Quantitative Climate Finance

Lecture - Summer 2014

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Agenda

United Nations Framework Convention on Climate Change

Background from United Nations Framework Convention on Climate Change can be found

http://unfccc.int/essential_background/items/6031.php

The Fifth Assessment Report (AR5) of the International Panel on Climate Change (IPCC) provides a clear and most up to date view of the current state of scientific knowledge relevant to climate change.
http://www.ipcc.ch

Greenhouse Gas Emissions and Climate Change

- Greenhouse Gas Emissions (GHG) are seen as a major reason for global climate change. Since CO_2 emissions are the main source of GHG emissions, GHG are measured in terms of CO_2 equivalents, CO2e.
- In 2010 we observed for the first time in many years an increase in GHG emissions, which makes it increasingly unlikely to met the World Climate Conference (Cancún 2010) target of a 2^o Celcius temperature increase by 2050.

Greenhouse Gas Emissions and Climate Change

- The climate change will lead to an increase of the probability and frequency of storms, floods, draughts according to the Intergovernmental Panel on Climate Change (IPCC).
- The overall stock of CO2e in the atmosphere is relevant. In 2007 CO2e were around 430 parts per million (ppm) rising around 2,5 ppm per year.
- Targets may be a certain temperature increase or a certain stock (with different flow paths)

Probabilities of Temperature Increases

Stabilisierungsniveau (in ppmv CO2e)	2°C	3°C	4°C	5°C	6°C	7°C
450	78	18	5	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Wahrscheinlichkeiten (%) ein Temperaturniveau im Gleichgewicht zu übersteigen[4]

Figure : Probability of Temperature Increase higher than

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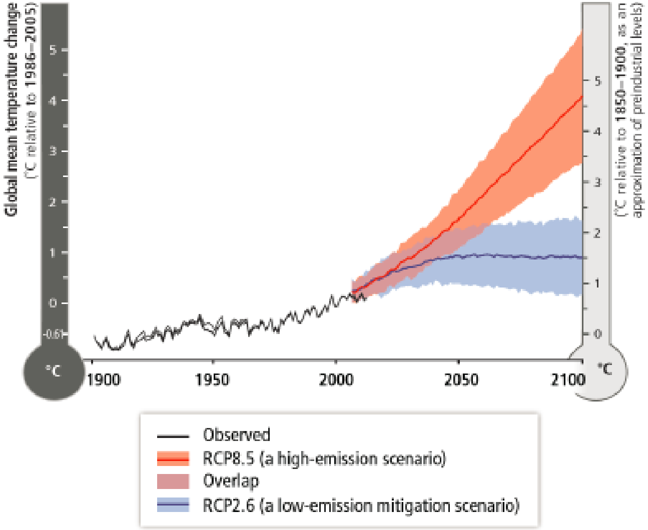
Carbon Target



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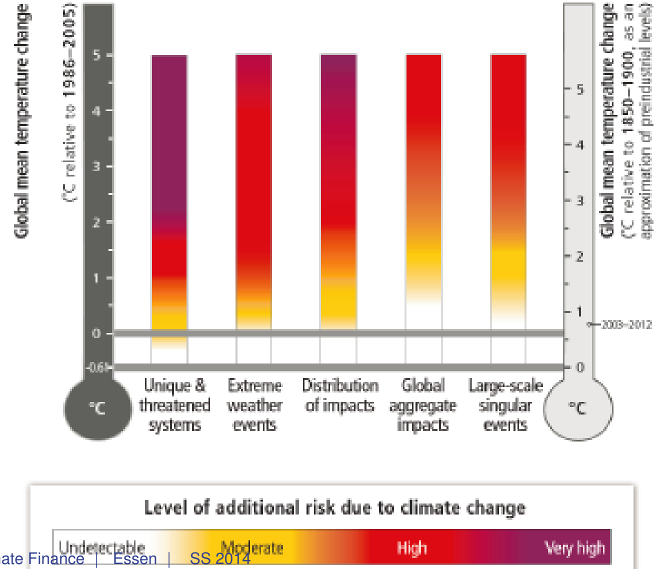


Consequences of Climate Change - High-Emission Scenario

- Global temperatures could rise by 5-7 Celsius this century - well above the 2 Celsius scientists regard as the safety limit
- Sea level rises will overwhelm 1-2bn people living in low-lying areas
- 4bn people could be put at risk of water shortages
- The ice caps will melt entirely
- The Amazon rainforest may die off

Consequences of Climate Change - Low-Emission Scenario

- World will warm by no more than 2 Celsius by mid-century and thereafter temperatures may start to decline
- Hottest parts of the world will suffer serious declines in crop yields, but increase in fertility in other areas will offset this
- Ice at the poles will diminish, but some reduced ice cover could remain
- Increase in floods, droughts and storms, but damage manageable
- Tropical diseases will spread, but not too far

Executive Summary

This report provides a snapshot of recent scientific literature and new analyses of likely impacts and risks that would be associated with a 4° Celsius warming within this century. It is a rigorous attempt to outline a range of risks, focusing on developing countries and especially the poor. A 4°C world would be one of unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on ecosystems and associated services. But with action, a 4°C world can be avoided and we can likely hold warming below 2°C.

Without further commitments and action to reduce greenhouse gas emissions, the world is likely to warm by more than 3°C above the preindustrial climate. Even with the current mitigation commitments and pledges fully implemented, there is roughly a 20 percent likelihood of exceeding 4°C by 2100. If they are not met, a warming of 4°C could occur as early as the 2060s. Such a warming level and associated sea-level rise of 0.5 to 1 meter, or more, by 2100 would not be the end point: a further warming to levels over 6°C, with several meters of sea-level rise, would likely occur over the following centuries.

Thus, while the global community has committed itself to holding warming below 2°C to prevent "dangerous" climate change, and Small Island Developing states (SIDS) and Least Developed Countries (LDCs) have identified global warming of 1.5°C as warming above which there would be serious threats to their own development and, in some cases, survival, the sum total of current policies—in place and pledged—will very likely lead to warming far in excess of these levels. Indeed, present emission trends put the world plausibly on a path toward 4°C warming within the century.

This report is not a comprehensive scientific assessment, as will be forthcoming from the Intergovernmental Panel on Climate Change (IPCC) in 2013–14 in its Fifth Assessment Report. It is focused on developing countries, while recognizing that developed countries are also vulnerable and at serious risk of major damages from climate change. A series of recent extreme events worldwide continue to highlight the vulnerability of not only the developing world but even wealthy industrialized countries.

Uncertainties remain in projecting the extent of both climate change and its impacts. We take a risk-based approach in which risk is defined as *impact multiplied by probability:* an event with low probability can still pose a high risk if it implies serious consequences.

No nation will be immune to the impacts of climate change. However, the distribution of impacts is likely to be inherently unequal and tilted against many of the world's poorest regions, which have the least economic, institutional, scientific, and technical capacity to cope and adapt. For example:

- Even though absolute warming will be largest in high latitudes, the warming that will occur in the tropics is larger when compared to the historical range of temperature and extremes to which human and natural ecosystems have adapted and coped. The projected emergence of unprecedented high-temperature extremes in the tropics will consequently lead to significantly larger impacts on agriculture and ecosystems.
- Sea-level rise is likely to be 15 to 20 percent larger in the tropics than the global mean.
- Increases in tropical cyclone intensity are likely to be felt disproportionately in low-latitude regions.
- Increasing aridity and drought are likely to increase substantially in many developing country regions located in tropical and subtropical areas.

A world in which warming reaches 4°C above preindustrial levels (hereafter referred to as a 4°C world), would be one of unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on human systems, ecosystems, and associated services.

Warming of 4°C can still be avoided: numerous studies show that there are technically and economically feasible emissions pathways to hold warming likely below 2°C. Thus the level of impacts that developing countries and the rest of the world experience will be a result of government, private sector, and civil society decisions and choices, including, unfortunately, inaction.

Observed Impacts and Changes to the Climate System

The unequivocal effects of greenhouse gas emission–induced change on the climate system, reported by IPCC's Fourth Assessment Report (AR4) in 2007, have continued to intensify, more or less unabated:

- The concentration of the main greenhouse gas, carbon dioxide (CO_2), has continued to increase from its preindustrial concentration of approximately 278 parts per million (ppm) to over 391 ppm in September 2012, with the rate of rise now at 1.8 ppm per year.
- The present CO_2 concentration is higher than paleoclimatic and geologic evidence indicates has occurred at any time in the last 15 million years.
- Emissions of CO_2 are, at present, about 35,000 million metric tons per year (including land-use change) and, absent further policies, are projected to rise to 41,000 million metric tons of CO_2 per year in 2020.
- Global mean temperature has continued to increase and is now about 0.8°C above preindustrial levels.

A global warming of 0.8°C may not seem large, but many climate change impacts have already started to emerge, and the shift from 0.8°C to 2°C warming or beyond will pose even greater challenges. It is also useful to recall that a global mean temperature increase of 4°C approaches the difference between temperatures today and those of the last ice age, when much of central Europe and the northern United States were covered with kilometers of ice and global mean temperatures were about 4.5°C to 7°C lower. And this magnitude of climate change—human induced—is occurring over a century, not millennia.

The global oceans have continued to warm, with about 90 percent of the excess heat energy trapped by the increased greenhouse gas concentrations since 1955 stored in the oceans as heat. The average increase in sea levels around the world over the 20th century has been about 15 to 20 centimeters. Over the last decade the average rate of sea-level rise has increased to about 3.2 cm per decade. Should this rate remain unchanged, this would mean over 30 cm of additional sea-level rise in the 21st century.

The warming of the atmosphere and oceans is leading to an accelerating loss of ice from the Greenland and Antarctic ice sheets, and this melting could add substantially to sea-level rise in the future. Overall, the rate of loss of ice has more than tripled since the 1993–2003 period as reported in the IPCC AR4, reaching 1.3 cm per decade over 2004–08; the 2009 loss rate is equivalent to about 1.7 cm per decade. If ice sheet loss continues at these rates, without acceleration, the increase in global average sea level due to this source would be about 15 cm by the end of the 21st century. A clear illustration of the Greenland ice sheet's increasing vulnerability to warming is the rapid growth in melt area observed since the 1970s. As for Arctic sea ice, it reached a record minimum in September 2012, halving the area of ice covering the Arctic Ocean in summers over the last 30 years.

The effects of global warming are also leading to observed changes in many other climate and environmental aspects of the Earth system. The last decade has seen an exceptional number of extreme heat waves around the world with consequential severe impacts. Human-induced climate change since the 1960s has increased the frequency and intensity of heat waves and thus also likely exacerbated their societal impacts. In some climatic regions, extreme precipitation and drought have increased in intensity and/or frequency with a likely human influence. An example of a recent extreme heat wave is the Russian heat wave of 2010, which had very significant adverse consequences. Preliminary estimates for the 2010 heat wave in Russia put the death toll at 55,000, annual crop failure at about 25 percent, burned areas at more than 1 million hectares, and economic losses at about US$15 billion (1 percent gross domestic product (GDP)).

In the absence of climate change, extreme heat waves in Europe, Russia, and the United States, for example, would be expected to occur only once every several hundred years. Observations indicate a tenfold increase in the surface area of the planet experiencing extreme heat since the 1950s.

The area of the Earth's land surface affected by drought has also likely increased substantially over the last 50 years, somewhat faster than projected by climate models. The 2012 drought in the United States impacted about 80 percent of agricultural land, making it the most severe drought since the 1950s.

Negative effects of higher temperatures have been observed on agricultural production, with recent studies indicating that since the 1980s global maize and wheat production may have been reduced significantly compared to a case without climate change.

Effects of higher temperatures on the economic growth of poor countries have also been observed over recent decades, suggesting a significant risk of further reductions in the economic growth in poor countries in the future due to global warming. An MIT study[1] used historical fluctuations in temperature within countries to identify its effects on aggregate economic outcomes. It reported that higher temperatures substantially reduce economic growth in poor countries and have wide-ranging effects, reducing agricultural output, industrial output, and political stability. These findings inform debates over the climate's role in economic development and suggest the possibility of substantial negative impacts of higher temperatures on poor countries.

Projected Climate Change Impacts in a 4°C World

The effects of 4°C warming will not be evenly distributed around the world, nor would the consequences be simply an extension of those felt at 2°C warming. The largest warming will occur over land and range from 4°C to 10°C. Increases of 6°C or more in average monthly summer temperatures would be expected in large regions of the world, including the Mediterranean, North Africa, the Middle East, and the contiguous United States

Projections for a 4°C world show a dramatic increase in the intensity and frequency of high-temperature extremes. Recent extreme heat waves such as in Russia in 2010 are likely to become the new normal summer in a 4°C world. Tropical South America, central Africa, and all tropical islands in the Pacific are likely to regularly experience heat waves of unprecedented magnitude and duration. In this new high-temperature climate regime, the coolest months are likely to be substantially warmer than the warmest months at the end of the 20th century. In regions such as the Mediterranean, North Africa, the Middle East, and the Tibetan plateau, almost all summer months are likely to be warmer than the most extreme heat waves presently experienced. For example, the warmest July in the Mediterranean region could be 9°C warmer than today's warmest July.

Extreme heat waves in recent years have had severe impacts, causing heat-related deaths, forest fires, and harvest losses. The impacts of the extreme heat waves projected for a 4°C world have not been evaluated, but they could be expected to vastly exceed the consequences experienced to date and potentially exceed the adaptive capacities of many societies and natural systems.

Rising CO_2 Concentration and Ocean Acidification

Apart from a warming of the climate system, one of the most serious consequences of rising carbon dioxide concentration in the atmosphere occurs when it dissolves in the ocean and results in acidification. A substantial increase in ocean acidity has been observed since preindustrial times. A warming of 4°C or more by 2100 would correspond to a CO_2 concentration above 800 ppm and an increase of about 150 percent in acidity of the ocean. The observed and projected rates of change in ocean acidity over the next century appear to be unparalleled in Earth's history. Evidence is already emerging of the adverse consequences of acidification for marine organisms and ecosystems, combined with the effects of warming, overfishing, and habitat destruction.

Coral reefs in particular are acutely sensitive to changes in water temperatures, ocean pH, and intensity and frequency of tropical cyclones. Reefs provide protection against coastal floods, storm surges, and wave damage as well as nursery grounds and habitat for many fish species. Coral reef growth may stop as CO_2 concentration approaches 450 ppm over the coming decades (corresponding to a warming of about 1.4°C in the 2030s). By the time the concentration reaches around 550 ppm (corresponding to a warming of about 2.4°C in the 2060s), it is likely that coral reefs in many areas would start to dissolve. The combination of thermally induced bleaching events, ocean acidification, and sea-level rise threatens large fractions of coral reefs even at 1.5°C global warming. The regional extinction of entire coral reef ecosystems, which could occur well before 4°C is reached, would have profound consequences for their dependent species and for the people who depend on them for food, income, tourism, and shoreline protection.

Rising Sea Levels, Coastal Inundation and Loss

Warming of 4°C will likely lead to a sea-level rise of 0.5 to 1 meter, and possibly more, by 2100, with several meters more to be realized in the coming centuries. Limiting warming to 2°C would likely reduce sea-level rise by about 20 cm by 2100 compared to a 4°C world. However, even if global warming is limited to 2°C, global mean sea level could continue to rise, with some estimates ranging between 1.5 and 4 meters above present-day levels by the year 2300. Sea-level rise would likely be limited to below 2 meters only if warming were kept to well below 1.5°C.

Sea-level rise will vary regionally: for a number of geophysically determined reasons, it is projected to be up to 20 percent higher in the tropics and below average at higher latitudes. In particular, the melting of the ice sheets will reduce the gravitational pull on the ocean toward the ice sheets and, as a consequence, ocean water will tend to gravitate toward the Equator. Changes in wind and ocean currents due to global warming and other factors will also affect regional sea-level rise, as will patterns of ocean heat uptake and warming.

1 Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." *American Economic Journal: Macroeconomics*, 4(3): 66–95.

Sea-level rise impacts are projected to be asymmetrical even within regions and countries. Of the impacts projected for 31 developing countries, only 10 cities account for two-thirds of the total exposure to extreme floods. Highly vulnerable cities are to be found in Mozambique, Madagascar, Mexico, Venezuela, India, Bangladesh, Indonesia, the Philippines, and Vietnam.

For small island states and river delta regions, rising sea levels are likely to have far ranging adverse consequences, especially when combined with the projected increased intensity of tropical cyclones in many tropical regions, other extreme weather events, and climate change–induced effects on oceanic ecosystems (for example, loss of protective reefs due to temperature increases and ocean acidification).

Risks to Human Support Systems: Food, Water, Ecosystems, and Human Health

Although impact projections for a 4°C world are still preliminary and it is often difficult to make comparisons across individual assessments, this report identifies a number of extremely severe risks for vital human support systems. With extremes of temperature, heat waves, rainfall, and drought are projected to increase with warming; risks will be much higher in a 4°C world compared to a 2°C world.

In a world rapidly warming toward 4°C, the most adverse impacts on water availability are likely to occur in association with growing water demand as the world population increases. Some estimates indicate that a 4°C warming would significantly exacerbate existing water scarcity in many regions, particularly northern and eastern Africa, the Middle East, and South Asia, while additional countries in Africa would be newly confronted with water scarcity on a national scale due to population growth.

- Drier conditions are projected for southern Europe, Africa (except some areas in the northeast), large parts of North America and South America, and southern Australia, among others.
- Wetter conditions are projected in particular for the northern high latitudes—that is, northern North America, northern Europe, and Siberia—and in some monsoon regions. Some regions may experience reduced water stress compared to a case without climate change.
- Subseasonal and subregional changes to the hydrological cycle are associated with severe risks, such as flooding and drought, which may increase significantly even if annual averages change little.

With extremes of rainfall and drought projected to increase with warming, these risks are expected to be much higher in a 4°C world as compared to the 2°C world. In a 2°C world:

- River basins dominated by a monsoon regime, such as the Ganges and Nile, are particularly vulnerable to changes in the seasonality of runoff, which may have large and adverse effects on water availability.
- Mean annual runoff is projected to decrease by 20 to 40 percent in the Danube, Mississippi, Amazon, and Murray Darling river basins, but increase by roughly 20 percent in both the Nile and the Ganges basins.

All these changes approximately double in magnitude in a 4°C world.

The risk for disruptions to ecosystems as a result of ecosystem shifts, wildfires, ecosystem transformation, and forest dieback would be significantly higher for 4°C warming as compared to reduced amounts. Increasing vulnerability to heat and drought stress will likely lead to increased mortality and species extinction.

Ecosystems will be affected by more frequent extreme weather events, such as forest loss due to droughts and wildfire exacerbated by land use and agricultural expansion. In Amazonia, forest fires could as much as double by 2050 with warming of approximately 1.5°C to 2°C above preindustrial levels. Changes would be expected to be even more severe in a 4°C world.

In fact, in a 4°C world climate change seems likely to become the dominant driver of ecosystem shifts, surpassing habitat destruction as the greatest threat to biodiversity. Recent research suggests that large-scale loss of biodiversity is likely to occur in a 4°C world, with climate change and high CO_2 concentration driving a transition of the Earth´s ecosystems into a state unknown in human experience. Ecosystem damage would be expected to dramatically reduce the provision of ecosystem services on which society depends (for example, fisheries and protection of coastline—afforded by coral reefs and mangroves).

Maintaining adequate food and agricultural output in the face of increasing population and rising levels of income will be a challenge irrespective of human-induced climate change. The IPCC AR4 projected that global food production would increase for local average temperature rise in the range of 1°C to 3°C, but may decrease beyond these temperatures.

New results published since 2007, however, are much less optimistic. These results suggest instead a rapidly rising risk of crop yield reductions as the world warms. Large negative effects have been observed at high and extreme temperatures in several regions including India, Africa, the United States, and Australia. For example, significant nonlinear effects have been observed in the United States for local daily temperatures increasing to 29°C for corn and 30°C for soybeans. These new results and observations indicate a significant risk of high-temperature thresholds being crossed that could substantially undermine food security globally in a 4°C world.

Compounding these risks is the adverse effect of projected sea-level rise on agriculture in important low-lying delta areas, such as in Bangladesh, Egypt, Vietnam, and parts of the African coast. Sea-level rise would likely impact many mid-latitude coastal areas and increase seawater penetration into coastal aquifers used for irrigation of coastal plains. Further risks are posed by the likelihood of increased drought in mid-latitude regions and increased flooding at higher latitudes.

The projected increase in intensity of extreme events in the future would likely have adverse implications for efforts to reduce poverty, particularly in developing countries. Recent projections suggest that the poor are especially sensitive to increases in drought intensity in a 4°C world, especially across Africa, South Asia, and other regions.

Large-scale extreme events, such as major floods that interfere with food production, could also induce nutritional deficits and the increased incidence of epidemic diseases. Flooding can introduce contaminants and diseases into healthy water supplies and increase the incidence of diarrheal and respiratory illnesses. The effects of climate change on agricultural production may exacerbate under-nutrition and malnutrition in many regions—already major contributors to child mortality in developing countries. Whilst economic growth is projected to significantly reduce childhood stunting, climate change is projected to reverse these gains in a number of regions: substantial increases in stunting due to malnutrition are projected to occur with warming of 2°C to 2.5°C, especially in Sub-Saharan Africa and South Asia, and this is likely to get worse at 4°C. Despite significant efforts to improve health services (for example, improved medical care, vaccination development, surveillance programs), significant additional impacts on poverty levels and human health are expected. Changes in temperature, precipitation rates, and humidity influence vector-borne diseases (for example, malaria and dengue fever) as well as hantaviruses, leishmaniasis, Lyme disease, and schistosomiasis.

Further health impacts of climate change could include injuries and deaths due to extreme weather events. Heat-amplified levels of smog could exacerbate respiratory disorders and heart and blood vessel diseases, while in some regions climate change–induced increases in concentrations of aeroallergens (pollens, spores) could amplify rates of allergic respiratory disorders.

Risks of Disruptions and Displacements in a 4°C World

Climate change will not occur in a vacuum. Economic growth and population increases over the 21st century will likely add to human welfare and increase adaptive capacity in many, if not most, regions. At the same time, however, there will also be increasing stresses and demands on a planetary ecosystem already approaching critical limits and boundaries. The resilience of many natural and managed ecosystems is likely to be undermined by these pressures and the projected consequences of climate change.

The projected impacts on water availability, ecosystems, agriculture, and human health could lead to large-scale displacement of populations and have adverse consequences for human security and economic and trade systems. The full scope of damages in a 4°C world has not been assessed to date.

Large-scale and disruptive changes in the Earth system are generally not included in modeling exercises, and rarely in impact assessments. As global warming approaches and exceeds 2°C, the risk of crossing thresholds of nonlinear tipping elements in the Earth system, with abrupt climate change impacts and unprecedented high-temperature climate regimes, increases. Examples include the disintegration of the West Antarctic ice sheet leading to more rapid sea-level rise than projected in this analysis or large-scale Amazon dieback drastically affecting ecosystems, rivers, agriculture, energy production, and livelihoods in an almost continental scale region and potentially adding substantially to 21st-century global warming.

There might also be nonlinear responses within particular economic sectors to high levels of global warming. For example, nonlinear temperature effects on crops are likely to be extremely relevant as the world warms to 2°C and above. However, most of our current crop models do not yet fully account for this effect, or for the potential increased ranges of variability (for example, extreme temperatures, new invading pests and diseases, abrupt shifts in critical climate factors that have large impacts on yields and/or quality of grains).

Projections of damage costs for climate change impacts typically assess the costs of local damages, including infrastructure, and do not provide an adequate consideration of cascade effects (for example, value-added chains and supply networks) at national and regional scales. However, in an increasingly globalized world that experiences further specialization in production systems, and thus higher dependency on infrastructure to deliver produced goods, damages to infrastructure systems can lead to substantial indirect impacts. Seaports are an example of an initial point where a breakdown or substantial disruption in infrastructure facilities could trigger impacts that reach far beyond the particular location of the loss.

The cumulative and interacting effects of such wide-ranging impacts, many of which are likely to be felt well before 4°C warming, are not well understood. For instance, there has not been a study published in the scientific literature on the full ecological, human, and economic consequences of a collapse of coral reef ecosystems, much less when combined with the likely concomitant loss of marine production due to rising ocean temperatures and increasing acidification, and the large-scale impacts on human settlements and infrastructure in low-lying fringe coastal zones that would result from sea-level rise of a meter or more this century and beyond.

As the scale and number of impacts grow with increasing global mean temperature, interactions between them might increasingly occur, compounding overall impact. For example, a large shock to agricultural production due to extreme temperatures across many regions, along with substantial pressure on water resources and changes in the hydrological cycle, would likely impact both human health and livelihoods. This could, in turn, cascade into effects on economic development by reducing a population´s work capacity, which would then hinder growth in GDP.

With pressures increasing as warming progresses toward 4°C and combining with nonclimate–related social, economic, and population stresses, the risk of crossing critical social system thresholds will grow. At such thresholds existing institutions that would have supported adaptation actions would likely become much less effective or even collapse. One example is a risk that sea-level rise in atoll countries exceeds the capabilities of controlled, adaptive migration, resulting in the need for complete abandonment of an island or region. Similarly, stresses on human health, such as heat waves, malnutrition, and decreasing quality of drinking water due to seawater intrusion, have the potential to overburden health-care systems to a point where adaptation is no longer possible, and dislocation is forced.

Thus, given that uncertainty remains about the full nature and scale of impacts, there is also no certainty that adaptation to a 4°C world is possible. A 4°C world is likely to be one in which communities, cities and countries would experience severe disruptions, damage, and dislocation, with many of these risks spread unequally. It is likely that the poor will suffer most and the global community could become more fractured, and unequal than today. The projected 4°C warming simply must not be allowed to occur—the heat must be turned down. Only early, cooperative, international actions can make that happen.

GHG Emissions are Externalities

- GHGs are global in origin and impact
- Some effects are long-term and governed by a flow-stock process
- There are great uncertainties in most steps of the scientific chain
- Failure to act may have large, possibly irreversible effect.

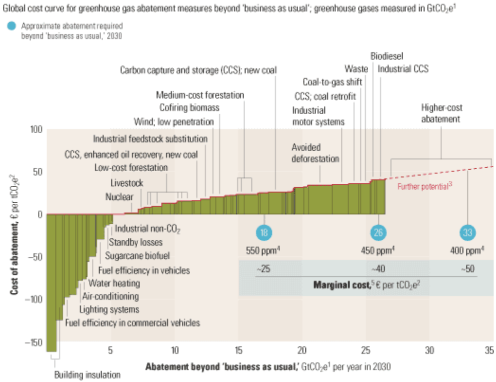
Challenges

- Economics of risk and uncertainty have to be used
- Links between economics and ethics have to be considered
- International economic policy plays an important role

Risks

- Relation between stock of GHG and temperature increase has to be considered: climate sensitivity
- General Circulation Models (GCM) of climate science produce via Monte Carlo Analysis probability distributions of outcome
- By design: high sensitivity to parameter values

Abatement Costs



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

Figure : Abatement Costs

KEY FINDINGS

- Total investment in renewable power and fuels (excluding large hydro-electric projects) fell for the second year running in 2013, reaching $214 billion worldwide, some 14% lower than in 2012 and 23% below the 2011 record. The decline reflected a sharp fall in solar system prices, and the effect of policy uncertainty in many countries. The latter issue also depressed investment in fossil fuel generation in 2013.

- If the drop in investment was a cloud, it had several silver linings. One was the sharply reduced cost of solar photovoltaic systems, which meant that a record amount of PV capacity (some 39GW) was constructed in 2013, and for less money than the smaller 2012 total of 31GW. A second silver lining was that 2013 brought a 54% recovery in clean energy share prices, stimulating equity raising by specialist companies on the public markets.

- A third was that in 2013 cost reductions and efficiency improvements enabled onshore wind and PV projects to be built in a growing number of locations around the world without subsidy support. Wind and PV may be able to out-compete fossil-fuel options as long as there are plentiful local sunshine or wind resources, low capital costs, and no cheap, indigenous coal or gas feedstocks.

- A fourth was that, renewable energy excluding large hydro made up 43.6% of the new power capacity added in all technologies in 2013 (the same figure as in the previous year), and raised its share of total generation worldwide to 8.5% from 7.8%. Global energy-related CO2 emissions would have been some 1.2 billion tonnes higher but for this contribution.

- Investment in wind was relatively resilient in 2013, falling just 1% to $80 billion, while that in solar tumbled 20% to $114 billion. Biofuels saw a 26% drop in investment to $5 billion, the lowest for nine years, while biomass and waste-to-energy fell 28% to $8 billion, and small hydro-electric (projects of less than 50MW) declined 16% to $5 billion. Geothermal was the only riser, investment in it gaining 38% to $2.5 billion.

- 2013 also saw an interruption to the previously rising trend of renewable energy investment in developing economies as a whole. After eight years of increases, this fell 14% last year to $93 billion. Investment in developed economies also retreated 14%, to $122 billion.

- Last year was the first ever that China invested more in renewable energy than the whole of Europe. The Chinese total, although down 6% to $56 billion, finished well ahead of Europe's shrunken $48 billion, down 44%. The US saw a fall of 10% to $36 billion, while India moved 15% down to $6 billion, and Brazil 54% down to $3 billion, the lowest since 2005.

- The only regions gaining ground in 2013 were the Americas excluding the US and Brazil, with a 26% increase to $12 billion, helped by positive trends in several Hispanic countries and in Canada, and Asia-Oceania excluding China and India, with a 47% rise to $43 billion. Japan was the biggest contributor to the latter move, as its solar boom helped to drive an 80% increase in renewable energy investment to $29 billion (excluding R&D).

- Among the different types of investment, asset finance of utility-scale wind farms, solar parks and other new installations fell 13% to $133 billion, while outlays on small-scale projects such as rooftop solar lurched downwards 25% to $60 billion – mostly due to the decline in PV system costs.

- Venture capital and private equity investment in specialist renewable energy companies slumped 46% to $2 billion, the lowest figure since 2005, as funds took a cautious view of young high-technology enterprises and of the chances of securing a profitable exit. Government research and development spending on renewables rose 3% to $5 billion, while corporate R&D was 6% lower at $5 billion.

- The star performer among investment types was public market equity raising by renewable energy companies. This jumped 201% to $11 billion, the highest since 2010, spurred on by the rally in clean energy share prices and by institutional investors' increased appetite for funds offering solid yields on portfolios of operating projects.

- Large hydro-electric projects, of more than 50MW, were another important area of renewable energy activity, albeit outside the main scope of the statistics in this report. At least 20GW of capacity are estimated to have come on stream in 2013, equivalent to approximately $35 billion of investment.

- Although investment in renewable energy capacity including all hydro in 2013 was once again below gross investment in fossil-fuel power, at $227 billion compared to $270 billion, it was roughly double the net figure for investment in fossil-fuel power excluding replacement plant.

Cost Comparison

- Compare cost of abatement with social cost of carbon (SCC)
- Calculation SCC in a time interval $[0, t]$
    - marginal social utility of consumption at time $\tau \in [0, t]$
    - impact on consumption at τ on all relevant preceding temperature changes
    - impact on relevant temperature increases of increases in preceding carbon stock
    - the impact of all relevant stocks of an increase in carbon emissions in τ

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Ethics

- How to value benefits accruing to different people at different times?
    - intratemporal distribution (between different people at the same time)
    - intertemporal distribution (between generations)
- The discussion focuses on appropriate discount factors and utility functions to capture values
- Utility functions need to take environment, health, type of consumption into account
- Technological progress has to be taken into account.

Instruments

- Price for GHG emissions (externalities are market failures)
- Technology and acceleration of its development
- Energy efficiency (in terms of information and transaction costs)
- International framework and collaboration

EU Roadmap 2050

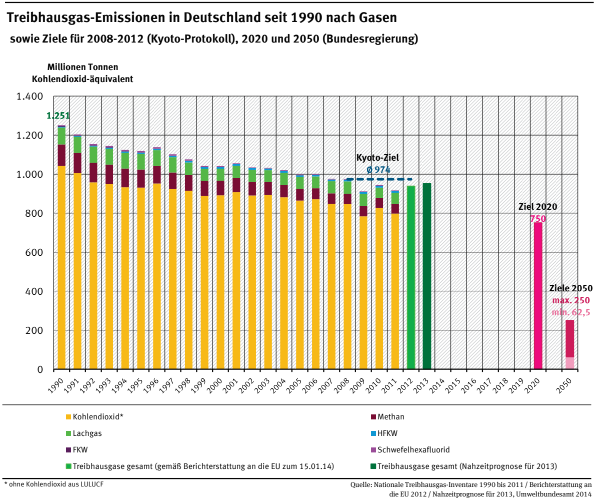
Headline Target for the EU to be achieved by 2020 relating to energy and climate change aims are

- reducing greenhouse gas emissions (GHG) by 20%,
- increasing the share of renewables in the EU's energy mix to 20%,
- achieving the 20% energy efficiency target.

Emission target

- To keep climate change below 2 Celcius, the European Council reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990.
- The EU Emission Trading System (ETS) is supposed to play a key role by generating a sufficient carbon price, which is long-term predictable.
- The EU considers taxation and technological support as additional measures.

CO2 Emissions Deutschland



Putting a Price on Carbon

- taxation
- carbon trading on the basis of allocation and auctioning
- implicit, via regulation and standards.

Possible policy responses I

- **Emission standards ("Command-and-Control")**
  Legal limit on the amount of the pollutant an individual source is allowed to emit. Problem: Standards ensure the required reduction but in practice it is not achieved in a cost-effective way (sources are usually allocated an equal reduction).
- **Taxes: Emission charges**
  Pollutor has to pay a fee on each unit of pollutant emitted. Problem: Does not necessarily lead to a lower pollution level.

Possible policy responses II

- **Taxes: Product charges**
  Control authority taxes the commodity that is responsible for the pollution instead of the pollutant. Problem: They are easy to administer. However, not every unit of the taxed product may have the same impact on the environment.
- **Emission trading**
  All sources are allocated allowances to emit either on the basis of some criterion such as historic emissions or by auctioning the allowances off to the highest bidder. The control authority issues exactly the number of allowances needed to produce the desired aggregate emission level. The allowances are freely tradeable. Advantage: Leads to a cost-effective allocation.