 2004; Rahmstorf *et al.,* 2005; Schoof, 2007). The release of methane from a thawing of the Siberian and North American permafrost is an additional tipping element that may directly increase global mean temperature and thus accelerate the process of global warming.

It is important to remember that these are merely examples. The exact consequences of such a major change in climate are difficult to predict, and surprises are likely.

Avoiding dangerous climate change

Following the United Nations Framework Convention on Climate Change (UNFCCC, 1992), in which states committed themselves to preventing 'dangerous interference' with the climate system, the European Union went one step further in pledging to limit the increase in global average temperature to 2 °C above preindustrial levels (EU limit, see Fig. 2). This means that global carbon dioxide emissions must be reduced by 50–80 % of the 1990 level by 2050 (Meinshausen *et al.,* 2009). This range of necessary emission reductions arises from uncertainty within the carbon cycle and the physical climate system, and from different possible emission pathways up to 2050.

While the exact emission reduction pathways are uncertain, one crucial fact clearly follows from a decision to stabilize temperatures: ultimately, carbon dioxide emissions must be reduced to practically zero. The reasons are that few permanent natural sinks exist, and that carbon dioxide, once released to the atmosphere, is removed only on a millennial time scale (Solomon *et al.,* 2009). Thus, the stabilization target of global mean temperature is determined by cumulative emissions (Allen *et al.*, 2009), and delayed emissions reduction results in the necessity to reduce more rapidly.

On the issue of stabilization targets, two further issues need to be kept in mind. First, for some major climatic subsystems, such as the great ice sheets in Greenland and Antarctica, a two-degree target might not be sufficient to avoid dangerous interference. Second, due to the slow pace and delayed reaction of the global climatic system, even after phasing out anthropogenic carbon dioxide emissions temperatures will not drop for several centuries and, additionally, sea level will continue to rise (Solomon *et al.*, 2009).

The global deal

A global deal is required to tackle the climate-related challenges outlined in the previous sections (see also Stern and Garbett-Shiels, this volume). If successful, such a far-ranging international effort will not only help avoid the worst impacts of climate change and protect the world's most vulnerable people, but will also initiate the process of restructuring the global economy towards ecologically oriented growth, focused on the creation of new jobs in low-carbon industries. New economic instruments and business models will be developed to put a price on carbon, and to ensure that opportunities for efficiency and renewable energies are generated. The best way to counteract the insecurity driven by high energy and commodity prices is to demonstrate the practical opportunities available in the creation of efficient and resilient societies. Currently, countries are focused on short-term crises and are not able to plan proactively for a low-carbon economy.

The UNFCCC and the Kyoto Protocol have been guided by the findings of climate science as documented by the Intergovernmental Panel on Climate Change (IPCC). In order to avoid operational disruption after the first commitment period of the Kyoto Protocol (ending in 2012), the next round of focused negotiations are scheduled to be completed by 2009 in Copenhagen. A post-2012 climate agreement that would represent a major step towards accomplishing a global deal must include the following key elements:

1. Developing a vision for international climate protection: low-carbon development and the 2 °C objective

The agreement should aim for all countries to achieve their national economic and development goals within the framework of a low-carbon strategy that safeguards the environment, strengthens their ability to adapt to the changes already underway, and allows for sustained economic welfare. Industrialized countries should demonstrate their intention to lead the way on the low-carbon transition, and should agree to support developing countries in their transitions. This vision acknowledges the fundamental need for ambitious adaptation support, particularly in the world's poorest countries, and reiterates the commitment to achieving the UN Millennium Development Goals. It also reaffirms that all peoples, nations and cultures have the right to survive.

The vision should include the 2 °C objective, which means countries agree to a long-term goal to at least halve global emissions of greenhouse gases by 2050 compared to 1990 levels, and to bring about a peak in global emissions in the next 10–15 years. If countries want a higher probability of staying below 2 °C, then a more ambitious target should be agreed. In addition to a vision for 2050, countries

should agree on emissions pathways for industrialized and developing countries with benchmarks in 2020 and 2030 that lead the way to the almost complete decarbonisation required by 2050. The goals should be regularly assessed in light of the latest scientific findings to avoid the risk of triggering critical climate tipping points.

2. Creating a global carbon market

Establishing a reliable and long-term price signal for carbon dioxide creates effective incentives for worldwide mitigation of greenhouse gas emissions (see Edenhofer *et al.,* this volume). A carbon market generates this price signal, while also creating the flexibility that participating companies need with regard to the timing and location of their required emissions reductions. Alongside emissions trading, the Kyoto mechanisms should be scaled up and the European Emissions Trading Scheme linked up to comparable systems in other regions (for example, in North America, Australia, Japan and other countries, including emerging economies).

Some of the Kyoto mechanisms should be reviewed, however. In particular, new sector-based crediting mechanisms for larger emerging economies and reform of the project-based Clean Development Mechanism for smaller developing countries are needed (see Liverman, this volume).

3. Agreeing on ambitious emissions reduction commitments for industrialized countries

A stable and sufficiently high price level on the international carbon market presupposes ambitious, absolute and binding emissions reduction targets for industrialized countries. Such binding targets also represent a politically necessary signal by those countries primarily responsible for the currently observed levels of climate change. By 2020 the industrialized countries should have reduced their emissions by around 30 % compared to 1990. By 2050 the emissions of this group of countries must be reduced by approximately 80 % (or even 90 or 95 % if a higher probability of risk reduction is desired). In order to build confidence in their intention to decarbonize their societies and encourage long-term planning, industrialized countries should put forward low-carbon action plans. These plans need to outline the process of economic transformation that will be undertaken to address unsustainable patterns of consumption and production (see Gell-Mann, this volume, for a more detailed discussion of transformation to sustainability). This process must promote a low-carbon economy and ensure deep emissions reduction targets in line with commitments.

4. Taking action in developing countries

One of the greatest challenges for a global deal is to build the confidence and capacity of developing countries to provide their populations with development, energy services and food security, while they start to decarbonize their societies. There is no model for developing countries to follow. The mitigation agreement should therefore provide significant external incentives for developing countries to move beyond business-as-usual (BAU) pathways, but should also expect them to undertake 'no-regrets' and low-cost measures based on their own means as well.

Overall, actions undertaken in developing countries should result in a substantial reduction of emissions below BAU. Collectively, these actions would be enough to ensure that developing country emissions peak no later than 2020–2025, a requirement if global warming is to remain below 2 °C.

Guided by the commitment to a substantial deviation from BAU, each major developing economy should submit a set of actions that can be incorporated into a low-carbon action plan. This would include measures that the country will implement unilaterally in defining its national baseline. The action plan would also outline what other measures can be taken conditional upon greater access to the global carbon market and technological and financial support.

What could such a low-carbon action plan look like? Some countries could assume sectoral obligations (for example, in the electricity sector); others could adopt more ambitious national policies and measures (for example, on renewables targets and housing standards); and yet other countries could adopt national efficiency targets (for example, on energy consumption in relation to GDP). Each plan should describe in a quantitatively verifiable way the substantial deviation from BAU.

5. Reducing emissions from deforestation and degradation (REDD) and other land use sectors

Climate change cannot be solved by addressing the energy system alone. Improved ecosystem management would avoid a substantial amount of emissions and restore many of the carbon sinks that once existed. In particular, about 17% of global emissions are caused by deforestation and forest degradation (Metz *et al.,* 2007, Fig. TS.1b). Therefore, the new climate change agreement needs to include enhanced actions for this sector. Each country could submit a national deforestation plan. This plan would outline the country's commitment and strategy to reduce deforestation emissions from an agreed national baseline, provided that financial support from industrialized countries is guaranteed. The agreement must also include the most efficient mechanism to provide this funding within the framework of a

carbon market: a commitment by industrialized countries to auction a percentage of their national allocation and designate it to REDD. In addition, a credible monitoring and review mechanism should be included to assess if, when, and how deforestation credits might be permitted to enter the global carbon market without jeopardizing market stability or causing the carbon price to fall dramatically.

In addition to tropical forests, peatlands and agriculture are priority areas where action is needed. A recent study of the United Nations Environment Programme (UNEP) suggests that the agricultural sector could be broadly carbon-neutral by 2030 if best management practices were widely adopted (Trumper *et al.,* 2009). Other societal goals could be achieved alongside carbon storage, such as improved soil fertility, new employment and income-generating opportunities, and biodiversity conservation.

6. Promoting technology: investment, innovation and transfer

The agreement should include a scaled-up technology cooperation mechanism, one that strikes a balance between building the capacity of all major economies to become innovation leaders, and supporting the needs of some countries for technology transfer.

Support for technology cooperation and diffusion needs to be rapidly expanded in order to meet the mitigation and adaptation challenges posed by climate change. A robust and comprehensive approach is needed to correct market failures and provide support along the entire technology innovation chain. This approach should leverage public and private finance to spur innovation and technology cooperation, with substantial focus on the international agreement but even greater focus on bringing bi-lateral and private capital in line with low-carbon action plans and strategies.

To address the need for rapid technology development and diffusion in the near-term the agreement should include a 'technology development objective' to at least double current levels of research, development and demonstration by 2012 and quadruple those budgets by 2020. In order to ensure focused investment, the agreement should contain a commitment from all countries to jointly develop a set of strategically important adaptation and mitigation technologies incorporated in 'technology action programmes'. The agreement should also include a new fund with two distinct functions: to increase investment in research, development & demonstration (RD&D); and to increase diffusion of new technologies in developing countries. The fund, through matching grants and other blended financing, would leverage public financing to catalyze a shift of private investment into low-carbon technologies. Private companies and developing countries would bid into this new fund.

Furthermore, to protect the interests of the innovator while also promoting diffusion of low-carbon technologies, the agreement should contain a 'protect and share' framework for managing intellectual property rights (IPR). This would facilitate joint ventures and public-private partnerships, and define systems for enhanced access, conditional on strengthened IPR protection. Countries failing to robustly protect low-carbon IPR would run the risk of losing their access to the proposed technology fund.

7. Supporting adaptation: climate-proof investments and risk management

The post-2012 agreement should send a clear signal to the poorest and most vulnerable countries of the world that they will not be left alone to deal with the increasing impacts of climate change. A new 'global adaptation framework' will need to be created to provide the vision, strategy and coordination to respond to catastrophes and climate-change impacts as they occur.

This framework needs to incorporate the key institutions with relevant expertise (Food and Agriculture Organization, World Health Organization, World Bank, UNDP, Red Cross, etc.) and should join up efforts inside and outside the Convention. It should base those strategies on input from regional adaptation centres, regional information systems on climate risks in developing countries, and national plans. The confidence of the donor community could be enhanced by assuring that the billions raised will be applied to the most urgent and critical needs.

In support of this framework, industrialized countries should give a firm undertaking both to honour their existing official development assistance (ODA) commitments and to provide additional resources for adaptation to climate change. A substantial share of the new resources should be channelled through an Adaptation Fund in order to promote predictability and transparency. In addition, donors should scale up their investment in disaster prevention and response, and should develop a global reinsurance scheme to provide a safety net for poor people exposed to climate change risk. Also, donors should agree to incorporate adaptation strategies and measures into their existing bilateral and multilateral aid programmes, and 'climate-proof' their investments without diverting funds from existing aid budgets.

8. Financing

A major element of the agreement will be *measurable, reportable* and *verifiable* financing. It is estimated that by 2015 the annual costs of action in developing countries will be approximately USD 70 billion for mitigation efforts in the power and transport sectors (Anderson, 2006), and USD 90 billion for adaptation (UNDP, 2007).

This compares with the 2008 ODA levels of approximately USD 120 billion (OECD, 2009). Developing countries will have to meet some of these costs themselves but will also expect substantial international support. The mix of financing responsibility between industrialized and developing countries will determine the 'fairness' of abatement commitments.

The expansion of the international carbon market will generate significant additional financing for mitigation programmes in developing countries.[1] These will be concentrated in industrializing middle-income countries such as China, India, Brazil and Mexico. As noted above, additional funding is needed in the areas of adaptation, reduction of emissions from deforestation, and technology cooperation. While the technology fund can likely leverage private sector funding, adaptation and deforestation will be more dependent on public funding. A number of potential mechanisms exist to generate the needed revenue: a) industrialized countries could pledge to contribute a share of their auction revenues from domestic emissions trading to mitigation and adaptation in developing countries; b) a share of each country's 'assigned amount' for the next commitment period could be monetized and invested in a set of international funds; c) a tax could be introduced on international bunker fuels to generate revenue (as well as to include the aviation and maritime sectors in national commitments); and d) countries could pledge direct budgetary support based on a set of agreed criteria.

In order to leverage external funding such as bi-lateral funds, measurable, reportable and verifiable criteria need to be agreed upon. This would enable donors to get 'credit' for contributions to low-carbon development plans not only through UNFCCC-related funds but also through other multilateral and bilateral initiatives.

9. Including international air and maritime transport

The sector with the most rapidly increasing emissions worldwide is international aviation and maritime transport. Up to now these sources have been exempt from emissions restrictions. The post-2012 regime should include targets to reduce emissions from these sectors.

In the midst of a financial crisis it may be difficult to imagine that a global deal such as that outlined above is possible. Countries are focusing on national economic priorities and job creation, dealing with a recession that is raising fears and could lead to greater isolationism. If a post-2012 agreement is not reached and the focus continues to rest on national-level activities, it is highly unlikely that the

[1] The World Bank (Capoor and Ambrosi, 2007) estimated CDM flows at USD 5 billion per year in 2006, and the UNFCCC (2006) estimates substantial future growth, generating USD 12 billion per year by 2012.

scientific challenge of climate change mitigation will be met. International agreements are created to raise the level of ambition, to generate a shared vision for a common endeavour, and to stimulate action at a faster pace than countries would normally pursue. Such agreements provide not only motivation but also the security that other major economies are also taking significant investment decisions to move in a new direction. A global deal on climate change is needed to build trust between industrialized and developing countries, trust that will be hard to rebuild if a deal is not struck. Exceptional and determined leadership is likewise needed to ensure that global transformation happens in time.

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