The Issue of Climate Change

2

2.1 The Causes of Climate Change

The warnings about global warming have been extremely clear for a long time. We are facing a global climate crisis. It is deepening. We are entering a period of consequences.

Al Gore

2.1.1 The Carbon-Temperature Conundrum

According to the Intergovernmental Panel on Climate Change (IPCC) which aggregates international research efforts on climate change, "global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a results of human activities since 1750 and in 2005 exceeded by far the natural range of the last 650,000 years" IPCC (2007), with an increase of 70 % of the global greenhouse gases (GHG)[1] emissions due to human activities between the two periods.

The parts-per-million metric (ppm), that describes the concentration of carbon dioxide in the atmosphere, went from 280 ppm at the early stage of the industrialized revolution (around 1850) to more than 391 ppm in 2012, a value 39 % higher than the maximum level that was observed in the last 800,000 years (as shown in Fig. 2.1).[2]

In the meanwhile, the average global temperature has followed a strikingly similar pattern of increasing and accelerating warming. Eleven of the last twelve years (2000–2012) were among the warmest years in the instrumental record of global surface temperature (since 1850) with almost permanent occurrences of positive

[1]The recognized GHG are carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, hydrofluorocarbons HFC, perfluorocarbons PFC and sulfur hexafluoride SF_6. Despite its influence on climate due to its ability to absorb infrared radiation, water vapor is not listed among the GHG gases.

[2]Source: NOAA.gov.

M. Chesney et al., *Environmental Finance and Investments*,
Springer Texts in Business and Economics, DOI 10.1007/978-3-642-36623-9_2,

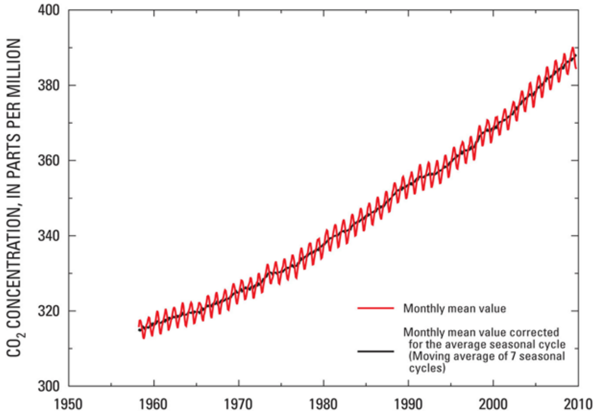

Fig. 2.1 Atmospheric carbon dioxide concentration measured at NOAA's Mauna Loa Observatory on Hawaii

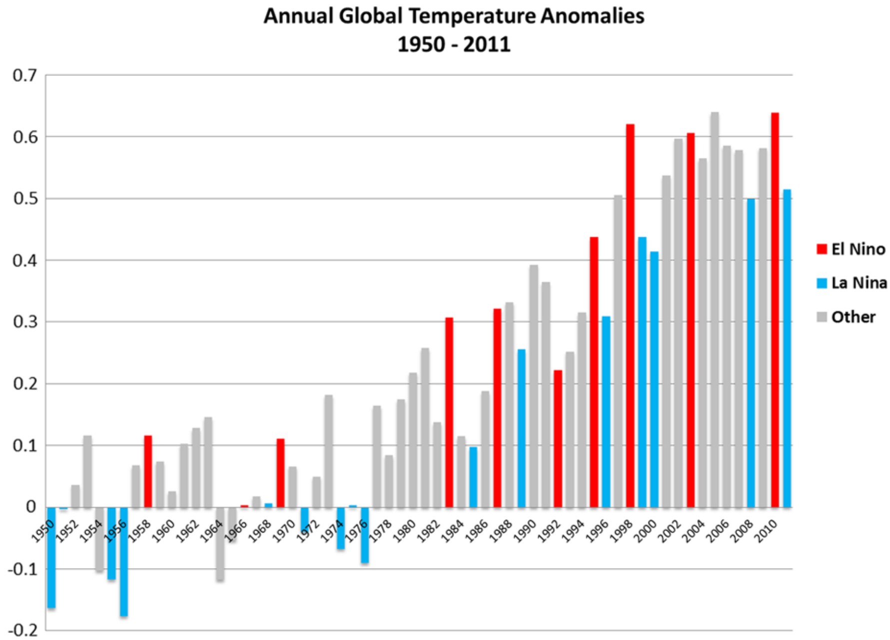

Fig. 2.2 Global temperature anomalies compared to long-term average (1950–2012). Source: NOAA.gov

temperature anomalies since 1980. Temperature anomalies from 1950 are presented in Fig. 2.2.

According to the fourth Assessment Report of the IPCC, the globally averaged surfaced temperature rose by approximately 0.7 °C between 1900 and 2009. For the last 50 years, global temperature rose at an average rate of about 0.13 °C per decade, almost twice as fast as the 0.07 °C per decade increase observed over previous periods.

The GHG Role in the Climate-Temperature Cycle

GHG are naturally present in the atmosphere and are not solely the results of anthropogenic activities. In the climate-temperature cycle, they play a fundamental role by absorbing and re-emitting solar radiation and causing the necessary warming of the earth's temperature. In the pre-industrial era, concentrations of GHG were stable but they rapidly increased afterwards (see table below: ppb means parts-per-billion).

Preindustrial levels of GHG concentration (source: IPCC)

CO_2	CH_4	N_2O	CFC-12
280 ppm	700 ppb	270 ppb	0

Current levels of GHG concentration (2009)

CO_2	CH_4	N_2O	CFC-12
387 ppm	1745 ppb	1045 ppb	533 ppm

As their concentrations in the atmosphere intensify, GHG act as a radiation trap that forces more energy to stay on surface and more heat to be produced, therefore causing global warming. In a general manner, each gas has a specific and complex cycle that involves interactions between the atmosphere, the terrestrial biosphere, the oceans, the sediments and the earth's crust. CO_2 for instance is produced, captured and dissolved through a short-to-medium-term carbon cycle involving carbon sources (fuel consumption, organic respiration, volcanic eruptions…) and sinks (forest uptake, sedimentation). Over the long term, CO_2 concentration in the atmosphere is subject to a decay rate permitted by the permanent sink role of oceans' sedimentation. Scientists tend to consider that it takes 55 years for emissions to be permanently removed from the atmosphere, with a half-life time of 38 years. Any attempt to reduce emissions has therefore to deal with the unavoidable inertia in the system and the existence of potential saturation limits of the natural sinks. Put differently, an efficient policy to reduce emissions, if it does not expect for slow practical results, could prove to be deceptive over the sort term.

Among the different GHG, CO_2 is the most important anthropogenic GHG responsible for global warming in terms of volume and absolute impact. According to the European EDGAR project on Global Emissions,[3] total global CO_2 emissions in 2011 had increased 3 % from 2010 to 34.0 billion tons and 45 % since 1990, the base year of the Kyoto Protocol. By comparison, global emissions in 1990 were

[3] http://edgar.jrc.ec.europa.eu.

Table 2.1 GWP values and lifetime, Source: IPCC AR4 report

Global Warming Potential (GWP)				
Gas	Lifetime	TH: 20 years	TH: 100 years	TH: 500 years
CO_2		1	1	1
CH_4	12	72	25	7.6
N_2O	114	289	298	153
HFC-23	270	12000	14800	12200
HFC-134a	14	3830	1430	435
SF_6	3200	16300	22800	32600

22.7 billion tons, an increase of 45 % on the 1970 level of 15.5 billion tons, as the consequence of increased use of fossil fuels and accelerated deforestations (while growth rates in CH_4 and N_2O emissions are mainly due to agriculture expansion).

In relative terms, gases have not the same effect on radiation retention: compared to CO_2, CH_4 and N_2O are present in less quantity in the atmosphere but have a greater capacity to create greenhouse effect. To compare their relative influence on global warming, scientists rely on a global warming potential (GWP) measurement instrument. The GWP is a relative scale that compares the greenhouse effect of a specific mass of gas to the same mass of CO_2 (having a normalized value of 1). The GWP measure accounts for the different decay rates of gases: a gas that generates relatively high greenhouse effect but that is dissolved rapidly has a high short-term GWP coefficient but a low long-term one. To account for this factor, GWP tables are given for specific time horizons (TH) (see Table 2.1).

While the relationship between carbon and temperature is no longer debated, it seems fair to acknowledge that the specific role of anthropogenic emissions in global warming is still the subject of specific scientific feuds, the most recent of them having occurred in November 2009.[4]

The so-called "climatoskeptics" are representing disparate groups of ideas and interests, gathered by their disbelief that climate change is an important issue to tackle, either because they consider that the scientific evidence remain flimsy and weakened by too much uncertainty or because they judge that other issues are much more important and effective and should be prioritized. Proponents of the first line of argumentations suggest that data are not entirely reliable, incapacitating any meaningful comparison of past patterns into current trends or that anthropogenic emissions are just a fraction of larger natural interactions not yet completely understood. However uncertain some results might be, it seems clear that a scientific consensus has now formed (embodied by the IPCC and other scientific institutions) and seems

[4]On November 19th 2009, the email server of the Climate Research Unit at the University of East Anglia (one of the most prominent research outlet on the issue of climate change) was hacked and email correspondences among its researchers were publicly disseminated. Dubbed "Climategate" by the press, the incident has revealed the bitter acrimony between climate change proponents and opponents and forced additional statements to reaffirm the existence of uncertainty in scientific evidence and results.

Table 2.2 Selection of modeling scenarios from the IPCC AR4 report (2007)

Illustration of the SRES storylines			
Storyline	*Schematic structure of scenario (horizon 2090–2099)*	*Projected temp (°C)*	*Sea level rise (cm)*
A1	Future world of very rapid economic growth, global population that peaks in mi-century and decline thereafter and rapid introduction of new and more efficient technologies	1.4–6.4	20–59
A2	Very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines	2.0–5.4	23–51
B1	Convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies	1.1–2.9	18–38
B2	World in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development	1.4–3.8	20–43

largely backed by the most recent measurements. Worryingly, those measurements tend to support a rather pessimistic prediction for climate change.

2.1.2 Global Warming Scenarios and Mitigation Strategies

For the purpose of policy decision-making and scientific discussions, the IPCC defined for its third assessment[5] (TAR, 2000) a set of scenarios exploring future development for GHG emissions. The IPCC improved on them for its fourth assessment,[6] despite some concern that the recent evolutions in emissions from the 2000–2007 period were not fully taken into account.

The scenarios, starting in 2000, differ by their storylines (A1, A2, B1, B2), which represent different demographic, social, economic, technological and environmental developments that diverge in increasingly irreversible ways. An overview is given in Table 2.2.

For each storyline, modeling teams of economists and scientists have computed sets of scenarios using integrated assessment models (IAM). Storylines A2, B1 and B2 have each one set of scenarios while the A1 storyline has three different sets that depend on alternative development of energy technologies: A1FI (fossil intensive), A1T (predominantly non-fossil) and A1B (balanced across energy sources).

[5] Special Report on Emissions Scenarios (SRES).

[6] by shifting the time horizon from 2100 to 2090–2099 and changing the method for the inclusion of uncertainties.

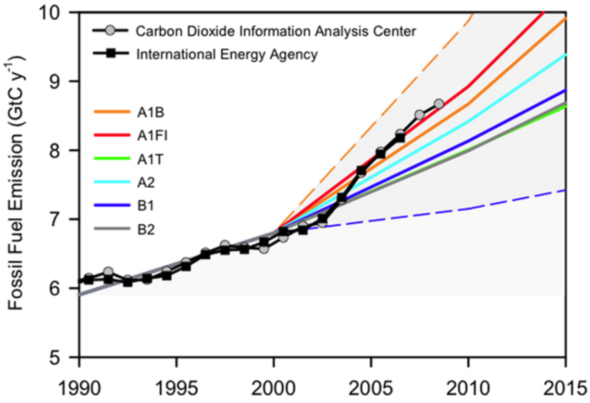

Fig. 2.3 Fossil fuel emissions: actual emissions compared to IPCC modeled projections. Source: Global Carbon Project (2010)

Scenarios are not ranked and are not attached to probability of occurrence. However, using the scenarios of the third assessment for the completion of the fourth assessment gave the advantage of backtesting the proposed models. By the end of 2009, it appears that the world is closely enough following the path of the A1FI model, with rapid economic growth and heavy reliance on fossil energies for countries such as China and India (Fig. 2.3).

The recent context of financial crises has had a modest disruptive impact on this trend, with an estimated −1.3 % reduction of fossil fuel emissions for the year 2009,[7] immediately absorbed by a rapid increase of 5.9 % per year in 2010 (due for a large part to a rise in energy inefficiency/carbon intensity).[8] This was expected to be the case, the reduction coming from a contraction of the economy but not from a change in the energy mix, see Fig. 2.4.

In order to assess mitigation costs, the IPCC has computed simulations[9] for stabilization scenarios around six specific CO_2-equivalent[10] concentration levels in the atmosphere, acknowledging that attempt to reduce concentration to 445–490 ppm CO_2-eq would require negative emissions for several decades (that is, higher uptakes than emissions). The different scenarios are presented in Table 2.3.

According to the sensitivity projections of the IPCC, any commitment to limit the global average temperature increase within a +2 °C limit would force to stabilize CO_2 concentration around 350–400 ppm. In December 2009, the latest concentration was estimated at 387 ppm, slowly increasing from the 375 ppm concentration recorded in 2005.

[7] Source: Global Carbon Project, Carbon Budget 2010.

[8] Carbon intensity is the amount of carbon (in terms of weight) emitted per unit of energy consumed.

[9] These simulations are to be amended for the fifth Assessment Report which will be issued in 2013 (for the Physical Science Basis) and 2014 (for the Impacts, Adaptation and Vulnerability and the Mitigation of Climate Change reports).

[10] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential. It is measured over a specified timescale, generally, 100 years.

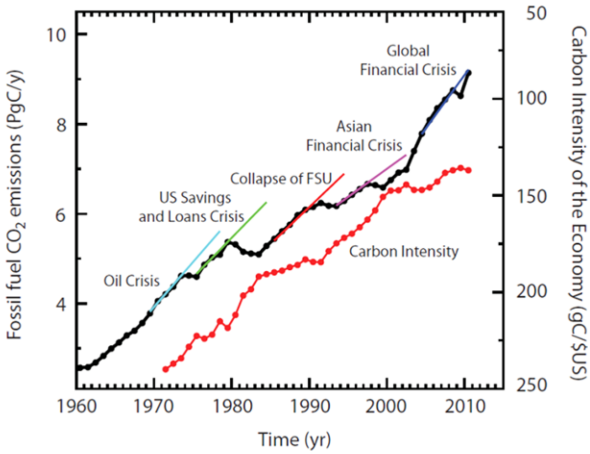

Fig. 2.4 Impact of recent financial crises on CO_2 emissions. Source: Global Carbon Project (2010)

Table 2.3 Concentration stabilization scenarios and impact on temperature increase and sea level rise. Source: IPCC

Scenario	CO_2 concentration at stabilization	CO_2-e concentration at stabilization	Change in global CO_2 emissions in 2050 (% of 2000 emissions)	Global average temperature increase (in °C)	Global average sea level rise (in m)
I	350–400	445–490	−85 to −50	**2.0–2.4**	0.4–1.4
II	400–440	490–535	−60 to −30	**2.4–2.8**	0.5–1.7
III	440–485	535–590	−30 to +5	**2.8–3.2**	0.6–1.9
IV	485–570	590–710	+10 to +60	**3.2–4.0**	0.6–2.4
V	570–660	710–855	+25 to +85	**4.0–4.9**	0.8–2.9
VI	660–790	855–1130	+90 to +140	**4.9–6.1**	1.0–3.7

A targeted concentration of 445–490 ppm CO_2-eq would represent a stabilized increase of temperature around +2–2.4 °C above the pre-industrial level. In the current context of increasing emissions, achieving a 350–400 ppm stabilization level will require a set of mitigation measure with different costs, areas of applicability and timing. IPCC has introduced in the stabilization scenarios a set of usable mitigation strategies, with increasing marginal cost: technology efficiency improvement, source of energy switching (ex: from coal to natural gas), development of renewable energies, demand reduction and carbon capture and storage. In all its storyline (A1, A2, B1, B2), the IPCC has included elements of mitigation (technology change and energy efficiency) that ensure emission reduction, up to 80 % compared to a "frozen 1990 technology" baseline.[11]

[11] Among other attempts to define mitigation strategies and abatement supply curves, the International Energy Agency (IEA) regularly publishes the Energy Technology Perspective Reports that include a detailed roadmap for energy technology, from both the supply and the demand sides.

2.1.3 The Environmental and Economic Impacts

Until damages are elicited and adaptation cost monetized, the urgency of taking measure against global warming remains for many elusive. In a traditional cost-benefit analysis, investing in mitigation makes sense only if it reduces damages and impacts up to the point where the local marginal costs of abatement and local marginal damages are equal. However, the issue of attaching costs to global warming and assessing impacts is a complex task that needs to overcome several hurdles: (i) regional and sectoral implications of a public good problem (externalities), (ii) presence of high degree of uncertainty, (iii) dynamic aspects and (iv) ethical issues.

Climate change damages are complex to precisely assess in a cost-benefit analysis because the main causes of the damages are not generated locally but are the results of collective externalities (in broad terms, the climate is a public good). Since some countries or regions will disproportionately suffer from the impacts in comparison with their emissions, it may prove difficult for them to define mitigation and adaptation strategies and adjust precisely to the severity of the damages, since they control only a limited share of the collective responsibility. This aspect leads to the second main difficulty, the importance of uncertainties in the impact valuation.

As Tol (2002) reminds us, *"the uncertainty about the impact of climate change is known to be large, because, climate change itself is rather uncertain in its magnitude and regional pattern, research on the impact of climate change needs substantial improvement, and the bulk of climate change will occur in a distant future"*.

Damages and costs are highly regional/sectoral and impose long-term, costly bottom-up studies with the extra difficulty to make them comparable (same set of baseline hypotheses, impacts defined on compatible storylines). This would require a concerted effort under the supervision of a centralized body, which has been the role played by the IPCC so far. However, its impact assessment does not provide clear monetized impacts, forcing further studies to rely on disconnected regional and sectoral assessments or to come up with ad hoc assumptions.

Damages and impacts are also dynamic in nature and susceptible of reinforcing loops or switching periods of positive and negative effects. To be able to compare across periods, a sound cost assessment requires the definition of a reliable and sensible discount rate: if the discount rate is low (down to zero), the model would almost imply an equal impact sensitivity across periods and generations, the view of the proponents of intergenerational equity. On the other hand, if the discount rate is high (or close to the market rates observed before the financial crisis), the damage assessment would mostly limit itself to the view of the current generation.

Most studies conduct impact analysis on a subset of the global regional/sectoral matrix, with important researches targeted towards agriculture, forestry and costal economic sectors. In a comprehensive effort, Tol (2005b) has summed up many

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Worth also noting but limited to the supply side, the consultancy McKinsey has computed an often-used abatement cost curve that includes all technologies available for less than the carbon permit's price limit of the first EU ETS phase. (A cost curve for greenhouse gas reduction, McKinsey Quarterly, 2007.)

Table 2.4 Estimates of the regional impacts of climate change as % of GDP (Source: Tol, 2005)

Estimates of the regional impacts of climate change (Horizon = 2100)				
	Studies			
	Pearce et al.	Mendelsohn et al.	Nordhaus and Boyer	Tol
Temperature increase (°C)	2.5 °C	2.5 °C	2.5 °C	1 °C
North America	−1.5 %			+3.4 %
USA	−1 % to −1.5 %	+0.3 %	−0.5 %	
OCDE Europe	−1.3 %			+3.7 %
EU	−1.4 %		−2.8 %	
OCDE Pacific	−1.4 % to −1.8 %			+1 %
Japan		−0.1 %	−0.5 %	
Eastern Europe/Former USSR	+0.3 %			+2 %
Eastern Europe			−0.7 %	
Middle East	−4.1 %		−2 %	+1.1 %
Latin America	−4.3 %			−0.1 %
Latin America	−4.3 %			−0.1 %
Brazil		−1.4 %		
South and Southeast Asia	−8.6 %			−1.7 %
India		−2 %	−4.9 %	
China	−4.7 % to −5.2 %	+1.8 %	−0.2 %	+2.1 %
Africa	−8.7 %		−3.9 %	−4.1 %

of those papers, both in their static and dynamic effects (see Table 2.4 where the estimates are expressed as per cent of Gross Domestic Product).[12]

From those estimates, it is apparent that the burden of climate change will not be borne equally across regions. One the hand, some countries should benefit from a temperature increase, which will positively mitigate the harsh conditions of their winters and increase economic outputs (for instance, Russia and Canada should experience positive GDP growth). Unfortunately, on the other hand, least developed countries (Africa, Southeast Asia) are predicted to be the ones suffering the most from global warming with an expected impact on GDP ranging from −3.9 % to −8.6 %.

Why Is the Developing World Especially Affected?

- The livelihood of the poor is known to be significantly dependent on natural resources.

[12] Pearce et al. (1996), Mendelsohn et al. (1998), Nordhaus and Boyer (2000), Tol (1999).

- When natural disasters destroy capital (be it machinery, cattle, or otherwise), the poor typically lack access to financial resources to restore the level of capital to its pre-disaster level.
- Areas of poverty are often located in places that are more susceptible to high variability in temperature and rainfall, such as hilly and steep slopes, and flood plains.
- Richer societies are more resilient societies as a result of the positive correlation between income and education, openness, financial development, and greater institutional capacity.
- In the words of the World Bank (Margulis and Narain 2009): *"developing countries face not only a deficit in adapting to current climate variation, let alone future climate change, but also deficits in providing education, housing, health, and other services. Thus, many countries face a more general "development deficit", of which the part related to climate events is termed the "adaptation deficit".*

The recognition of the partial ineluctability of global warming combined with the slow deployment of mitigation strategies have forced economists and policy makers to reconsider the importance of adaptation as a complementary measure to climate mitigation.

While adaptation is defined as the set of activities conducted to *offset* partially or in totality the averse impacts of damages due to global warming, mitigation covers the strategies to *reduce* the amount of GHG emissions. Adaptation can be divided between anticipative (*ex ante*) and reactive (*ex post*) strategies. For instance, the selection (and R&D) of drought-resistant crops prior to explicit climatic changes can be considered as a proactive measure, while emergency vaccinations in case of climate-related pandemics belong to reactive adaptation. In practice however, *"the distinction between anticipative and reactive adaptation is intuitively clear, but difficult to delineate with precision in a dynamic setting"* (Lecocq and Shalizi 2007).

Strengths and Weaknesses of Adaptation Measures

Strengths

1. Adaptation is by definition local/regional/sector-based: adaptation measures in effect privatize policies against climate changes by largely limiting the benefits of adaptation to those having invested in it.
2. Adaptation avoids the free-riding problem traditionally associated with mitigation and does not require concerted and simultaneous actions, fostering the advancement of regional or local projects.
3. Adaptation projects are often less costly and easier to set up.

4. Adaptation provides short-term protection against early damages.
5. For developing countries without mitigation issues, it represents the main set of strategies (ex: Africa).
6. Adaptation should be able to deal with extreme events.

Weaknesses

1. Larger uncertainties for anticipative projects.
2. Absence of a common performance indicator to compare the results of different adaptation projects.
3. Could lure countries with large emissions to give up on their mitigation projects, especially if they have short-term views (or equivalently, high discount rates).
4. Creating private goods and benefits, adaptation can foster or reinforce inequalities.
5. Projects are easily mixed with development targets already in place, impeding access to additional resources (ex: The Copenhagen Green Climate Fund).

Strengths and Weaknesses of Mitigation Measures

Strengths

1. Mitigation is the only long-term solution to reduce the anthropogenic part of climate change.
2. In general, mitigation strategies and efficiencies have been more studied and present less uncertainty about their benefits. As the IPCC notes, uncertainties are much larger at the local/sectoral level than at the global level.
3. Mitigation will have global benefits that are not excludable (equity value).
4. In negotiations, mitigation strategies could be different but they have the same performance metric which allows for comparisons and allocations.

Weaknesses

1. Mitigation is a public good: non-excludable and non-rivalrous. It creates agency problems, either through free-riders or barriers to collective action.
2. It involves international negotiations that are extremely difficult to manage with elusive search for consensus.
3. It is a long-term process that has no impact on short-term damages.
4. For numerous developing countries with little emissions but large exposures to impacts, it does not represent an effective policy.

Table 2.5 Estimates of adaptation costs in developing countries for 2010–2015 (Source: IIED, 2009)

Adaptation costs in developing countries for 2010–2015 (Source: IIED, 2009)	
Source	US$ billion per year
World Bank (2009)	75–100
UNFCCC (2007)	27–66
UNDP (2007)	86–109
Oxfam (2007)	more than 50
Stern (2006)	4–37

It is now clear that adaptation policies will have to be put in place, both as a way to cope with dramatic and extreme events and as a way to adapt to permanent changes of our environments. However, adaptation cost assessments are still lagging behind damage impacts studies and still lack a homogeneous corpus of evidence and measures.

Considering this limited amount of research conducted on adaptation strategies, it remains unclear how and to what extent adaptation and mitigation strategies interact with each other in a dynamic setting.

A classical example is Air-Conditioning: A/C systems are adaptation measures deployed in building to limit effect of global warming but at the same time, they increase energy consumption and the potential release of GHG. In this simple case, the correlation would be *negative* between the two measures. At the other end of the correlation spectrum, *positive* correlation may be found in deforestation finance (REDD), for which mitigation measures (decreased deforestation) provide adaptive instruments against floods and landslides.

While being cheaper in the short term than the range of available mitigation strategies, adaptation will have nonetheless important costs. Table 2.5 shows a range of estimates covering adaptation costs in developing countries.

In conclusion, it seems clear that an a optimal policy against climate changes and their impacts will have to combine both mitigation and adaptation. While adaptation are easier to implement, bear less uncertainties and can be privatized (partially avoiding free-riding effects), mitigation strategies are the only capable to reduce GHGs in the atmosphere in order to reestablish a viable long-term CO_2 concentration. Simply relying on adaptation measures could increase risk of reaching tipping points while being more and more costly to keep up with increased damages.

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